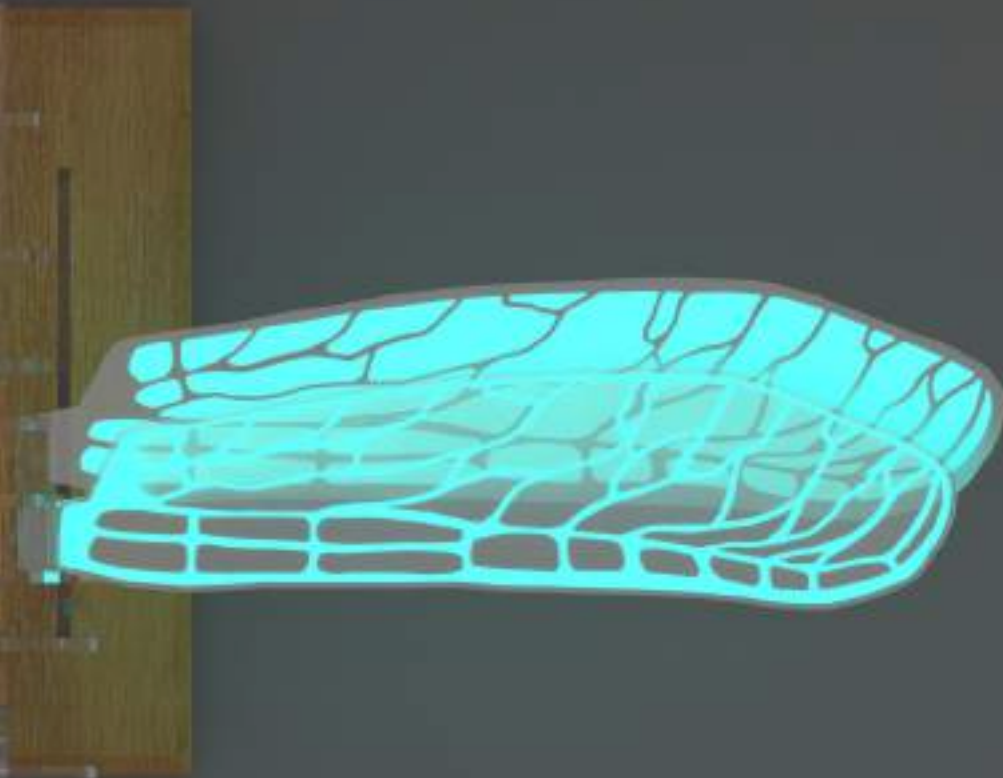


# Electroluminescence

a 15 minute Do-It-Yourself method



Master thesis  
Industrial design engineering - IPD  
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Graduation project

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# Acknowledgements

I had always expected to finish the master by designing a product like I have done many times during this study. When the project crossed my path it immediately caught my attention. Never had I heard about electroluminescent materials, let alone knowing the ability to use this material in a Do-It-Yourself construction.

As soon as the project took shape it became clear I would not be designing a product, but designing a new construction method for electroluminescent panels, a new tool for designers and design students. This meant the last few months have been a busy and very educational period.

Of course this would not have been possible without my chair Kaspar Jansen, who I would like to thank for allowing the possibility to work with this material and this kind of project. Also providing in-depth knowledge on the subject and continuous enthusiasm. Next I would like to thank my mentor Sylvia Pont who helped me stay on track, providing positive feedback and guidance throughout the project.

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And last but not least I would like to thank my parents for their support throughout my life no matter what.



# Executive summary

This report contains the process that has lead to the creation of a novel “do it yourself” construction method for electroluminescent (EL) panels. These types of panels have unique visual characteristics like doubles sided illumination, high bendability and thin panel construction. Multiple DIY construction methods already exist, but these methods lead to long construction times with a reasonable probability of malfunctioning panels. This combination can deter students and designer from exploring EL materials. In order to make EL materials more appealing, a new method is developed that takes significantly less time, is easier to apply and has an high success rate.

The report will start with the exploration of working principle behind light and light emission by EL materials. For electroluminescent materials this means placing powdered phosphor in a strong and alternating electric field. This field is created by placing the phosphor and a dielectric (non-electrically conductive) layer between two electrodes phosphor. The most important variables that influence the field strength, voltage and dielectric properties, are thoroughly analyzed. Combining this knowledge with existing and experimental developments in EL creates a proper understanding of the working principles behind EL. This knowledge is required when creating a new construction method.

Understanding the working principles behind EL has lead to two distinct directions of material testing. The first was focused at testing different materials on their ability to function as an dielectric and bonding a pre-made phosphor layer and electrodes together. The second direction focused on finding a material that is able to function as dielectric layer while also functioning as a binding material for the powdered phosphor. This exploration of different construction

techniques has lead a final method that combines of powdered phosphor and UV curing adhesive.

With the new construction method still in its infancy, a new exploration of the application method for the UV mixture is started. Changing the order of different construction steps in order to improve the end result resulted in two construction methods. One for a single sided and one for a double sided emissive EL panel. Both methods show vast improvements over existing DIY methods in terms of construction time and the chance of a malfunctioning EL device. Both two method are validated by multiple user tests. An additional test is carried out that compares the new method with the existing (DIY) screen printing method. This enables a direct comparison on the end result and the time that is required for each method. The user tests allow the project to end with a conclusion and recommendations on the final construction method.

Additionally a demonstrator model will be made. This model, created using the new construction method, will show off the unique visual properties of EL.

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# Introduction

When designing a product, designers and design students select materials based on what they know and generally what is practical when creating a design. Relatively unfamiliar materials are electroluminescent (EL) materials. These materials emit light when they are exposed to an strong enough alternating electric field.

Besides the unique properties of this material, it can be used to create extremely thin and bendable light emitting panels, this material can be used to create custom designs. There are multiple methods available for students to create the different layers required for a DIY EL panel. Even with an impressive project like the *Regenlicht* umbrella (Claus, 2016), the material has remained fairly unfamiliar.

A reason for this unfamiliarity can be the time that has to be invested in learning the a construction techniques like screen printing. Using this method it can easily take approximately 2 - 2.5 hours to fully complete an EL panel and has an high chance of failure, especially when someone is not skilled in using screen printing equipment. This limits the potential of integrating the exploration of EL materials during a course like Materials for Design (an elective course of the masters at IDE, TUDelft).

Since it can take quite some time and effort to create a panel and after such an investment a malfunctioning panel

will not stimulate a student to continue exploring EL materials. In order to make EL materials more reachable for students and designers, an easier and faster construction method will be created

## Report structure

The first chapter will focus on analysing the working principles behind EL and existing DIY methods. This will be used to make a concrete formulation of the projects goal.

The second chapter will explore different materials that can be used to reach the goal. It will end with the selection of a single method that has provided the best results.

The third chapter will focus on improving this method in order to make it a valid construction method.

In the fourth chapter the new method will be tested on its ability to create EL devices that provide similar effects as is possible with previous DIY methods.

In the final chapter the new method will be validated though multiple user tests which will lead to the final conclusions and recommendations. After the validation, the construction of a demonstration model will be explained.

All additional relevant information can be found in the appendix. Appendix 1 contains a list of all the important materials and equipment used during this project.

# A N A L Y S I S

This part of the project will consist of examining the working principles behind EL in order to gather proper knowledge on what effects the working of EL devices. This knowledge will be used to experiment with new construction methods of EL devices, in the next chapter, and will help understanding the results of these experiments in order to come to meaningful conclusions and choose a final construction method.

To gain insight in the possibilities of EL devices currently commercially available products, experimental EL devices and available DIY EL construction methods will be analysed.

# Light

There are many different ways light can be generated, e.g. by creating quickly collapsing air bubbles inside a liquid called sonoluminescence as these are created by sound waves. Light can also be generated by chemiluminescence, Fig1, a method in which a chemical reaction between different materials is responsible for the emission of light. This project is all about electroluminescence, light created by applying an electric current or a strong electric field to certain materials, but this will be explained later. First a quick explanation of what light is will be given.

## What is light?

Light, normally referring to visible light, is the part of the electromagnetic spectrum that we humans can perceive with

our eyes. It consists of photons which are small pockets of energy, the amount of energy is dependant on the wavelength of the photon.

Light can have different types of origins but for EL the fundamental mechanism behind the creation of light lies at the atomic scale.

Atoms are made out of protons and neutrons making up the nucleus and surrounding the nucleus are one or more electrons depending on the amount of protons. Protons are positively charged and the electrons are negatively charged which causes atoms to often have an equal amount of protons and electrons. These electrons go around the nucleus in different orbits, also called an electron shell. These shells have a certain amount of energy and electrons can only exist in



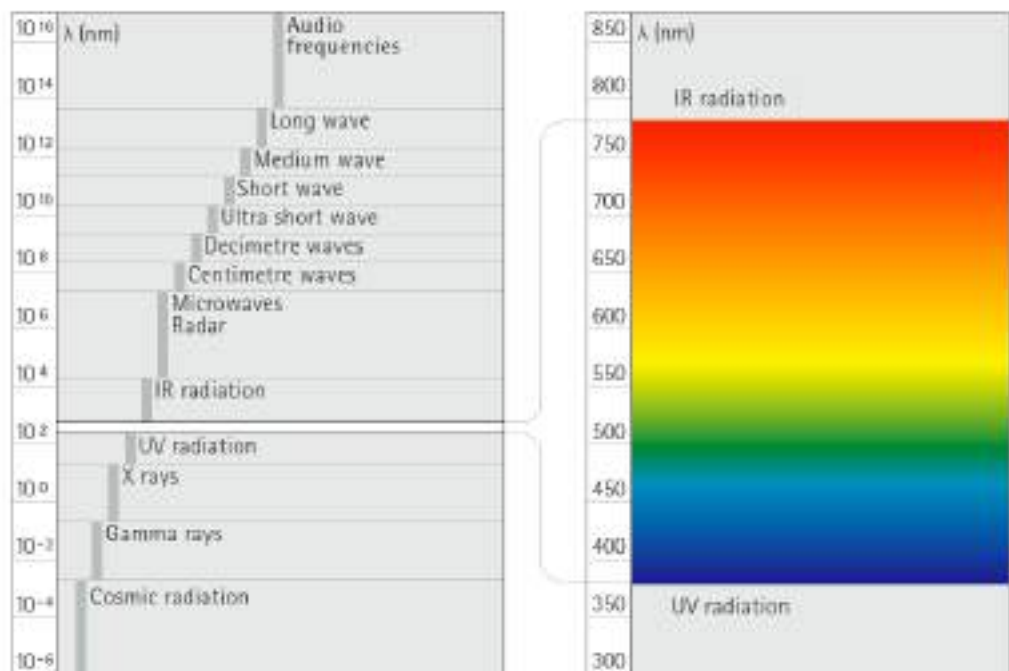
▲ Fig1. Two examples of bioluminescence, light created by animals as a result of a chemical reaction. Left algae, right jelly fish.

these shells, not in between two different shells. Generally each shell can only hold a specific amount of electrons and these electrons orbit the nucleus in the shells that are closest to it. Since electrons are attracted to the protons they fill up each shell before moving to a higher orbit. Once the electrons of an atom are in their lowest energy and stable configuration it is said to be in the ground state. Electrons can be knocked into a higher shell (energy level) by impact of a photon with the right amount of energy causing it to be in an excited state. Once it is in the higher shell it instantly wants to fall back into a lower shell. Once it falls back the excess energy is released in the form of a photon. The energy (wavelength) of the photon is dependant on the difference in energy level between the two shells.

## Spectrum

Like stated before light is the part of the visible electromagnetic spectrum. To be more precise the wavelength of the visible light spectrum runs from approximately 380 to 780 nm (Ganslandt & Hofmann, 1992)(Fig2). When a photon has more energy the frequency will be higher meaning the wavelength will be shorter. This means that the photons that are perceived as red have a wavelength between 620 and 780 nm. These will carry less energy than photons that are perceived as violet, these photons have a wavelength between 380 and 450 nm. The amount of energy of photons in the visible spectrum ranges from 1.65 to 3.26 eV (electronvolt). This means that the colour of a photon created by an electron that returns to

Fig2. Electromagnetic spectrum with visible light running from 380nm to 780nm (Ganslandt & Hofmann, 1992)



its ground state from the excited state is dependant on the difference in energy level between the two shells. A larger difference will shift the colour of the light to the violet part of the spectrum.

Light emission in EL devices is slightly different from the example given before since in EL the crystalline structure of the phosphor plays an important role and electrons are not bumped to higher energy states by photons but by other means which will be explained in the following paragraph.

# Electroluminescence

The working principle behind EL that are interesting and matter for creating an EL device will be explained clearly. For more in depth information on each of the subjects the Phosphor handbook is a very extensive (1000+ pages) book on properties and application of phosphors.

## Basic construction

Most EL devices are made by creating a sandwich construction of a very thin layer of phosphor powder and a thin dielectric (non-electrically conductive) layer between two electrodes. A high frequency and high voltage alternating current (AC) is applied on the electrodes (DC EL devices do exist but are far less common (Yen, et al., 2007)). This creates a strong electric field between the electrodes. This makes it essentially a parallel plate capacitor (Fig3). The electric field, if strong enough, causes the emission centres in the phosphor to emit light. The alternating current in this type of construction is important because the

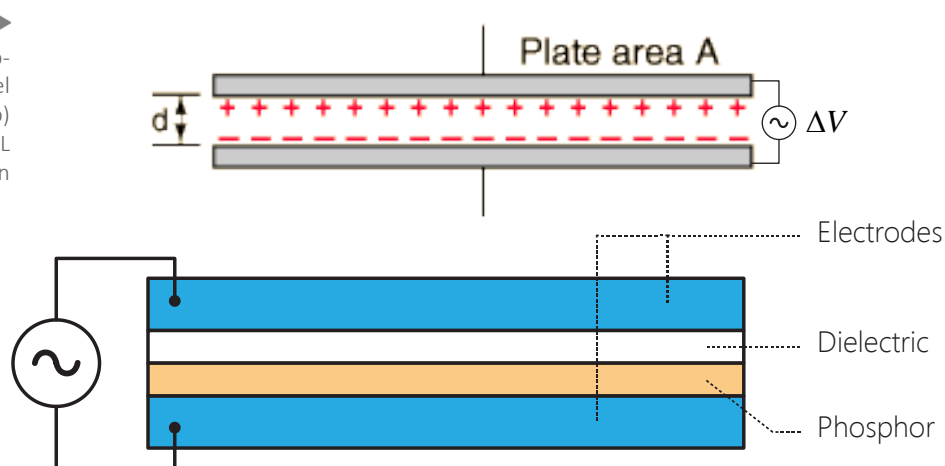
emission only takes place when the electric field changes direction.

This is the working principle behind EL devices in a nutshell. The different aspects of this principle will be explained next.

## Electrodes and electric field

In a parallel plate capacitor two plates with an opposite electric charge are placed in close proximity without actually touching each other. This is done by placing a non conductive layer, the dielectric, between the two plates. The difference in electric charge creates the electric field which can be calculated using the formula  $E = \frac{\Delta V}{d}$  and is measured in volts per meter (V/m-1). The difference in voltage between the two electrodes is indicated with  $\Delta V$  and the distance between the electrodes by  $d$  (Fig3). Increasing the field strength can be done by increasing the voltage or by decreasing the distance between the electrodes. The aim is to reduce the distance as this

Fig3. Graphical representation a parallel plate capacitor (top) and the standard EL device construction (bottom)





will lower the required voltage which will reduce the power consumption.

## Dielectric

The dielectric layer is an electrical insulator that prevents the two electrodes from touching. Electrodes that touch each other can lead to a short circuit.

The first electrical property that is relevant for a working EL device is the relative permittivity (previously known as the dielectric constant) which is calculated using  $\epsilon_r = \frac{\epsilon}{\epsilon_0}$ . The permittivity of the material is indicated by  $\epsilon$  which is divided by the electric constant  $\epsilon_0$ . The relative permittivity indicates the ability of the molecules in a material to orient themselves in the direction of the electric field. A high value indicates a better ability of the molecules to orient themselves in the field direction. This increases the capacitance, the ability to store energy. This increased capacity also increases the output of an EL panel.

The second property is the dielectric strength which is measured in MV/m and indicates the voltage that can be applied on the electrodes before the dielectric material suddenly breaks down and starts to conduct electricity. If this

occurs, irreversible damage is done to an EL device. The general rule is: with an increased permittivity comes with a lower dielectric strength (Fig4).

This means that an increased light output by using a dielectric material with a high permittivity or a low thickness comes with an increased risk of electrical breakdown. Fig5 shows the relation of several materials with their relative permittivity and their dielectric strength.

The dielectric material used for screen-printing is BaTiO<sub>3</sub> and has a high relative permittivity and a high breakdown voltage making it an ideal dielectric material for EL.

However for EL devices using pocket inverters, which provide approximately 100V ([www.cytron.io](http://www.cytron.io)), and with a total layer thickness (dielectric and phosphor layer) of 50-100 micron, the minimal breakdown voltage should be above 2 MV/m ( $100V/0.00005=2.000.000$  V/m).

This means that there is room to decrease the thickness of the dielectric layer to a couple of micron in order to minimize the total distance between the electrodes.

Fig4. List of relative permittivity of several materials. A combination of general plastics and materials used in EL devices(CES edupack 2017)

Material	Relative permittivity	Breakdown voltage MV/m
Vacuum	1	11.0
PP	2.1-2.3	22.7-24.6
Silicone	2.9-4	15-25
PET	3.5-3.7	16.5-21.7
Epoxies	3.5-5.7	11.8-19.7
tpPUR	6.6-7.12	15.1-16.4
Silicon	11-12	5-12
BaTiO <sub>3</sub>	14	20
Zirconia	12-25	4-6

## Phosphor

Phosphor is the material that is responsible for the actual emission of light. Light emitting phosphors suited for EL are made out of a host material that is doped with a small amount of a different material.

## Host

The host material of a phosphor consists of atoms that are arranged in a (crystal) lattice structure (Fig6). During this project the phosphors used are based on the host material ZnS (zinc sulphide). ZnS is part of the so called IIb-VIb compounds. Other host materials in this group that are also able to emit visible light (i.e. the materials with a bandgap of at least 1.6eV) are ZnO (zinc oxide), ZnSe (zinc selenide), ZnTe (zinc telluride) and CdS (cadmium sulfide).

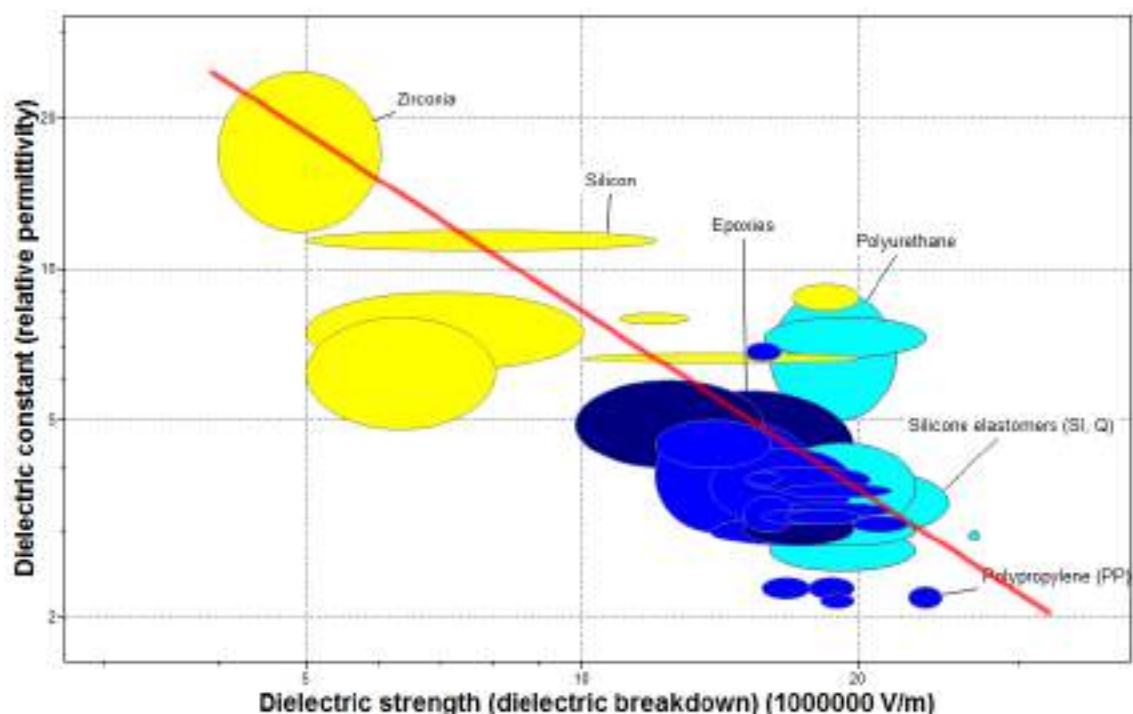
## Dopant

The dopant material is added in just a few volume percentages and is used to change the colour of the light that is emitted by the phosphor powder. This change is caused by the difference in energy level between the valence and conduction band using different dopants.

## Energy bands

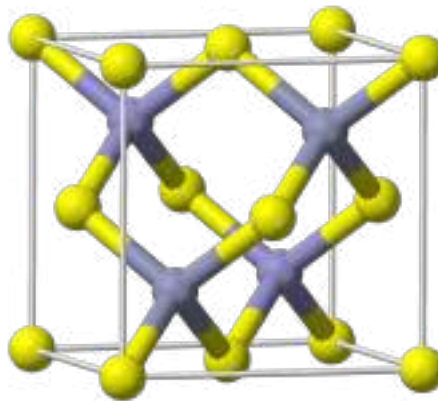
Due to the lattice structure the electron shells of the separate atoms will start to form discrete energy bands. The electrons will fall into the lowest energy state possible, their ground state. The outermost energy band where electrons exist in the ground state is called the valence band. However, there are energy bands that have a higher energy level that are not occupied when the electrons are in their ground state. These bands are

▼ Fig5. Graph of the relative permittivity compared to the dielectric strength of several materials. Yellow indicate ceramics, the blue are polymers and elastomers. Data is collated using CES Edu-pack 2017

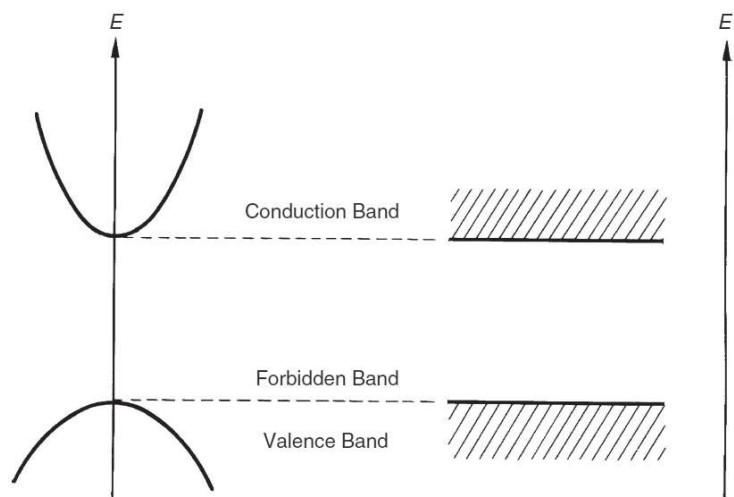


called the conductive bands. Electrons in the valence band are bound to their atom. Once they get energized enough to get knocked into a conduction band, in this case by a strong enough electric field, they are able to move practically freely throughout the lattice, hence the name conduction band. It is possible for the valence band and conduction band to overlap making the material a conductor. A small gap between the valence and conduction band makes the material a semiconductor and a large gap makes the material an insulator. This gap is called the bandgap (or forbidden band) and electrons cannot exist in this location (Fig7).

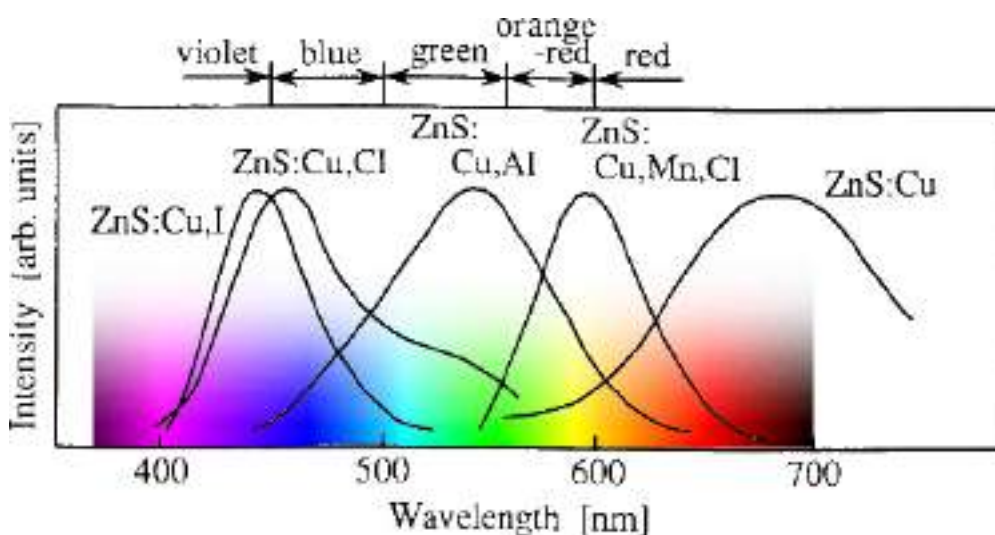
Free flowing electrons are captured by the dopant. At that location they will return to the valence band through radiative recombination. This process releases energy in the form of a photon. Using a different dopant can change the bandgap, this changes the energy that is released when an electron returns to its ground state, causing the emission of a photon in a different wavelength, i.e. different dopants are used to create different colours (Fig8).



◀ Fig6. Zinc blende structure most common in ZnS crystals



▲ Fig7. Band gap in crystals. E = energy



◀ Fig8. Different types of phosphors based on their dopants and their corresponding colour (Yen1 et al., 2007).

## Brightness

The brightness of an AC EL panel can be increased in two ways, either by increasing the frequency of the AC, thus switching electric field direction causing emissions to become more frequent which increases the brightness, or by increasing the voltage which creates a stronger electric field causing more emission centres to emit light. Both methods have their limitations. Changing the frequency is limited by how fast the molecules in the dielectric can reorientate themselves, this decreases the relative permittivity and electric field strength (Zeus), and the voltage is limited by the breakdown voltage of the dielectric.

Both methods will have a decreased efficiency at higher frequency and voltage (Fig9).

## Degradation

As stated before phosphors are subjective to degradation during use. An example is the phosphor paint from dupont. They have provided graphs to show the speed at which the output of the phosphors decays over time. Depending on the type of paint it shows that under normal circumstances it can take from 700 hours up to 3200 hours of use before the phosphors has a reduced output of 50 percent compared to the original output. When heated to 60 degrees celsius the degradation is accelerated and is decreased to 70 to 330 hours (Fig10).

The exact mechanisms behind the degradation of phosphor powders is not entirely clear and not all phosphor powder

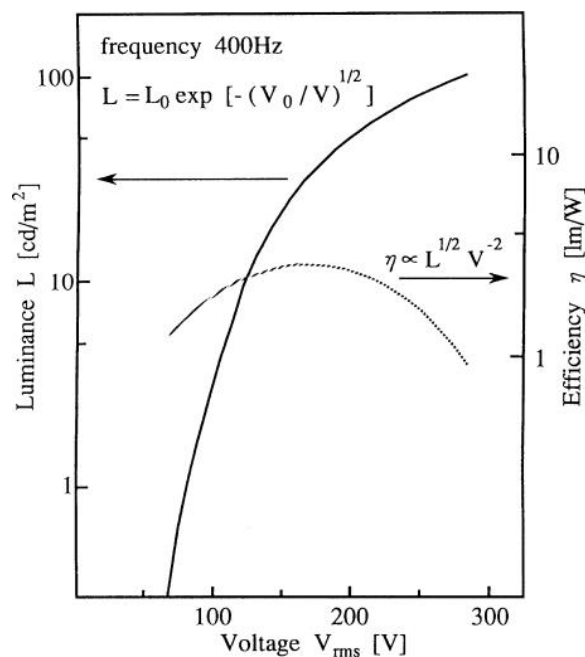


Fig9. Luminance , voltage and efficiency graph at a set frequency (Yen, et al., 2007).

show the same degradation behaviour (Swart et al., 1999) . For ZnS:Cu one of the reasons could be the blunting of the Cu needles after continuous bombardment of electrons which decrease the internal electric field, this type of damage is not reversible. However it is shown that least a part of the brightness can be recovered by annealing which can recover approximately 70-80% of the previous brightness (Medling et al., 2013).

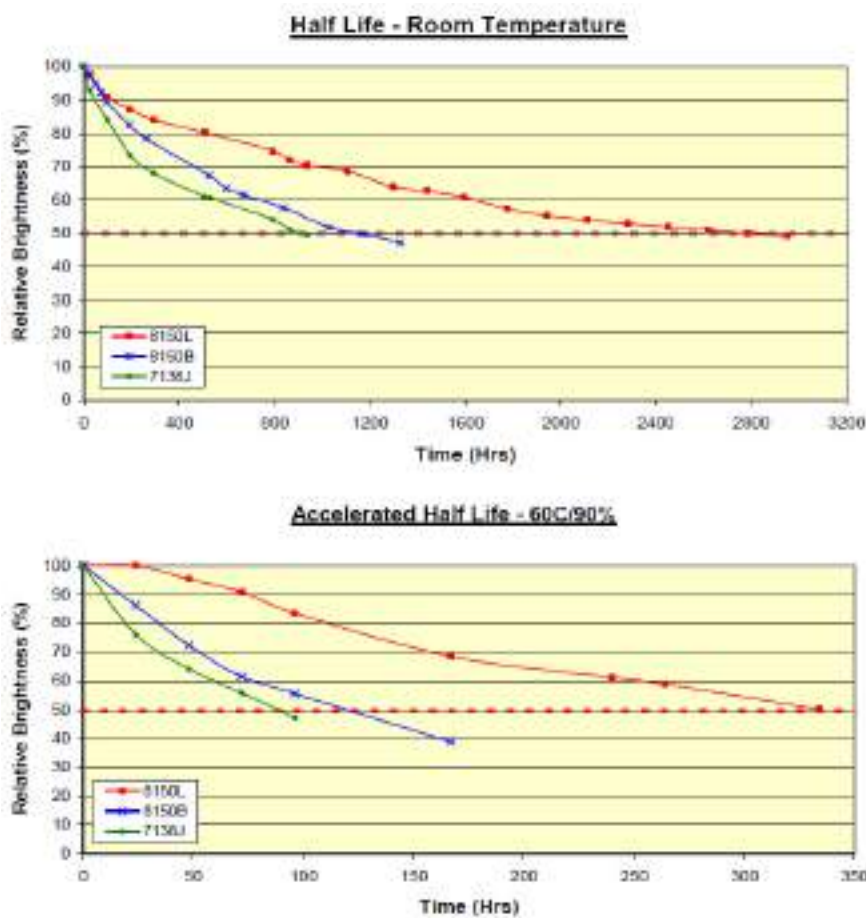


Fig10. Graphs provided by Dupont that show lowered emission over time of three of their phosphors. Negative influence of temperature is visible in lower graph.

# Existing products

There are many different suppliers that can be found online, that sell EL devices ready for consumers to use. Since this project's main focus will be on flat EL panels, these types will be looked into first but other applications of EL technology will also be looked into.

## EL panels

This type of EL device is available in two main configurations.

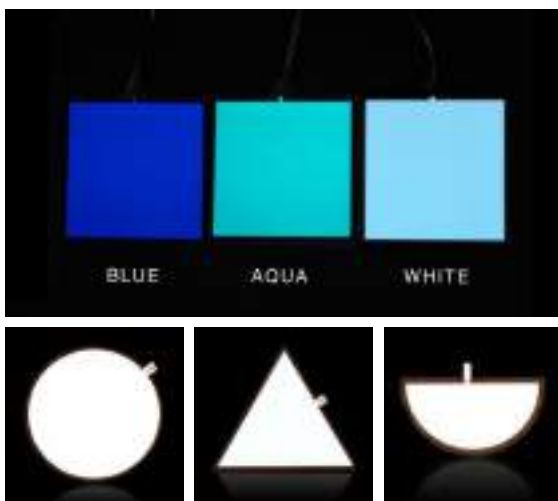
### Standard :

This version of the prefabricated EL panels is available in different sizes, colours and shapes (Fig11). The most common shape is rectangular. They come with an attachment point to which a pocket converter can be attached. This makes it easy to get it working. Some distributors also note that the panel can be cut into any desired shape as long as the attachment point for the converter is attached and the shape is continuous. This does mean that once a part is cut off it is

rendered useless and can be discarded. This is wasteful since these panels do not come cheap. An A4 size panel sells for approximately 50-60dollar.

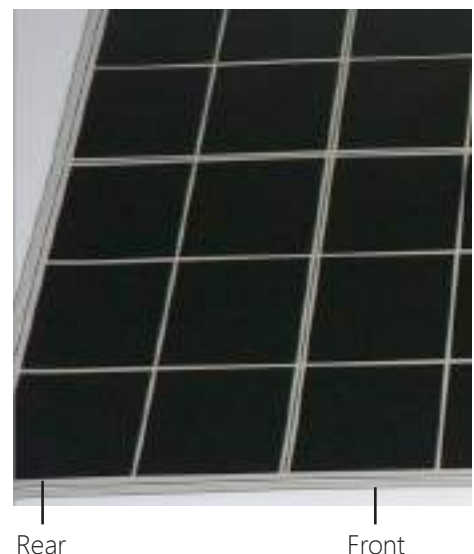
### Cuttable panels:

Besides standard prefabricated panels there are versions that do not have the converter already attached. Instead of a direct attachment they allow for the user to cut the panel in any desired shape provided that the shape is connected to the outer edge. Once a part of the panel has no connecting to the edge, the panel will not work. The panel requires the converter wires to be connected to the two outside lines separately (Fig12). The outside line is connected to the front electrode and the inner line to the rear electrode. This type of panel provides more flexibility to the end user as parts that are cut off can still be used to create working panels.



◀ Fig11. EL panels in different colours and different shapes.

▶ Fig12. Type of EL panels that can be cut multiple times. The shape has to be connected to both outside lines, one is the front and the other is the rear electrode.





### EL tape

This type of EL device is comparable to the EL panel i.e. the construction of the different layers is similar. They frequently come pre-assembled into a working length of tape. They do provide the possibility of being cut in half and attach a converter on either end. This can be done using either conducting glue or a soldering iron (Fig14).

### EL wire

Like the name suggests this type of EL device is in the form of a wire. It comes in many different colours which can either come from a different type of phosphor or have a coloured outside layer that filters the light Fig19. The basic construction of EL wire is in essence the same as an EL panel. The core of the wire is made out of copper and works as the rear electrode. The phosphor layer is

wrapped around the core and around this layer are very fine insulated copper wires. The insulation is the dielectric and the copper wire is the front electrode. The construction of EL wire allows for the effect of a “chasing” EL wire where the thin copper wires are separately connected to the converter and turned on and off sequentially creating the effect that dots of light are traveling along the wire.



Fig13. Construction of EL wire

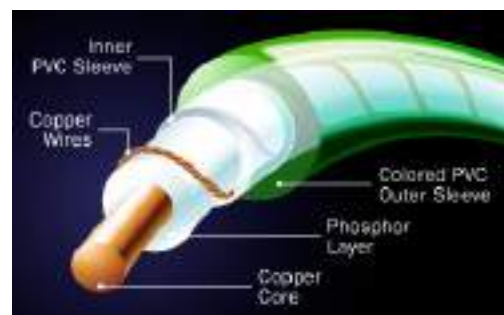


Fig14. EL tape



Fig15. Costume decoration using EL wire.

## DIY EL

The EL devices that can be bought off the shelf offer the possibility for customization. There are panels that can be cut into custom shapes and even panels that cannot be cut can be modified. If parts of the rear electrode are removed, panel will stop illuminating those parts. The electric field be gone at that location (Fig16). These two examples enable people to customize their EL devices but do not offer the true flexibility of DIY methods. In order to see the benefits and limits of commercially available DIY methods they will be briefly discussed. Currently there are two commercial methods that can be used to create working EL devices that both need to be handled like a type of paint. One method is based on spray painting techniques and the second uses screen printing in order to apply the different layers. The paint used for each method is not interchangeable with each other. This is because for spray painting a less viscous paint is required while screen printing

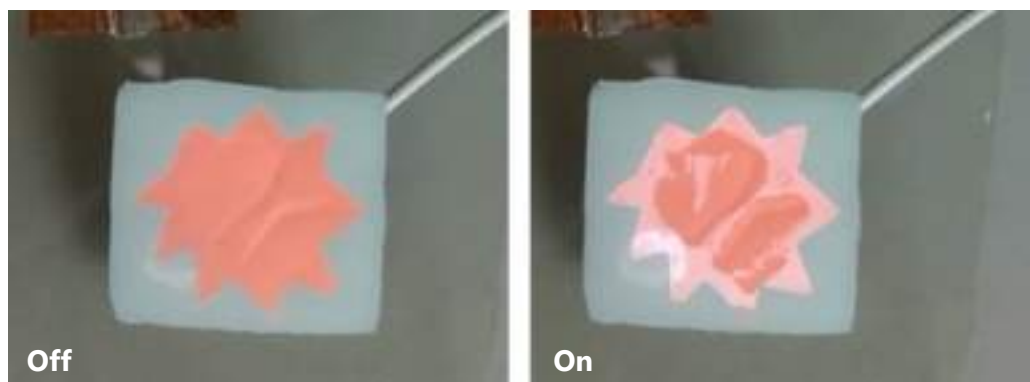
requires a more viscous paint.

Both methods require a similar build-up of the functional layers. Applying a rear electrode (if the panel is not applied on a conductive surface, otherwise this surface can function as rear electrode), followed by the application of a dielectric layer, the phosphor layer and ending with a (semi) transparent top electrode.

### Screen printing

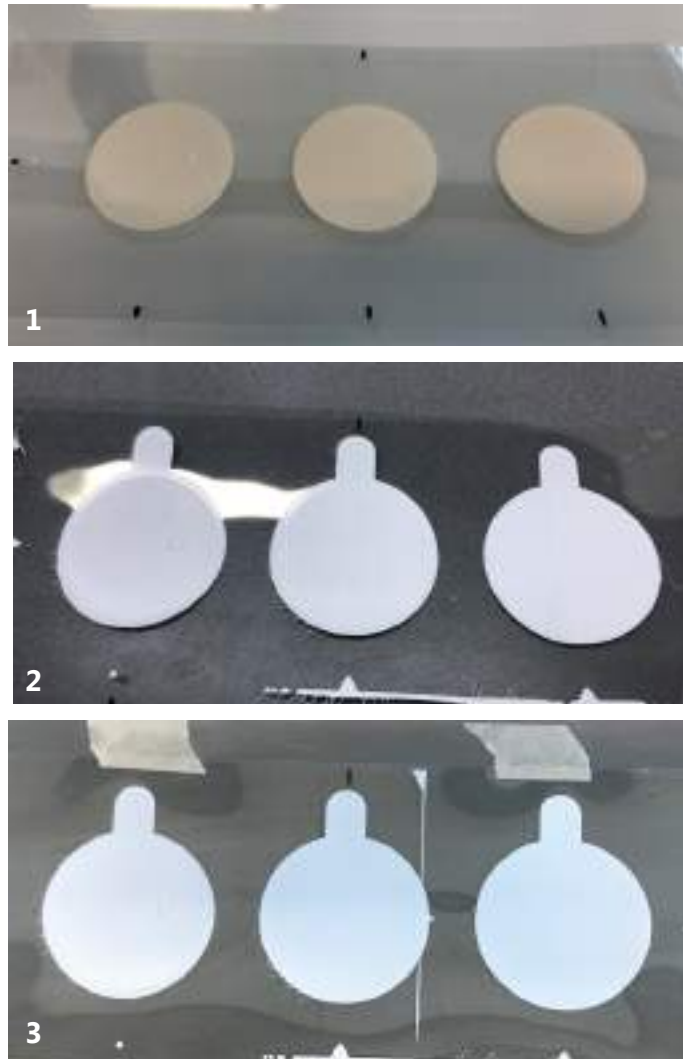
EL paint that is suitable for screen printing is manufactured by multiple companies. Two of those are Dupont and Gwent who both offer similar coloured EL paint. Like the spray paint each layer has to be applied separately, the difference being that only the dielectric layer needs to be applied 2 to 3 times when screen printing in order to prevent holes from forming in this layers which can cause a short circuit. However adding extra layers of dielectric will weaken the electric field. In the ideal situation using less layers is better.

▼ Fig16. Example of a EL panel where the rear electrode has been partially removed which removes emission on the front at those locations. ([www.enactiveenvironments.com](http://www.enactiveenvironments.com))





With screen printing most layers only need to be applied once, only the dielectric layer requires multiple layers. Is suitable for flat surfaces and can be used to make EL devices the size of somewhere between A3 and A4 size (and smaller). Size is limited by the dimensions of the mesh and the oven that is used. The materials that are required (besides the paints) are multiple screen printing meshes (different paints require different mesh sizes) that have the design of each layer applied, a squeegee, cleaning tools (acetone and microfibre cloth) and an oven. The oven is needed because although application of the layers can be done under normal conditions drying each layer will take 10 -15 minutes in an oven at 130 degrees C. First hand experience has taught that preparing the meshes beforehand, cleaning the meshes and preparing the new ones when a layer is drying in the oven is the most efficient method of making an EL device using screen printing. This still means that each layer will take approximately 20 minutes to make. When applying all layers (5-6 depending on the amount of dielectric layers) this amounts to between 2.5 and 3 hours (preparation included). Especially when you have no real experience with screen printing, chances are that you will end up with a defective EL device. The screen printing method has been tested with varying results, Fig17 & Fig18.



▲ Fig17. Testing was done creating a simple shape with from left to right, 1, 2 and 3 dielectric layers. With no real previous experience with screen printing other than creating less than five other test EL devices the main difficulties are: the properly aligning the different layers and depositing an even layer of paint. To decrease the amount of layers necessary ITO PET was used as front electrode, depositing the phosphor on the ITO side.

Fig18. The test resulted in only one working device. This is the one with three dielectric layers applied. The others did not emit light at all.



### Spray paint

Currently the only brand associated with producing and selling paint that is suitable for spray painting is called lumilor. They produce this paint in five different illuminating colours. Each of the different functional layers has to be applied in very thin layers and has to be applied multiple times in order to reach proper coverage of the surface. Each layer requires 5 to 7 minutes drying time between coats and 15 to 20 minutes drying time between each functional layer. A direct quote from their website : "Three to five hours is needed to apply all of the layers of LumiLor in standard conditions". An upside is that the work can be done at room temperature, both when applying and drying the layers.

This method is suitable for turning large (Fig20) and 3d curved surfaces (Fig22) into light emitting surfaces.

The list of items ellumiglow mentions that are required or recommended in order to properly apply the different layers (Fig23) can form an obstacle and can prevent people from using this method. If you are a professional spray painter this will likely not be an issue. However, for designers or design students, getting access to all materials can be difficult , as well as properly applying all layers. Without proper experience spraypainting can lead to applying not enough or too much paint. Both can easily lead to partially or fully malfunctioning EL devices. Not enough paint could result in short circuits when both conductive layers touch, or dark spots in the luminous when the phosphor is not applied properly. Applying too much paint can cause drips that can cause the conducting layers to touch, resulting in a short circuit.



◀ Fig19. Application requires standard spraypaint equipment

▼ Fig20. EL spray paint is suitable for large surfaces



Not Included BUT REQUIRED:

- Well ventilated area
- Compressor, airlines and fittings
- HVLP gravity fed spray guns
- Automotive grade clearcoat
- Respirator
- Nitrile gloves
- Red Scotch Brite pads 320-400 grit
- Rubbing alcohol
- Blue fine line tape 1/2"
- Green or Yellow masking tape 3/4" and 1/4"
- Masking paper 3"
- Drill or Dremel with 3/32" drill bit
- Tack rags
- Touch up brush pack - varies sizes
- Multimeter
- Infrared heat gun 500-650 degrees Fahrenheit
- Timer
- Strainers 120-140 micron
- Mixing cups 8 oz or 32 oz
- Stir sticks- glass or plastic \*\* NO METAL OR WOOD \*\*
- PPS system with attachments
- Black light - wand, cannon, or bulb

Recommended Items:

- Spray suit
- Paint stand and cart
- Popsicle sticks (for J-B KwikWeld)
- Mixing plate (for J-B KwikWeld)
- 2 - Wash bottles (alcohol/thinner )
- Heat lamps and stand
- UV Goggles (when using blacklight)

Fig21. The four materials required for EL spray paint.



Fig22. Covering a motorcycle tank with EL spray paint for 3d-curved surfaces.



▲ Fig23. List of equipment needed and recommended when applying EL spraypaint ([www.ellumiglow.com](http://www.ellumiglow.com)).

# Experimental developments in EL

Before continuing to the experimental part of the project two other interesting researches will be discussed. It is interesting to see what other experimental EL technologies can do. Instead of looking to create a fast method for EL device construction these researches look into increased output and stretchable EL devices.

## Triple and double layered

(Kim, et al., 2011)

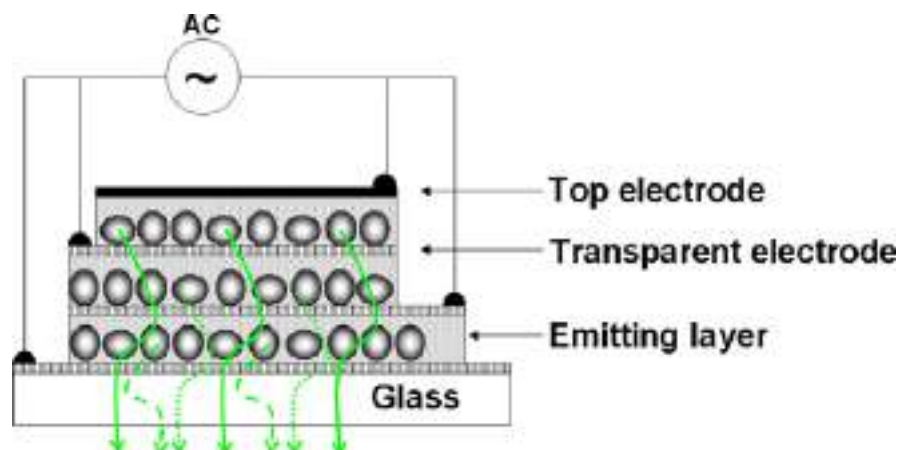
Conventional EL devices are made from two electrodes, a dielectric and a phosphor layer. A research done by Kim et al. in 2010 looked into what happens when an EL device is not made out of one but two and three emitting layers. It can be seen in Fig24 that all layers are attached to each other with the electrodes connected in a parallel configuration. In order to reduce manufacturing steps the binding material for the phosphor (a polyvinylidene fluoride based polymer

, ELPR530) doubled as dielectric layer. Each phosphor layer was spin coated and dried in a oven while gravity caused the phosphor particles to sag which caused the binder to form a thin layer on top of the particle which acts as an insulating layer. They explain that this is possible using this method because the binder has a low viscosity which allows the particles to sink down while being covered by the binder. Screen printing paint has a high viscosity which makes it difficult for the binding material to fully cover the phosphor particles.

They tested the brightness of the single, double and triple structures by increasing the voltage and frequency.

Their results show that at a fixed frequency increasing the voltage ( up to 150V) does increase the light output in the double and triple layer (compared to the single layered device) but it does not double and triple the output. This is likely due to the light being absorbed by each layer it passes through.

▼ Fig24. Construction method of the triple layered EL device.



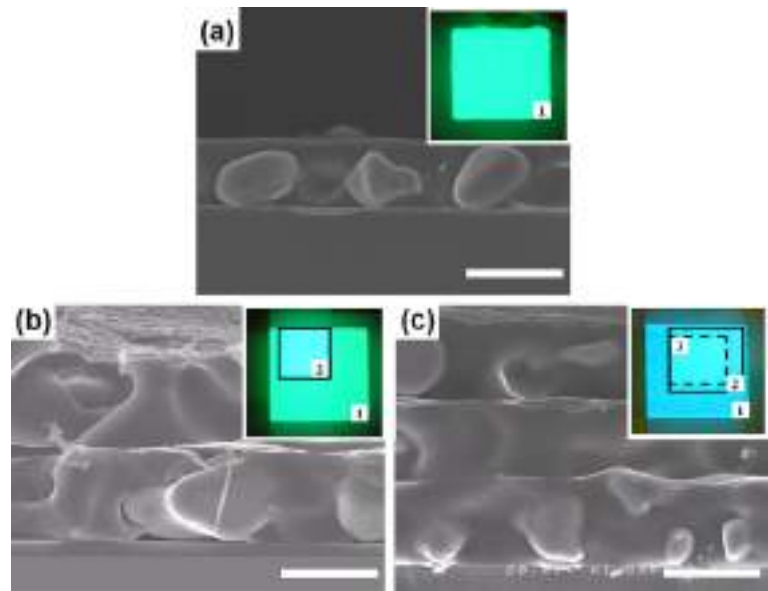


While changing the voltage is not very efficient, changing the frequency at a fixed voltage shows a much more interesting result. Up to about 2 kHz nothing interesting is happening. After this point the brightness starts to increase exponentially and from 8 kHz the double and triple layered constructions become more than two and three times as bright compared to the single layer construction. They stopped at 12 kHz at which the triple layered construction increased in brightness more than six times compared to the single layer, 1460 cd/m<sup>2</sup> for the triple layered compared to the 230 cd/m<sup>2</sup> for the single layered construction (Fig26).

They conclude that this effect is caused by an increased capacitance in the double and triple layered constructions which combined with the increased frequency addresses a different emission mechanism.

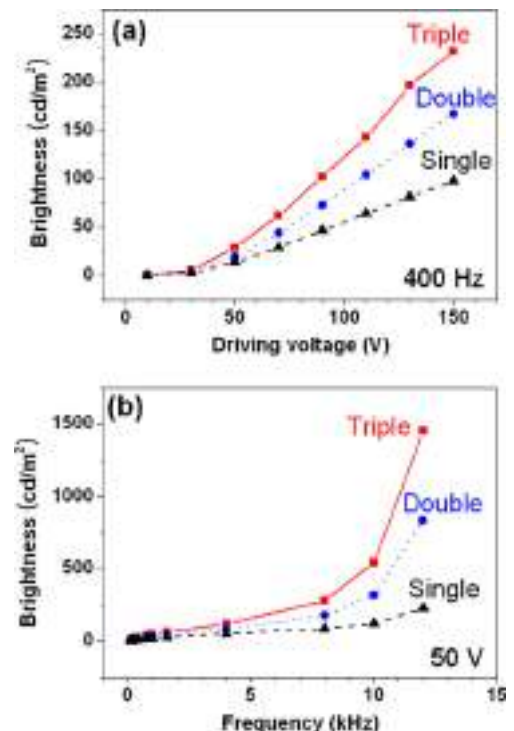
Significantly increasing the output while lowering the used voltage can be very interesting for applications where a high voltage cannot be used and it can make EL technology more attractive simply by requiring a lower voltage (a high voltage can be dangerous).

For this project it is too difficult to quickly build these double or triple layered constructions since extremely thin transparent electrodes need to be applied for this method to work.



▲ Fig25. SEM (Scanning electron microscope) images of the single, double and triple layered EL devices. It is clear that the binding material isolates the phosphor particles. The coloured squares show the emission compared to the other devices. The number indicates the amount of layers. \*Depending on the medium this report is viewed on differences might not be clearly visible.

► Fig26. Graphs of the brightness of the single, double and triple layered EL devices with a fixed frequency and increasing voltage (top) and a fixed voltage with increasing frequency (bottom)



## Hydrogel

(Larson et al., 2016)

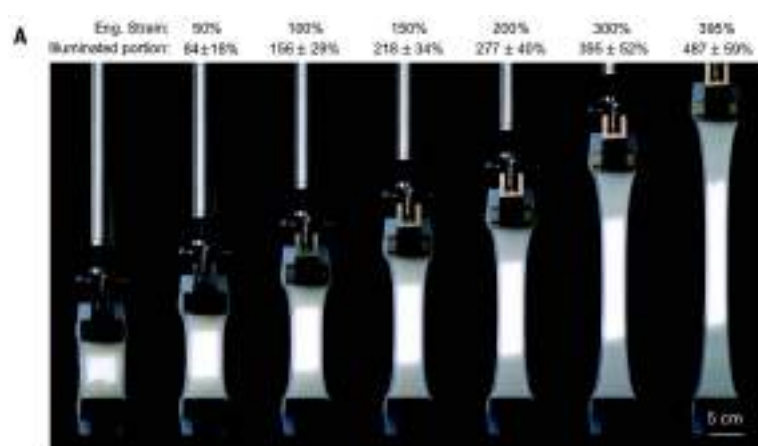
All previously mentioned EL devices are devices that are flexible, i.e. they can be bent or twisted (up to a point), but are not able to be stretched. That is an aspect this study tries to solve.

Larson et al. have chosen to use ionic hydrogels over other types of stretchable electrodes (other stretchable electrodes can be based on a electrically conductive nanowire mesh construction), because these are soft and have a lower increase in resistance once they are stretched (compared to nanowire meshes). Besides being able to cope with large strains, the electrodes also need to have a high transparency in order to let the light out. Ionic hydrogels contain both properties. In order to create a stretchable

light emitting layer, phosphor powder is mixed with a silicone elastomer (Eco-flex 00-3 to be precise) which was also able to function as dielectric layer. This removes the need to apply a separate insulating layer. Combining this resulted in highly stretchable EL devices which can be seen in Fig27. The construction used can be seen in Fig29. Another example can be seen in Fig28. The end of a pencil is pressed against a small EL device which shows that by stretching the device will locally emit more light. This is caused by the distance between layers getting smaller (they are being pressed together), resulting in an increase of the electric field strength.

Although interesting, for this project it is not applicable as the creating of such an device is time consuming. Each layer takes a couple of hours to create. The preparation of the ionic hydrogel takes

▼ Fig27. Using a hydrogel construction strains of 400 percent are possible.

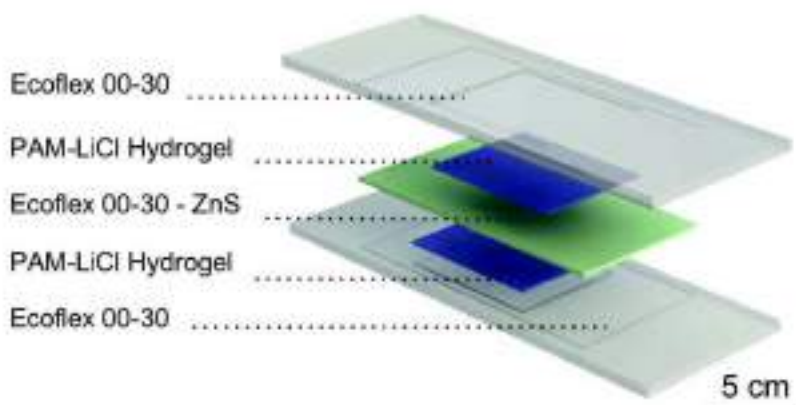


▼ Fig28. Pushing a pencil against the stretchable EL device.



4-6 hours. Furthermore hydrogels slowly dry out once they are made, losing flexibility and conductivity in the process. Both studies have elements in them that are interesting for this project. The combination of phosphor and dielectric, which removes the application of a layer, is an idea that can be used in the new method for the fast creation of an EL device. Less layers will probably require less time. The stretchability aspect is too far fetched for the scope of this project but the increased light output might be worth looking into.

▼ Fig29. Construction of an EL device using hydrogel and silicone.



# Project goal

After exploring existing DIY methods and the working of EL a concrete project goal can be formulated.

*“ Create an easy do-it-yourself method for constructing an EL device, that takes less than 15 minutes ”*

With the initial goal of creating an easier and faster method for creating EL panels, the new goal has made it clear what actually needs to be achieved. The goal of fifteen minutes might seem extremely short comparing it to existing methods, as these methods will take more than two hours. But, multiple steps will be taken to reduce, or simplify, the required steps when creating an EL panel.

## Reducing steps

The two existing DIY methods have a clear method of constructing the different layers. Depending on the usage of a conducting substrate, three (using an

conductive substrate) or four (not using an conductive substrate) layers need to be applied. This does not include the repeated application of certain layers in order to make them fully functional. The aim is to combine layer where possible and remove the need of applying certain layers multiple times.

## Conceptual directions

There are two main conceptual direction in this project for quickly creating EL devices. The first conceptual direction is a dry layering concept. This means all layers are pre-manufactured in dry sheets. These layer can be put in the right order and be bonded by an external input, e.g. using heat to laminate the layers together using hot melt adhesive sheets (Fig30).

The second conceptual direction will explore the usage of materials that can change its state in a short time, seconds to minutes, once they are activated by an external input, e.g. UV curable adhesives.

Fig30. A laminator can be used to quickly bond different layers.





Both methods rely on the materials properties to change their properties in a very short time based on external influences.

First each layer will be discussed on the specifications and limitations that need to be taken into account before ideas are generated and tests are performed.

### Electrodes

For the electrode the decision is made to mainly use ITO PET. This is a layer of PET covered with a thin layer of ITO (indium tin oxide). This is conductive layer that is vulnerable to scratches with can remove conductivity, this means it needs to be handled with care.

The usage of ITO PET serves two purposes. It will remove the need of manually applying an electrode, i.e. the silver electrode when screen printing, and the

transparent property of ITO PET allows light to escape.

Both electrodes can be made from ITO PET when a double sided EL device is required. When a single sided EL device is sufficient one of the ITO PET layers can be replaced by another, less expensive conductive material, i.e. aluminium foil. There are no real limitations on the thickness of the electrode since this will not affect the electric field, this will form between the two electrodes. For a flexible EL device it should be as thin as possible.

ITO PET can be acquired in different type of packaging and protection.(Fig31 and Fig32).

▼ Fig31. ITO PET can also be supplied on a roll.



▼ Fig32. A sheet of ITO PET. This supplier has covered the conductive ITO side with a blue protective foil which has two functions, protection the ITO layer and it works as an indication of which side is the ITO side. It is not possible to determine which side is the ITO side by sight. Some supplier cover both sides with a similar coloured foil which means the conductive side needs to be determined manually. This can be done by attaching two pieces of conductive copper tape and use a multi meter to measure the resistance.



## Phosphor

The base material for this layer is powdered phosphor. The phosphor that is ordered for this project has an average grain size of 29 $\mu$ m according to the manufacturer (Fig33). There are two main directions that can be taken with this material. It can be combined with a binder. This could allow the creation of very thin layers that are ready for use. Cutting these sheets into the desired shape and use a type of adhesion technique to bond it to the electrodes. Using this method, the material for binding the phosphor particles together could act as a dielectric material or the material used to bond the phosphor sheets to the electrodes might work as dielectric layer.

The second direction is to combine the phosphor with a binder. This can be stored in a container. This makes it ready to be applied when needed. It should be able to adhere to the electrodes and the dielectric layer.

## Dielectric

As mentioned the dielectric can be part of the electrode, part of the phosphor layer or it can be a separate layer. Regardless of where it is located there are a few properties that are required that do not change. The dielectric will have to be transparent or at least highly translucent if a double sided EL device is required. This allows the maximum amount of light out of the device instead of trap-

▼ Fig33. Phosphor powders are shipped in small sealbags. Name given by the producer and indicated emission colour and chemical composition. Actual emissive colour can be found in appendix 2.

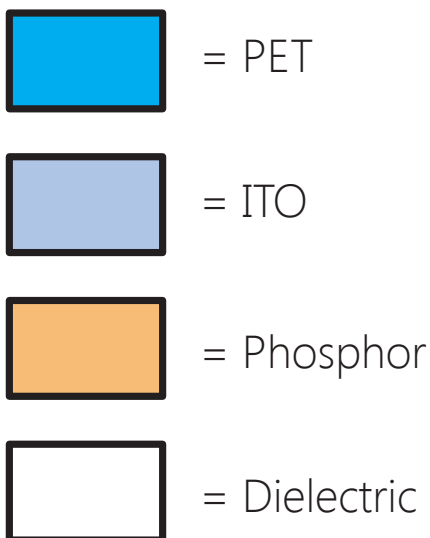


- D310B - Blue-White (ZnS:Cu, YAG)
- D611B - Orange-white (ZnS: Cu, Mn)
- D417B - Dark blue (ZnS: Cu, Al)
- D512B - Green (ZnS: Cu)

ping it inside the dielectric. In a single sided device the dielectric does not need this property since it can be placed between the phosphor layer and the rear electrode without significantly influencing the light output. Ideally the dielectric is as thin as possible without compromising the dielectric strength, failing to do so can result in dielectric breakdown. The challenge is to find a material that can be thin, has a high relative permittivity and a high dielectric strength in order to maximize light output.

Illustrations on how the tested devices are constructed, ordering of different layers, follow the colour scheme that can be seen in Fig34.

▼ Fig34. Colours used to indicate different materials in the report.



## M A T E R I A L   T E S T I N G

After exploring existing products, experimental EL devices and the working principles behind EL, this chapter will cover the testing of different materials on their potential in DIY EL devices.

With a dry layering technique in mind, the first half of this chapter will include materials that are able to bond different layers. They will be mainly tested on their dielectric capability and its effect on the light emission.

In the second half of the chapter multiple materials are not only tested on their dielectric capability but also to function as an binder for the phosphor particles.

The chapter will end with a construction method that will be used to advance the project.

# Testing

Based on the research done on the working of EL and existing DIY methods multiple materials are selected to test their performance in an EL device. It might not actually be possible to use certain materials, as they might not bond properly or undergo a reaction with another material rendering them useless.

Based on the research done for this project and that of the graduation project done by Stan Claus (Claus. 2016)(he found materials that have potential in reducing EL construction time but was unable to create devices that emit sufficient light) multiple materials are selected that are expected to have potential in quickly creating an EL device. The materials that are selected and tested are meant to function as the dielectric layer and bond the phosphor layer to the electrodes or to bond with the phosphor and double as dielectric layer.

Gathering the materials that are suitable for a working EL device ended up being more difficult than expected. This was mainly because the thickness of the

material plays a major role in EL devices. Manufacturers of the DIY paints say the thickness of the dielectric and phosphor layers combined should be approximately 60-70 micron (Processing guide DuPont) to be able to use it with a small inverter, Fig35. This is when using dielectric layer based on barium titanate (30um thick) which has ideal properties, a high permittivity and high dielectric strength. Other materials are likely to have a lower permittivity which would require an even thinner layer in order to reach the same output (assuming the phosphor layer has a similar thickness). An example of this is double sided tape. There are many different types of double sided tape available in stores but these are often too thick and those available for industry use are still relatively thick and those with extreme thinness (less than 10um) need to be ordered in very large quantities. 3M sells this tape in rolls of 1 meter wide and 200m long. This is a too large quantity for this project (Fig36).

▼ Fig35. Pocket inverter used for testing the samples



▼ Fig36. Price for 1x200m 3M 82600



Companies were found that provided samples of hot melt adhesive sheets and powder, ITO PET with a very thin layer of PET and extremely thin double sided tape. This meant testing could proceed with a variety in thickness for different (potential) solutions.

An initial test sample is made using the screen printing method in order to get a feeling of how much a properly working DIY EL device puts out. The luminescent output is not measured because a visual comparison of the test sample against

the screen printed version will be sufficient in this stage. Emission of the test sample can be seen indoor with, Fig37, and without light, Fig38.

The tests start with analyzing the potential of different materials on their dielectric layer capabilities. The screen printing DIY method is used to compare the output to the test sample in order to determine the effectiveness of the dielectric layers. Next new methods of processing the phosphor in order to create EL devices are tested.

▼ Fig37. Test sample during normal indoor lighting.



▼ Fig38. Test sample in a dark room







# Double sided tape as dielectric

## Goal

This test aims to determine the usability of regular double sided tape as a means to bond different layers in an EL device. Also the usability as a dielectric layer will be tested.

## Testing

The first tests are done to test the dielectric application of multiple double sided adhesive tapes. To test the influence of the tape's thickness and material on the light output five different tapes are selected to test with, Fig39. The tapes that are chosen vary in thickness, in construction (some are made from a carrier with adhesive on both sides and others are made from a single layer of adhesive) and in the material they are made from. The tapes that are used are:

- I Tesa 5338 (consumer tape)
- II Tesa 4972
- III Tesa 4959
- IV Tesa 4900 PV9
- V 3M 467MP - 200MP

Because the variable in this test is the double sided tape the phosphor and electrodes are the same in all test samples. ITO PET is used for both electrodes and the phosphor that is used is applied using the screen printing method. The phosphor is applied to the ITO side of one of the electrodes and set to dry in the oven. Pieces of tape are placed on the ITO side of the second electrode, fully covering the surface from left to right, providing proper insulation. Finally the second electrode is placed on top of phosphor and the whole sample is firmly pressed down (Fig40), an illustration of this construction can be seen in Fig42. This is done using a pressure roller to ensure all layers are tightly bonded. Each sample is made twice to provide a more accurate outcome, (both samples should provide a similar result). One of each tape samples is heated using an iron for 30 seconds on the highest heat setting to determine if this influences the output. It could potentially improve the out-



▲ Fig39. Tape samples, usually for the industrial market, from TESA.



▲ Fig40. A test sample with double sided tape bonding one electrode to the phosphor layer.

put by slightly melting the tape causing it to spread better between the two electrodes. A handheld inverter is connected and turned on to observe the results.

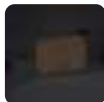



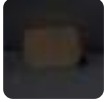
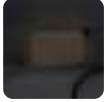
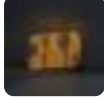
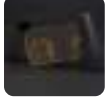
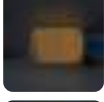
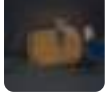
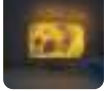
### Results

All of the samples worked on the first try, although some of the tapes resulted in a extremely low output, Fig41. Each tape showed two very similarly performing samples and applying heat appeared to have no positive influence on the light output. Two of the tapes performed significantly worse after the application of heat.

All samples showed dark spots, some more than other. These can be caused by:

- The pieces of tape are narrow, requiring multiple pieces to be placed very close to each other by hand, which creates small gaps.
- Uneven application of phosphor creating small bumps and holes that caused the tape to not adhere properly.
- Air gets trapped between the tape and phosphor layer, increasing the distance between the electrodes and lowering the relative permittivity.

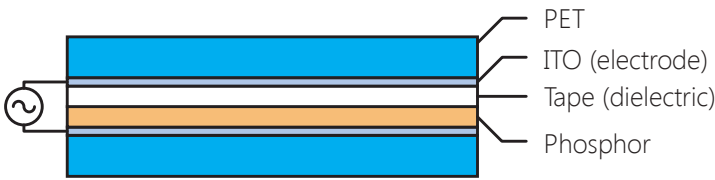
The results show that the two tapes with a thickness of 100 micron barely emit light. Tape II and V have a similar output although tape V is 20 percent thicker. This is probably caused by the difference

	Thickness	Backing	Adhesive	Sample 1	Sample 2	Sample 2 heated
I	~100	Unknown	Unknown			
II	48	PET	Tackified Acrylic			
III	100	Non-woven	Tackified Acrylic			
IV	50	none	Acrylic			
V	60	none	Acrylic			
Clingfilm	10					

▲ Fig41. Table that indicates the thickness of each tape, the material that is used for the backing and what type of adhesive is used. All emission photos are made in the same environment using the same settings on the camera in order to compare the samples on brightness.

in relative permittivity of the acrylic compared to the PET. The best performance is reached using tape IV, which has almost the same thickness as tape II but again the difference in relative permittivity enables a higher output. Ideally double sided tape of 5 micron should also be tested, but could not be obtained at the time of testing. Instead a sample was created using cling film, which measured 10 micron thick, since it is expected to reach a similar output that can be obtained using the 5 micron tape. Because cling film does not does not have any

▼ Fig42. Basic construction of EL devices that use tape as dielectric.



adhesive, the sample had to be handled very carefully. It was also very difficult to remove all the air that was trapped causing large dark spots. It did light up showing a significantly higher output than the tape samples (which gives an indication what could be reached using the 5 micron tape). However the output appeared to still be less than the test sample made using barium titanate as dielectric.

### Conclusion

Double sided tape has potential in a method for fast EL device construction but it stands or falls with the thickness of the tape that is used. Compared to the screen printing sample that uses BaTiO<sub>3</sub> as dielectric, the tape will have to be significantly thinner than the 40 micron (of the BaTiO<sub>3</sub>) in order to compensate for the lower relative permittivity.

### Discussion

In a later stage during the project double sided tape measuring 5 micron thick was obtained and tested on its performance as dielectric (appendix 3). Although it provides a good output this sample has large areas that emit no light. This is caused by the material used to bond the phosphor to the electrode, UV curing adhesive. The tape bonded poorly with this material. There were no screen printed sample available to test with and recreating them would take too much time.

However it does show that double sided tape has the potential to be used to bond a phosphor layer to the electrodes without compromising the brightness (Fig44).

Fig43. Graphic representation of how double sided tape can be used to bond a dry phosphor layer to two electrodes.

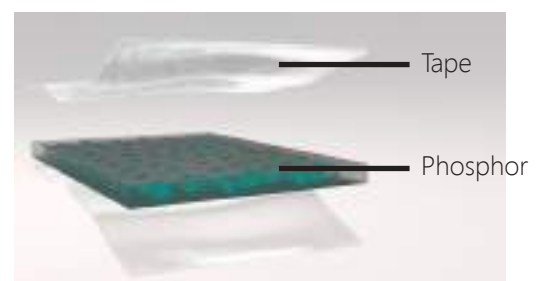
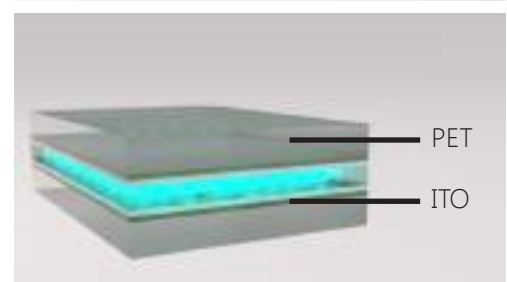
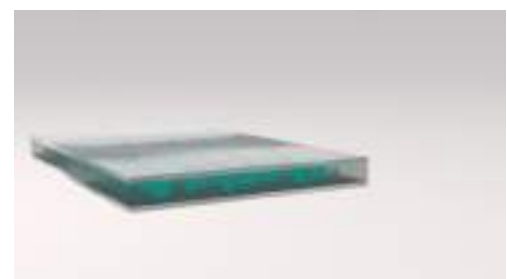
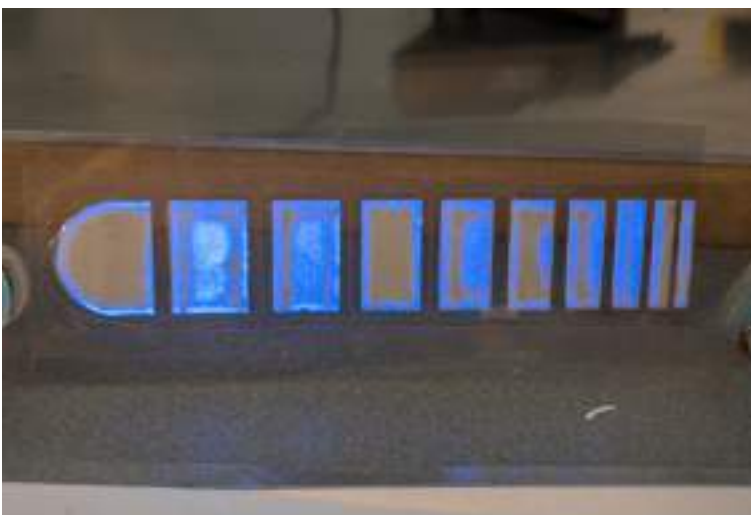


Fig44. Output of a sample that used double sided tape of 5 micron thick.



# ITO PET with varying PET thickness

## Goal

In order to reduce the amount of layers that need to be applied, the PET layer of an ITO PET electrode can theoretically work as the dielectric layer. This can be done by layering the EL device with the ITO PET flipped applying the phosphor on the PET side. A visual of the order of the different layers can be seen in Fig455. Previous testing with tape has already shown that the dielectric layer should be less than 50 micron. The ITO PET that was already available at the start of the project has a thickness of 125 micron. Which has shown to be too thick as dielectric (Claus, 2016).

## Thin ITO PET

Finding ITO PET with a thickness of less than 50 micron was difficult since most companies required a minimum order quantity. The Chinese company Mianyang Prochema Commercial Co.,Ltd. Was able to send samples of varying thickness. During shipping a mistake was made and the ITO PET of 25 micron was not shipped. The 80 micron ITO PET did ship and was tested while the 25 micron ITO PET was reshipped.

## Testing

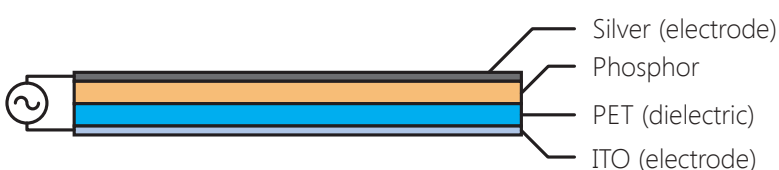
With the thickness of PET as the variable in this test, the front electrode is the ITO layer and the screen printing silver ink of Dupont is used as rear electrode. The phosphor is applied using the screen printing ink and method. The phosphor is applied on the PET side of the ITO PET and the silver ink electrode is placed on top of the phosphor layer. Each layer is dried separately in the oven.

Using the 80 micron ITO PET this method was successful. However, the 25 micron ITO PET started the curl in the oven. This might be caused by the difference in expansion between ITO and PET when heated. This can be more pronounced in the 25 micron sample since the PET is thinner, making the layer of ITO relatively thicker. The sample made using the 25 micron ITO PET was accidentally made using a different colour of phosphor.

## Results

Both devices emitted light, albeit very faintly. Fig47 shows the emission of the 80 micron PET sample and Fig46 shows the 25 micron sample. The 25 micron is slightly brighter but a direct comparison

Fig45. Basic construction of EL devices that use PET as dielectric.



is not possible due to the difference in phosphor that is used. A new sample is not made since the 25 micron ITO PET curls when curing in the oven, which is unwanted.

### Conclusion

It is difficult to reach a clear conclusion on the output between the 80 en 25 micron PET, as two different phosphors are used.

A conclusion can be drawn on the usage of the 25 micron ITO PET when using the screen printing method. It is possible to use the 25 micron PET as an dielectric,

but due to the curling when placed in the oven, other preparation need to be made to prevent this behaviour. A weight can place weight on the edges or it can be placed place it in a frame to hold it straight.

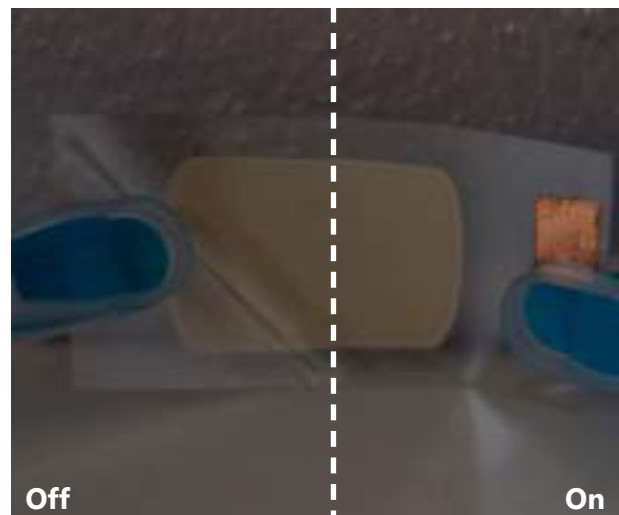
Using the 25 micron PET as dielectric will be explored with other materials, i.e. materials that do not need to be heated in order to cure. This will enable better understanding of dielectric capabilities of 25 micron PET.



Fig46. 25 micron sample. Accidentally white phosphor with a lower output is used making it barely visible with ambient light.



Fig47. 80 micron sample on, output barely visible.



# Conductive double sided tape

## Goal

Because cling film has shown to work well as dielectric, but lacks the adhesive properties, it is placed between two pieces of electrically conductive tape. This is done to explore the effectiveness of this construction in an EL device.

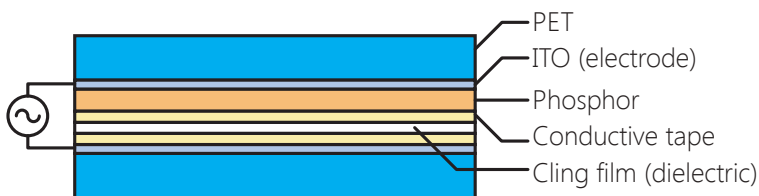
## Conductive tape

The conductive tape used in this test is Z-axis conductive tape, i.e. it will only conduct electricity across one axis. It is a double sided adhesive layer filled with particles that are not in contact with each other. This causes the tape to only conduct electricity from top to bottom.

## Testing

The conductive tape is placed on top of a piece of cling film, while trying to remove as much air as possible. A piece of conductive tape is placed on the other side. The film/tape construction is placed directly on the ITO side of a piece of ITO PET and another piece of ITO PET with phosphor applied (using screen printing) is placed on the other side, Fig48.

Fig48. Sample schematic ▼



◀ Fig49. Prepared samples

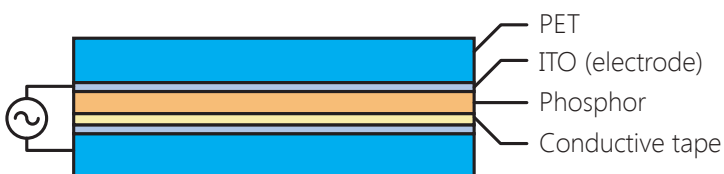


◀ Fig50. Faint glow of the test sample.



◀ Fig51. Emission with only tape and no dielectric

▼ Fig52. Construction with only tape and no dielectric



## Results

The output of the sample was very low Fig50. This is caused by the fact that the dielectric layer is not just the cling film but a combination of the cling film, a layer of z-axis tape and the phosphor layer. The assumption was made that the phosphor layer would be conductive, since a separate dielectric layer is required when screen printing (if the phosphor layer is not conductive why is the separate dielectric layer required?). This setup has shown that the assumption was false.

## Conclusion

Applying double sided tape to both sides of a dielectric layer is useless for an EL device. It does not provide a thin dielectric layer but creates a thick layer which reduces the electric field strength.

## Discussion

Because the need for a separate dielectric layer is called into question, since the phosphor layer is not conductive, a quick test sample is made to test an EL device without a separate dielectric layer. A piece of conductive tape is placed on top of the phosphor layer and connected with the ITO side of a piece of ITO PET, just to see what happens (Fig52). The test sample emits relatively bright light, almost as much as the test sample, Fig51. This further raises the question why the screen printing method requires a separate dielectric layer when clearly the binder in the phosphor ink can work as a dielectric layer.



# Castable silicone

## Goal

This test is performed in order to test the ability of silicone to function as a binder for the phosphor and as dielectric. If it is possible to create sheets of a silicone and phosphor mixture this might make it possible to cut it to size and place it between two electrodes in order to quickly make an EL device.

## Testing

This test is done using castable silicone rubber (Smooth-On Dragon Skin 20). This material is also used in the stretchable EL devices created by Larson et al., showing the potential in being used as a binder but also work as a dielectric layer. By placing strips of regular household tape, which has a thickness of 40 micron, at a distance of 5cm on the edge of a piece of glass (Fig53), a tool is created

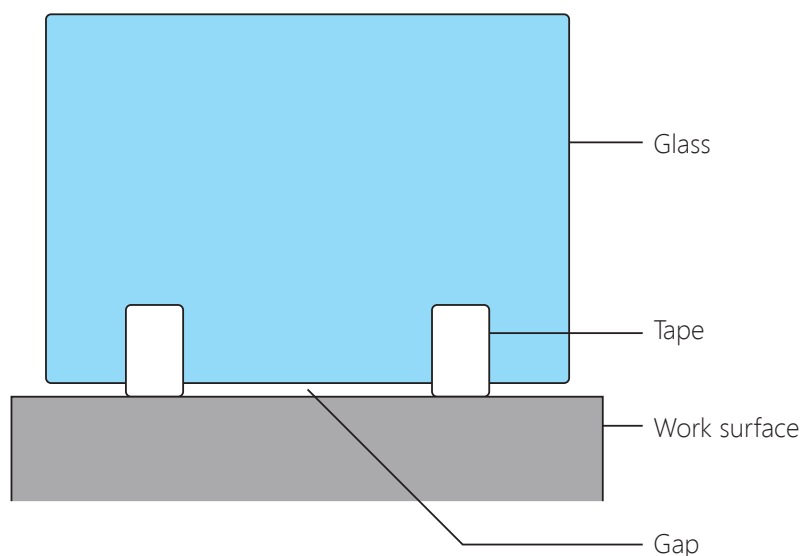
that can be used to create thin layers of silicone. It is important that the surface the silicone will be spread on, and the tool that is used, is flat and smooth (Fig54). Small bumps can prevent the creation of a layer of silicone with an even thickness.

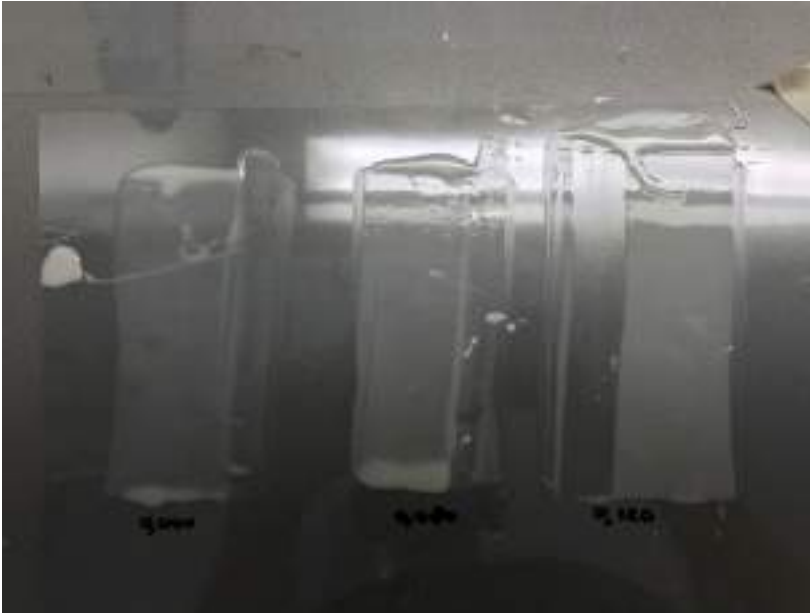
Multiple layers of tape are used to create sheets of silicone with varying thickness. One, two and three layers of tape are used to create pieces of silicone that are approximately 40, 80 and 120 micron thick, Fig55. The concentration of the phosphor particles is equal in all samples and is based on the paper of Larson et al., which equals 8 percent in volume. The silicone is made by mixing two parts in equal weight, part A and part B. The phosphor powder is first mixed with part B since this has a lower viscosity than part A. This makes it easier to make sure

▼ Fig53. Tape attached to a sheet of glass



▼ Fig54. The gap between the work surface and the glass has the thickness of the piece of tape.





▲ Fig55. Three different layers during curing. Their opaqueness shows which one is thick and which one is thin.



◀ Fig56. Barely visible emission in a normal lit room.

the phosphor is mixed properly before mixing in part A.

Once cured the silicone is difficult to handle, especially the 40 micron piece, easily sticking to every surface it comes into contact with.

Because this test also aims to determine the effectiveness of the silicone as a dielectric, a first test is conducted by simply placing the pieces of silicone between two electrodes. The construction of the layers can be seen in Fig57. The samples need to be handled with care as no adhesive is in place to keep the layers in place. This would add to distance between the two electrodes (weakening the electric field and lowering the output). The tackiness of the silicone is enough to keep the construction together long

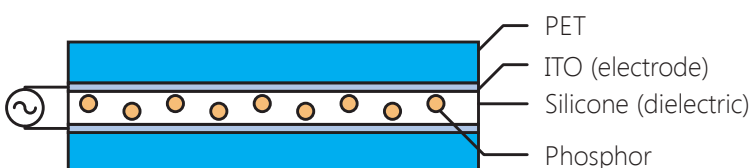
enough to test the output.

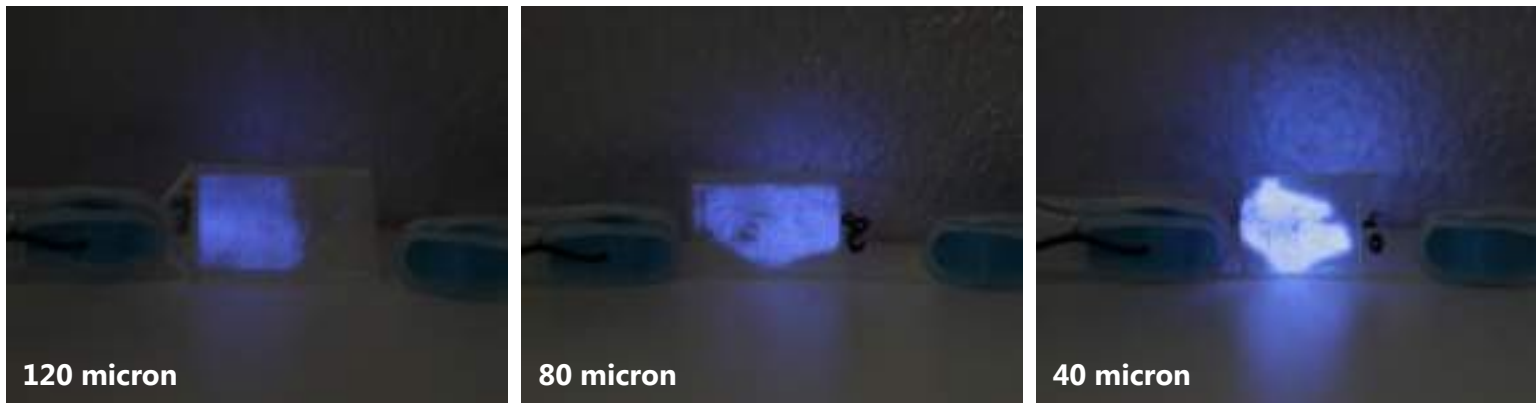
Another sample is made using double sided tape that has one side that is specially made to bond with silicone (PPI tapes, RD-449). The silicone sheet is sandwiched between two pieces of this tape.

## Results

All samples worked and no breakdown took place. The two thickest samples have a relatively similar output. This can be explained by the increase in electric field strength when going from 120 to 80 micron but a decrease of the total amount of phosphor particles (the volume percentage of the phosphor is similar but the volume of the thinner samples is lower hence the lower amount of phosphor particles).

▼ Fig57. Basic construction of EL devices that use silicone as dielectric.





▲ Fig58. Emission of the three test samples

When comparing the 80 to 40 micron thick samples the output of the 40 micron sample is surprisingly high. In Fig58 it is clearly visible that this sample puts out significantly more light than the other two samples even though it has the lowest amount of total phosphor particles. This might be caused by some sort of threshold in electric field strength which triggers more emission centres to emit light.

The sample with double sided tape did not emit any light. On the website of the manufacturer it is stated that the tape has a thickness of 25 micron, which would add an expected 50 micron to each silicone layer. This would still make it relatively thick but acceptable for the test. In reality the tape is 75 micron thick which adds 150 micron to the total distance between the two electrodes. Even with the 40 micron silicone it will still create a 190 micron gap between the two electrodes. This distance will make the electric field too weak to create emission in any of the silicone samples.

### Conclusion

Silicone rubber can work as dielectric and binder but emission is only high enough at a very low thinness at which it becomes too difficult to handle. This can be fixed by using double sided tape that can bond with silicone rubber, which should be a very thin tape in order to add as little extra thickness as possible.

### Discussion

Because Dragon Skin 20 has a curing time of 4 hours it is not suitable for creating a custom EL device in a short amount of time. However mixing it with silicon is easy and creating sheets of silicon is also possible (appendix 4) which could lead to pre-made sheets of silicone with embedded phosphor particles that can be cut to size and bonded with two electrodes (a proper binding material is also required). The method used to create the sheets could be explored further in another project.

# Hot melt adhesives

Hot melt adhesives (HMAs) are thermoplastic materials that are solid at room temperature, become liquid when heated and can create a bond when they cool down. HMAs come in different forms (Fig59). The focus will be on HMAs in powder and sheet form. They can be used to quickly create a bond between two materials simply by heating, applying pressure and letting it cool. Based on the type of HMA it is possible to be manufactured transparent and colourless.

HMAs are not made purely out of thermoplastic polymers. Besides the different types of polymer which have different bonding and melting temperature characteristics, other materials are added to change the properties of an HMA. The main additives are tackifiers, waxes

and antioxidants, other additives can be used based on the required properties of a HMA.

The additives in a HMA are used to improve bonding characteristics with certain types of substrates. Because different types of substrates, e.g. metals and plastics, have different surface properties a HMA that adheres well to one, might not adhere well to the other (Kim, et al., 2005).

The quick bonding, combined with the optical properties, would theoretically make it a good basis for a method to quickly create EL devices. At room temperature HMAs can be used to properly align the different layers for an EL device after which only heat and pressure have to be applied in order to bond the separate layers.

▼ Fig59. Different forms of HMAs. From left to right: Hot glue gun, film and granules.



# Hot melt adhesive sheets

More detailed information in Appendix 5

## Goal

The goal of the following test is to determine if HMA sheets can be used to create sheets that contain phosphor particles and be pressed between two electrodes in order create a functioning EL device.

## Testing

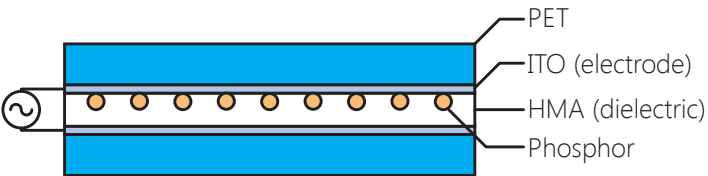
The first type of HMAs that are tested are hot melt adhesive sheets. Because ITO is not a common material, no HMAs could be found that are made to specifically bond with ITO. In order to find an HMA that will create a proper bond, different sheets are acquired through different suppliers. Five different HMA sheets are tested (Fig60). They differ in the material they are made of, the thickness of the sheet (varying between 20 and 120 micron) and the structure of the

	iCraft	RD-441	Fusion Plus	Fixmount Ultra	DigiMount
Specified Thickness	-	25	50	50	50
Measured Thickness	50~120	20~25	45~50	80~100	40~45
Sample Thickness	315~340	280~290	310~320	335~350	295~315
Heated HMA Thickness	55~80	20~30	50~60	75~90	35~55

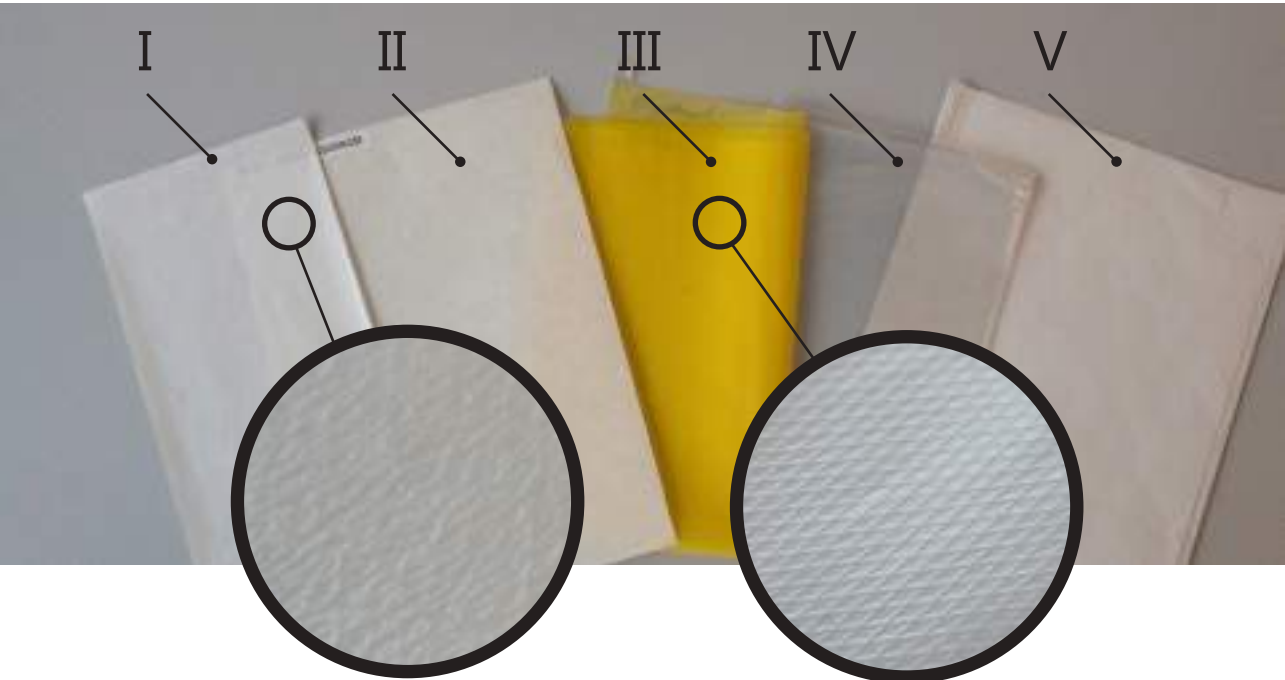
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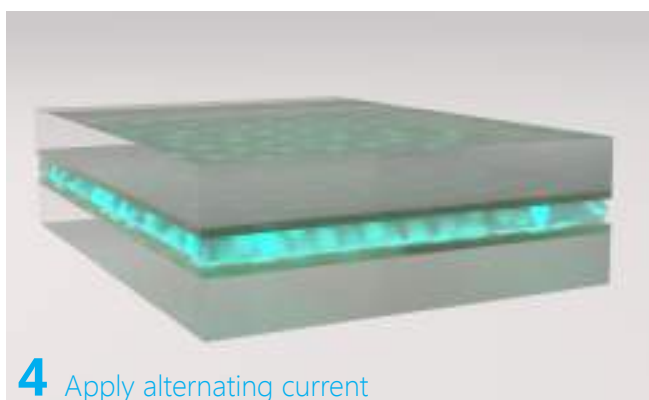
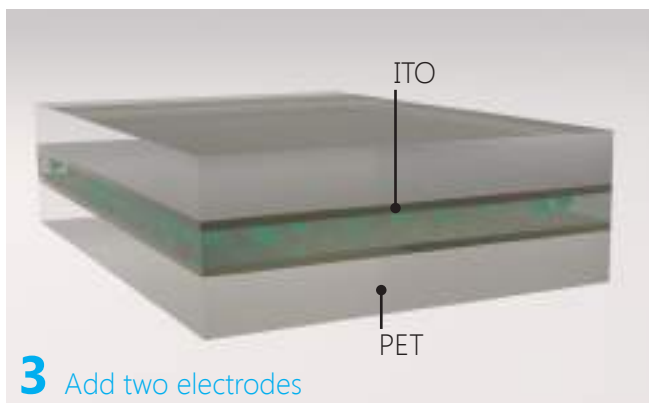
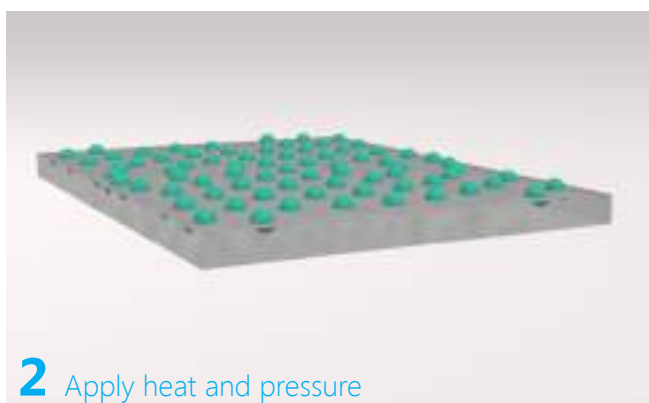
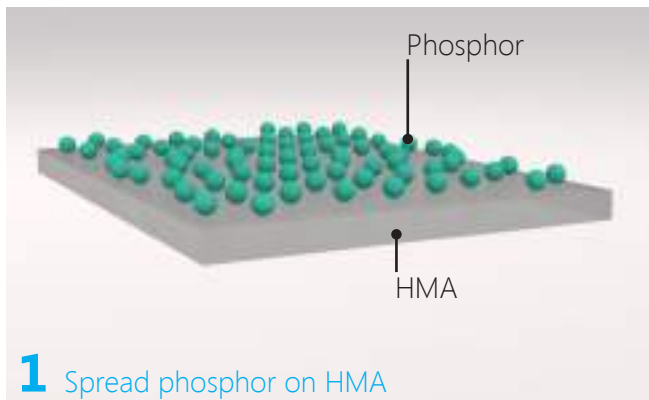
▲ Fig61. Measurements done on the HMA sheets before and after being heated. The samples consist out of two layers of ITO PET, adding 260 micron to the total thickness, and a layer of HMA.

▼ Fig62. Basic construction of EL devices that use silicone as dielectric.



▼ Fig60. The different sheets of HMA that are used during this test. Two HMAs have a clear texture.





sheet (some are smooth and some have a clear structure). The different sheets of HMA are:

- I iCraft Hot Melt adhesive (decofoil)
- II RD-461 (PPI Tapes)
- III Digimount (Biedermann GmbH)
- IV Fusion Plus (Biedermann GmbH)
- V Fixmount ultra (Biedermann GmbH)

Initial testing is done to determine the thickness of the HMAs after they are heated (Fig61) to determine how much they will add to the distance between the electrodes. This test will also function as a test to determine how well they bond with both ITO and PET. The main focus will be on the bond that is made with ITO, with a construction in mind that can be seen in Fig62.

Next multiple methods of combining the phosphor particles with the HMA sheets are tested. The basic principle behind this can be seen in Fig63. First the HMA and phosphor sheet is prepared, spreading the phosphor particles on top of the sheet and place this between two sheets

Adhesion to:	ITO	PET
iCraft	+	±
RD-461	-	-
Fusion Plus	-	±
Fixmount Ultra	-	±
Digimount	±	±

◀  
Fig63. Graphical representation of the idea behind pressing the particles into a sheet of HMA in order to create an EL device



of wax paper. This will prevent the HMA from sticking to anything except the phosphor. By applying heat and pressure the particles are pushed into the sheet of HMA. The heat is provided by an iron set to approximately 200C and pressure is applied by leaning on the iron (for 2 minutes) while it is heating up the sample. Letting it cool down essentially makes it a sheet that can be cut into shape, placed between two electrodes. After heating it and letting it cool again it is ready to use.

### Results

The first test showed that only the iCraft and Digimount HMAs can bond well with ITO (and PET). These are both HMAs that have a rubbery feeling. The iCraft is therefore chosen to use in the test using the phosphor powder.

Applying the described method that is shown in Fig63, resulted in samples that are too thick and only showed emission near the edges, Fig64. This is likely because the HMA was not able to flow

enough between the electrodes, only near the edges it has the space to flow freely resulting in a thin enough layer to enable light emission. After heating it for 10 minutes at 200 degrees C the results did improve slightly (Fig65). Emission was still brighter on the edge of the sample and it did not provide an equal spreading of the phosphor. An attempt was made to create space for the HMA to flow into by cutting it into strips once the phosphor is pushed in. This should enable the HMA to also flow towards the inside instead of only flowing outwards. It did provide the better results but still far from ideal (Fig66). Heat and pressure were applied for 10 minutes.

### Conclusion

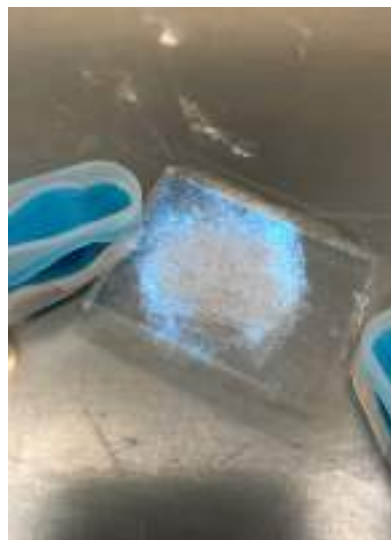
Using HMA sheets to capture phosphor particles is possible. Using it to create a homogeneous emission is not.

A thinner sheet could improve the centre emission but might still leave the problem of a visible difference in emission between the centre and the edges.

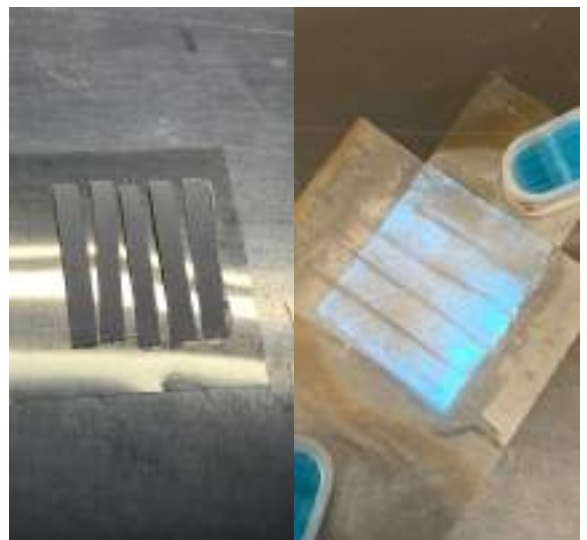
▼ Fig64. Emission after applying heat for 2 minutes



▼ Fig65. Emission after applying heat for 10 minutes.



▼ Fig66. Cutting strips to create more space for the HMA to flow into.





# Hot melt adhesive powder

## Goal

This test is done in order to determine if an EL device can be made by mixing HMA powder with phosphor powder.

## Material

The material used in this test is an HMA powder from Intercol. They were unable to provide exact information on the type of HMA other than it is made to bond with PET. They reported that the average grain size is less than 100 micron.

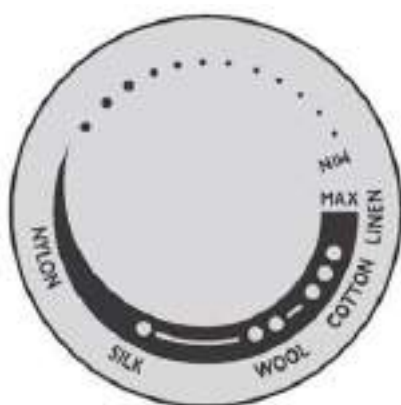
## Testing

Without further information on the amount of heat and time that are required for proper bonding, a small test is performed in order to determine these variables. The required heat and time is determined by placing a small amount of the HMA powder between two pieces of ITO PET and place the iron on top, applying firm pressure for 60 seconds. Three samples are made this way with

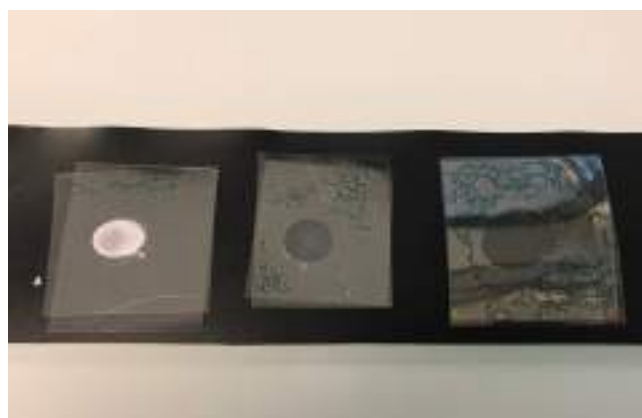
an increase in temperature between the samples. These settings are the silk, wool and cotton settings (Fig67) which are approximately 150, 175 and 200 degrees respectively. The highest setting showed the best result and is used in the rest of this test (Fig68).

For the application of the HMA and phosphor mixture a piece a vinyl is first placed on the ITO side of a piece of ITO PET which is then placed on a smooth work surface. The vinyl has the parts removed where the powder will go (the shapes are cut using a vinyl plotter, Roland GS-24). The shape that is used can be seen in Fig69. The vinyl stencil has rectangles of increasing widths to test the ability of this method to create smaller details and how well it can cover larger surfaces. The powder is placed on top and spread using a box cutter blade. The blade is stiff and has a very straight edge which makes it ideal for spreading the powder carefully. The friction of the

▼ Fig67. Basic settings of an iron.



▼ Fig68. The results of the 150, 175 and 200 C test.

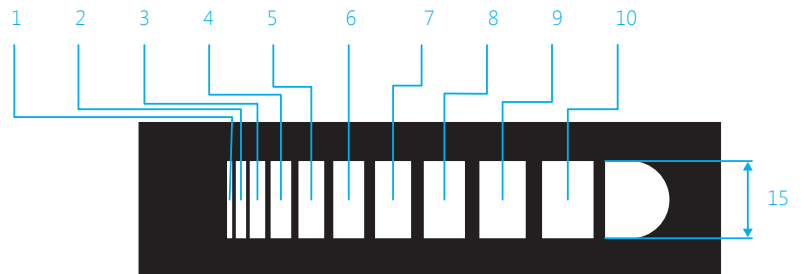


PET and work surface is enough to keep the sample in place when spreading the mixture.

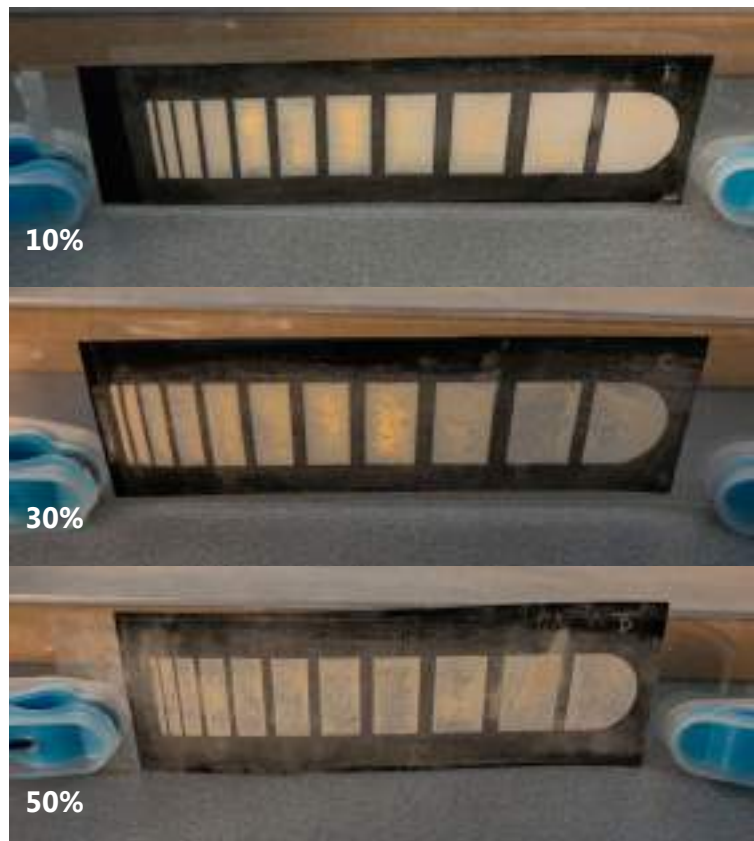
Multiple mixing ratios are tested to determine how well they bond and how much light is emitted. Adding more phosphor might increase the light emission but decrease the ability of the HMA to melt and cover all of the phosphor properly. The tested ratios are 10, 30 and 50 weight percentages of phosphor in the mixture. The remaining weight is the HMA powder.

The vinyl is placed on the ITO side. After applying the mixture, a piece of ITO PET is placed on top with the ITO side also facing the mixture. This enables testing the dielectric capabilities of the HMA powder. The schematic construction of the samples can be seen in Fig71 and in more detail in Fig72.

In case the powder mixture is not able to also function as dielectric, a test is done using the 25micron ITO PET where the mixture is applied on the PET side. This will ensure no dielectric breakdown will occur and might make it possible to create a transparent EL device. The transparent EL device will be made by first carefully removing the vinyl after the powder has been spread (Fig74).

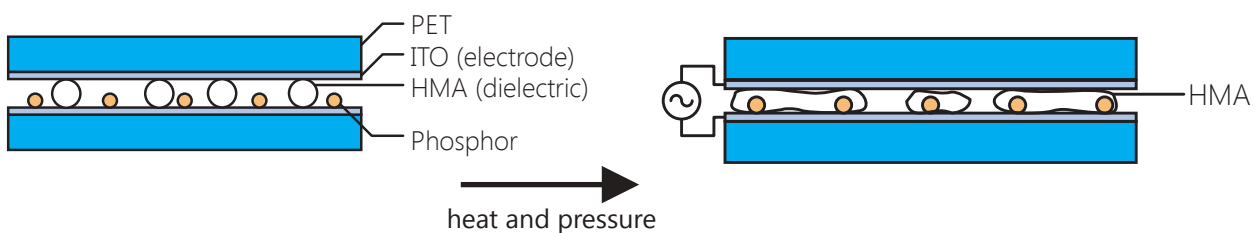


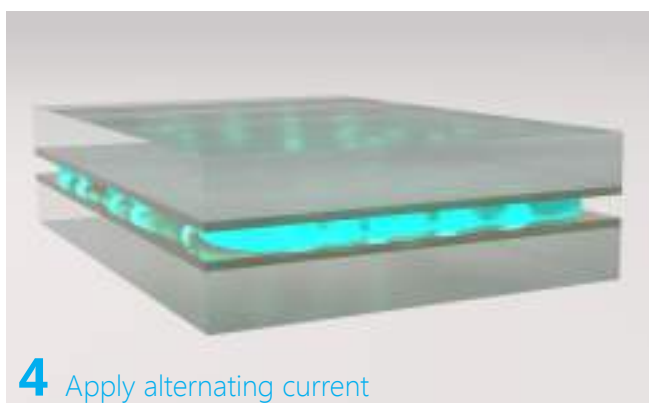
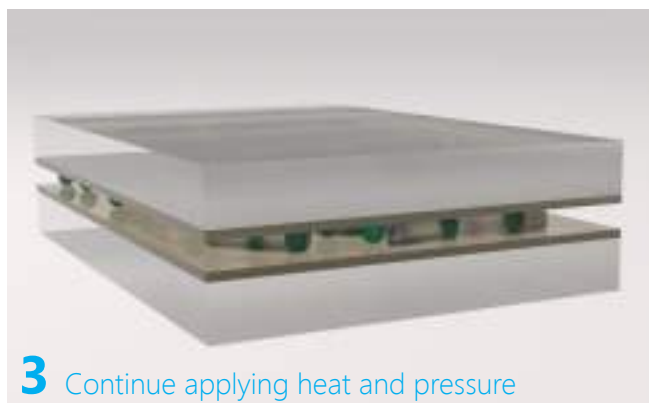
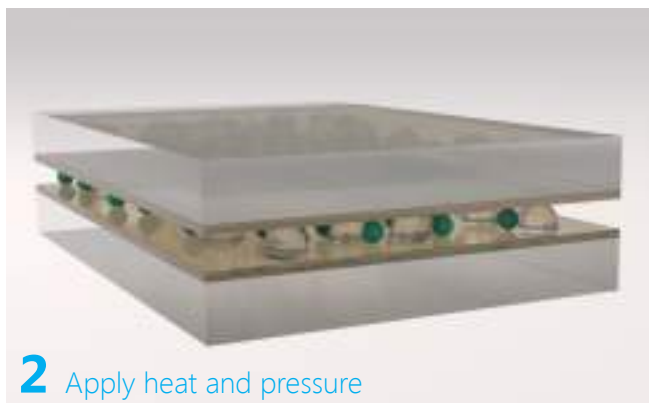
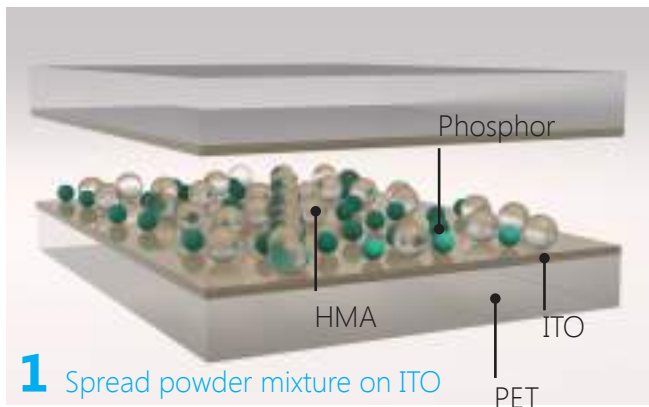
▲ Fig69. Shape of the vinyl cut outs used for this test. Dimensions are in mm.



▲ Fig70. Testing increasing percentages of phosphor powder in the mixture to determine the influence on bonding properties and the light emission. The percentages are the amount of phosphor in weight

▼ Fig71. Basic construction of EL devices that use silicone as dielectric.





## Results

For the percentages test the yellow phosphor is used which has a lower emission than the phosphors. It is still able to show that the 10 percent mixture has the best overall performance, providing the most homogeneous emission. The emission is slightly higher in the 30 percent mixture but is not homogeneous. The 30 percent mixture does not emit light. The 10 percent mixture is used in the following tests. Using the blue phosphor the results did show light emission but it was only located near the centers of the rectangles, while some of the rectangles barely emit any light at all. The results can be improved by applying heat for a longer amount of time. The iron was put on top of the sample for 10 minutes, with no additional pressure other than the weight of the iron. The output improved but also caused a short circuit, this can be seen in Fig73.

To prevent the EL device from short circuiting the 25 micron ITO PET is used. As expected this resulted in a lower emission compared to the first test (the PET creates a thicker dielectric layer). However the emission was more homogeneous and this method enabled the creation of the smaller details (Fig75).

Both methods provided working samples which were bendable (Fig76). Unfortunately the adhesion was partially lost af-

◀ Fig72. Graphical representation of the idea behind melting the HMA powder. This will cover the phosphor particles and will form a continuous layer between the two electrodes.

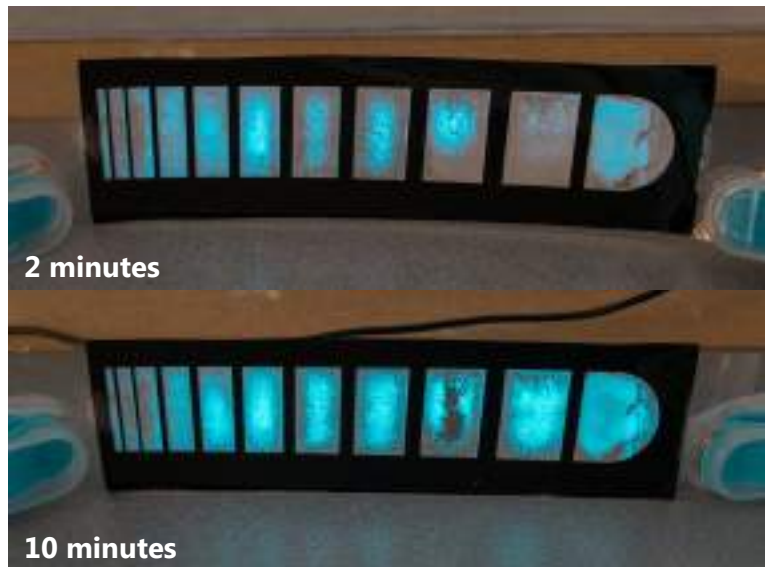
ter one day. Testing the samples on their emission and bendability the day after which they were made, all samples delaminate almost instantly after bending it only a small amount (Fig77). The delamination is likely to be caused by weak bonding strength with ITO.

### Conclusion

Using HMA powder does not provide sufficient insulation, as dielectric breakdown can occur using a pocket inverter. Using it in combination with the 25 micron PET was partially successful. If a HMA powder can be found that is able to create a better bond, this method has the potential in using it for quickly creating EL devices.

For now this method will not be used as, finding a suitable powder will take too much time.

▼ Fig76. This method provides bendable EL devices.



▲ Fig73. Short circuit in one of the larger rectangles results in permanent damage to this part.



▲ Fig74. Removing the vinyl



▲ Fig75. Sample using PET as dielectric

◀ Fig77. Delamination after only a small amount of force is applied.

# UV curable adhesive

More detailed information in Appendix 6

## Goal

Create an easy to apply mixture that can double as binding material and dielectric and can cure in an instant

## Material

After reading about radiation curing adhesives (Brockmann, 2009), the idea was formed to use this in combination with the phosphor powder. This would create a mixture that will remain liquid when it is applied and will remain liquid until it is applied properly. After the application it can be cured in a matter of seconds. For this test two different UV adhesives are used. Bison Glass Glue and Loon UV Wader repair.

## Testing

The testing and application method is similar to that of HMA powder and will therefore not be explained again. An illustration of this idea is shown in Fig78. The main difference is the activation method of the adhesive. It is not heated, instead it is cured using UV light. The speed of curing is tested first by a small amount of glue between two pieces of ITO PET and put it underneath a source of UV light

## Results

The Wader Loon adhesive cures within 10 seconds if enough UV radiation is applied, providing the potential capability of creating EL devices in a matter of minutes.

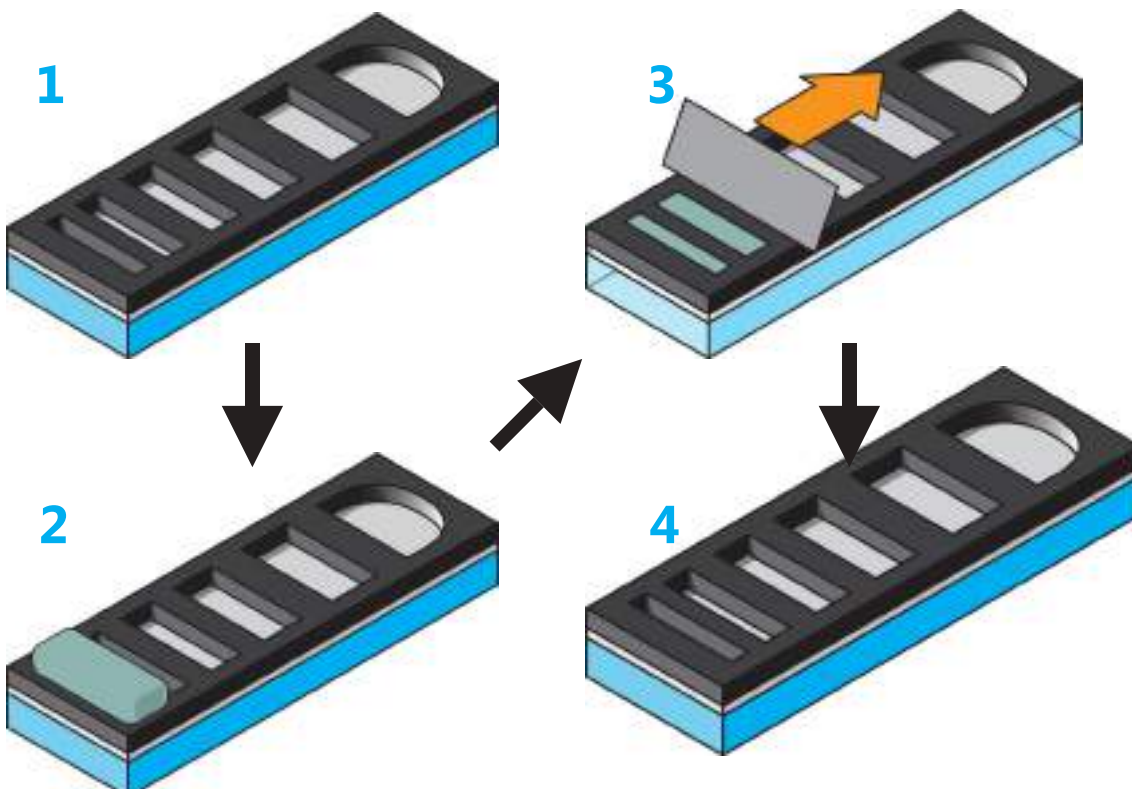


Fig78. Illustration of application method using vinyl on a piece of PET ITO.  
Step 1, apply vinyl  
Step 2, add a small amount of the mixture  
Step 3 & 4, spread it with a piece of metal with a straight edge.



Testing the dielectric capabilities of two different types of UV curable adhesives shows similar results. Both are able to insulate sufficiently, preventing short circuiting even if the samples are bent, which is clearly visible in Fig80. Even though they both have a slightly different viscosity they both fail to cover the smaller rectangles on the first try. Using more adhesive in subsequent attempts provide better coverage of the smaller rectangles. Like with the silicone the samples have a higher output at the places where the electrodes are closer together



▼ Fig79. Basic construction of EL devices that use UV adhesive as dielectric.

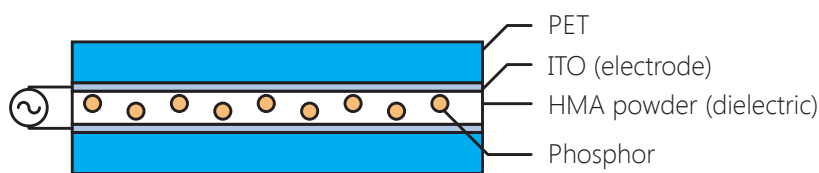
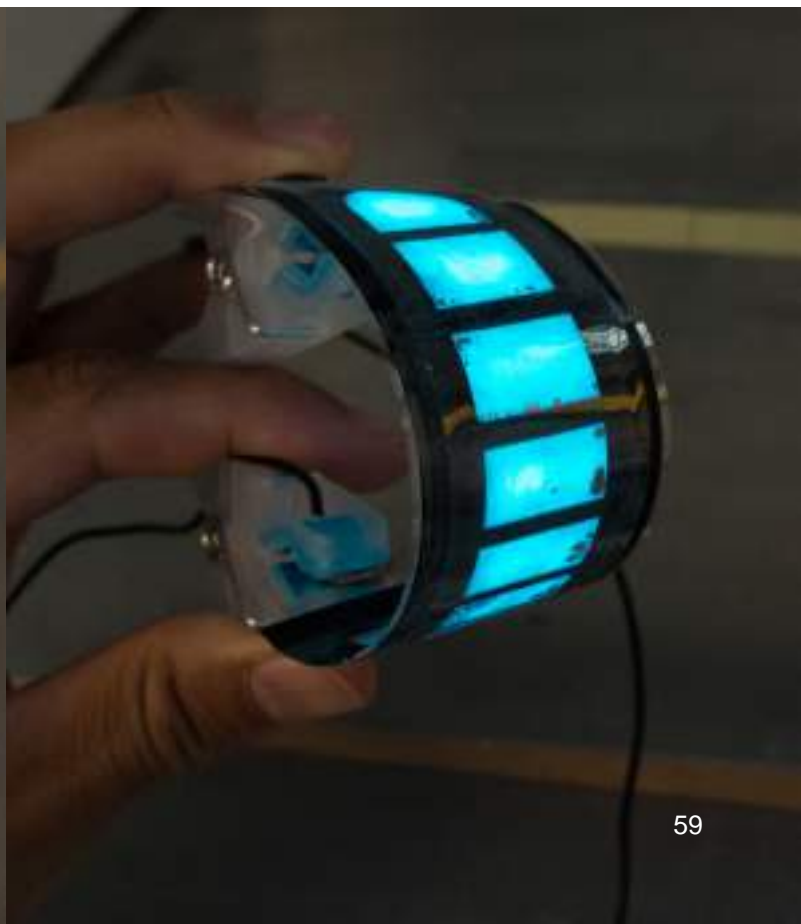


Fig80. Properties of this construction are, high output, very flexible and no need for a separate dielectric layer. The 25 micron ITO PET (left) is significantly more flexible than the 125 micron ITO PET (right)

▲ Fig81. Loss of output and details if the PET is used as dielectric.



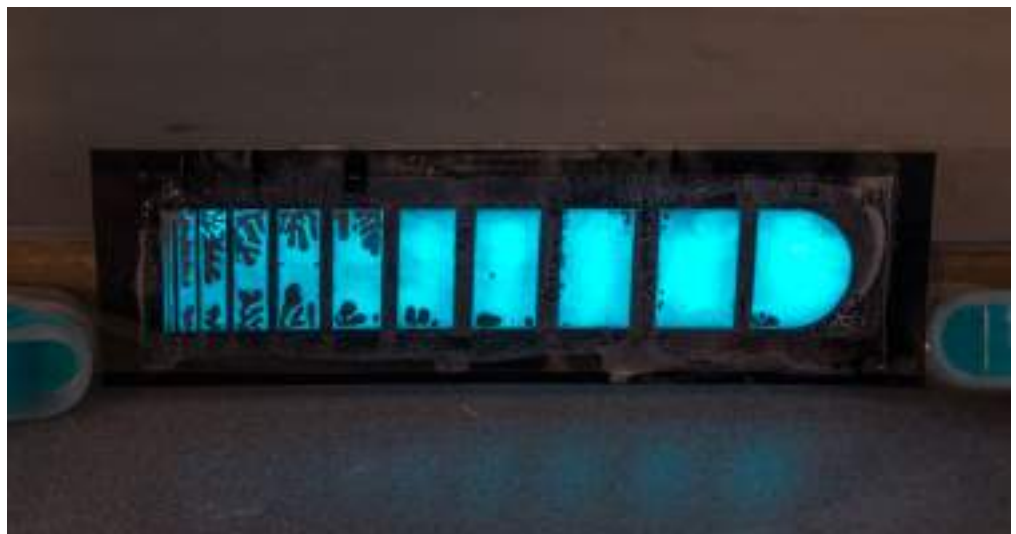
(even slightly transparent), meaning less phosphor particles but a stronger electric field. The construction can be seen in Fig79.

Testing the performance using the 25 micron ITO PET resulted in a significant loss of brightness and cause the smaller rectangles to combine losing the possibility of small details, Fig81.

## Conclusion

A relatively easy and very quick method of creation EL devices, from start to finish this method can be used to create working EL devices within 10-15 minutes. There are still some downsides to using this method, like pockets of air trapped between two the electrodes. Using the PET as a dielectric does not work properly and actually not even necessary.

▼ Fig82. Even though the improper coverage is unwanted it does provide a nice effect.



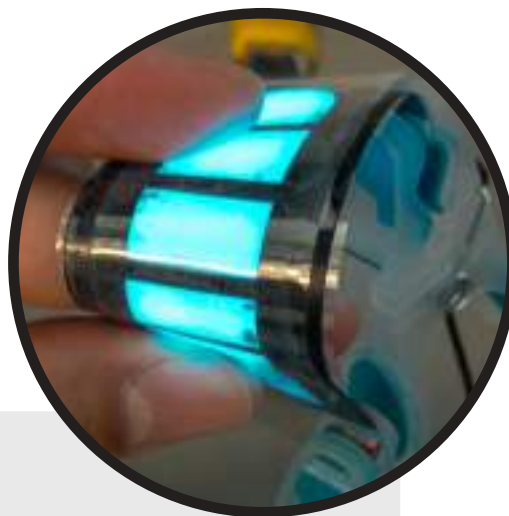
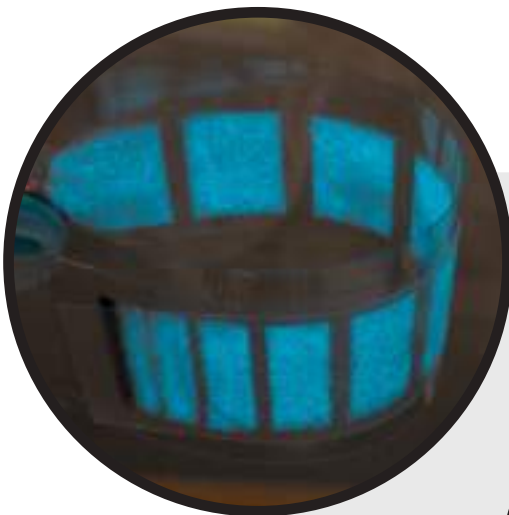
### Material testing conclusion

This chapter can be divided into two parts, one focusing on the ability of different materials to function as a dielectric, the double sided tape, PET with varying thickness, conductive tape and silicone. The other focusses on the binding ability. The different materials do not only need to work as dielectric but should also function as a binding material for the phosphor and electrodes.

Both parts had a different type of construction method in mind. The part focusing on the dielectric capabilities was based on the idea that a sheet of phosphor, combined with a type of binder that allows such a sheet, needs to be bonded with the electrodes. These test were therefore only partial solutions to the bigger problem of fast DIY EL. However this is a necessary aspect that has to be solved if such a construction method has any chance of succeeding.

The second part of this chapter focused more on an overall solution, which is more difficult since the solution must combine all the previous requirements. All of the three tested methods provided a working EL device, albeit with larger and smaller points of improvement, and have potential in becoming a quick method for DIY EL.

The the last method shows to be the most promising of all tested methods. It appears to be quick, provides proper light emission and no breakdown occurred in any of the tests. This method will therefore be used to continue the project with.





## U V - T W E A K I N G

Because the UV adhesive has given the best result it has been chosen to fine tune the application method further in order to create bright and evenly lit EL devices. This is done by testing multiple properties of the phosphor and UV glue. Creating different phosphor/glue mixture properties, letting the UV glue dry in the open air or underneath a transparent electrode and playing with the irradiation time can all influence the ability to create a good working EL device.

# UV adhesive - properties

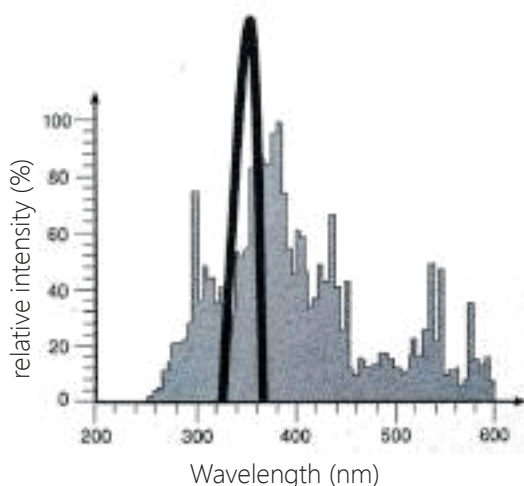
Like stated before UV curing adhesives can fully cure within a matter of seconds and remain liquid if no or not enough UV light is present. This property makes it very suitable for quickly creating EL devices. The user has plenty of time to apply the phosphor mixture and once properly in place it can be cured in seconds.

UV adhesives have this property because they contain initiators that can absorb certain wavelengths of the electromagnetic spectrum, which makes them photoinitiators. The absorption of the light adds enough energy to start a very rapid chemical reaction which causes the adhesive to cure. The part of the spectrum which different UV adhesives can cure differs. A source that emits enough light in a certain spectrum must be used in order to obtain fast curing results, Fig83. Too little energy will not activate the photoinitiators.

The adhesives can be placed in two main categories, namely the radical and cationic UV adhesives. Most commercially available UV adhesives are radical adhesives and are acrylate based. This means

that when the UV source is removed the curing stops and the surface that is in contact with oxygen does not cure. The latter can be seen as a downside but can also be used as an advantage as will become apparent in this chapter. The cationic UV adhesives are epoxy based and will continue curing even when the UV source is removed and are not inhibited by the presence of oxygen.

The first UV glue test was done using small tubes of glue which contained only a couple of ml of glue. This was enough for small scale testing. Since the choice is made that UV adhesive will be used in the continuation of the project, a larger container needs to be acquired. The main requirements are that it should be transparent, affordable and should not be too viscous in order to be able to properly mix the phosphor. The chosen UV glue is the Loca TP-1000N (Fig84), an acrylic based adhesive. The choice for a radical adhesive is mainly because they make up almost all UV adhesives and both test adhesives are radical adhesives meaning similar results are expected.



◀ Fig83. Emission spectrum of a iron doped discharge lamp and the absorption range of a photoinitiator (Brockmann, 2009). Light outside the range does not get absorbed.

▼ Fig84. Packaging of the TP-1000N UV glue



# UV adhesive application improvement

## Testing the new glue

Loca TP-1000N is normally used for smartphone screen repairs. This means it has to be highly transparent and colourless, otherwise it would influence the output colours and brightness of the screen. For EL devices this also means the light output is not hindered by blockage due to the glue and the colour will remain true to the phosphor that is used, although a coloured glue could also help put out different colours. Trying out this glue for the first time showed that it has a lower viscosity, making it easier to mix, and took longer to properly cure using the same UV light as used in the testing phase. Because this glue is different from the other two, it is tested on its performance using different volume percent-

ages of phosphor. The percentages that are tested are 5, 15 and 25. The testing method is similar to the one used for the other glues, applying the mixture, adding a piece of ITO PET on top and let it cure under UV light.

The tests have shown that with decreased amount of phosphor the emission goes down and so does the coverage which can be seen in Fig85. The reduction of coverage can be explained by the lower viscosity of the lower percentage mixtures (viscosity is not measured but the difference can be clearly felt while mixing the glue and phosphor powder). When the top piece of ITO PET is placed on the sample with the mixture already applied, a lower viscosity causes the mixtures to puddle together more,

Fig85. Three different volume percentages phosphor tested

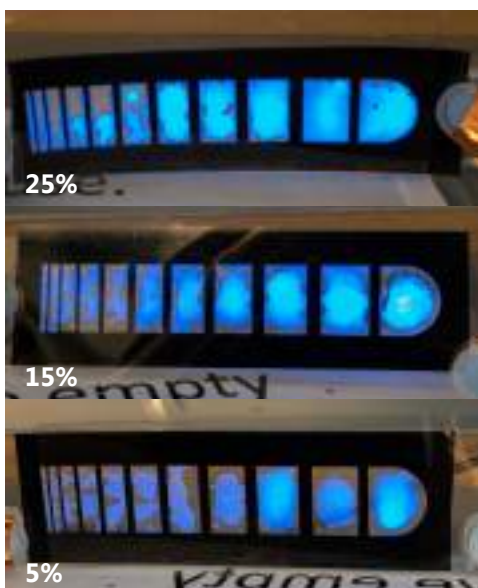


Fig86. The transparency of the the different samples. From left to right: 25, 15 and 5%.



preventing proper spreading. An upside of the lower concentration of phosphor particles is that the transparency of the sample goes up (Fig86). The 15 percent mixture is chosen for the rest of testing. The output of light is good enough and the amount of phosphor used is 40 percent less compared to the 25 percent mixture. This is important since the phosphor powder stock is limited during this project and ordering new powder will take multiple weeks.

### Colour emission

The four phosphors that are available for this project are mixed with the glue, (fifteen volume percentage of phosphor), - to see the different colours and observe the differences between the four.

The sample can be seen in Fig87. The differences of the phosphors are clearly visible. At similar concentrations the emission varies strongly depending on the type of phosphor. When thinking about mixing phosphors to create other colours this should be taken into account. The method used to create this sample is application method III which will be explained next together with other tested application methods.

Fig87. Colour test sample shows of the brightness of each of the available phosphors. It is clearly visible that while all phosphor mixtures have a similar concentration the output differs strongly with the blue being brightest and the yellow being the lowest.



Fig88. Sample creation process.



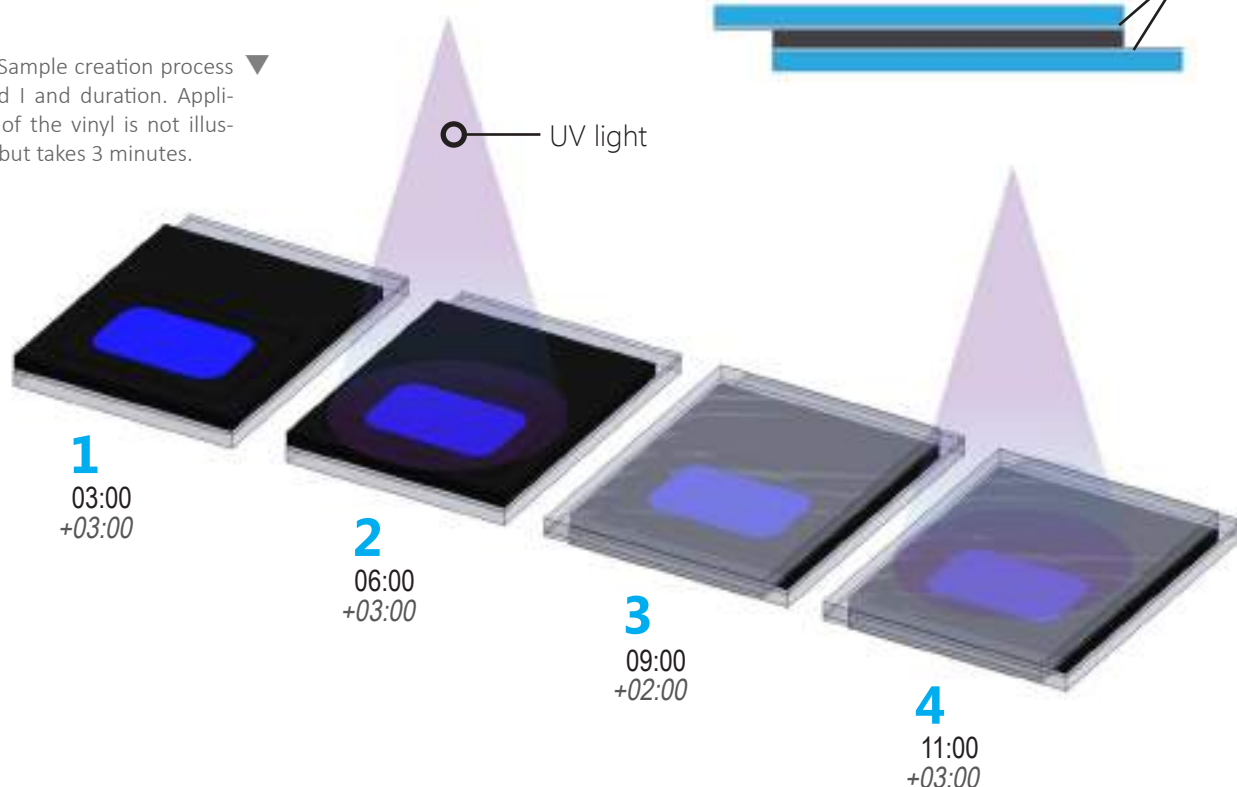
## Application method I

### *One phosphor layer drying on air*

Using the previous application method of spreading the mixture over a stencil the phosphor/glue mixtures showed proper coverage after it is applied. Only when the top electrode is placed, the mixture starts to move and creates air pockets between the top and bottom electrodes preventing even coverage. In order to tackle this the method of curing the adhesive before applying the top electrode is tested. Like previously mentioned, oxygen can prevent curing in some types of UV adhesives and it seems that the liquid surface of the cured glue still has bonding properties. This property enabled the following work method (Fig89):

1. Apply the phosphor mixture
2. Let it partially cure underneath an UV lamp
3. Apply the second electrode
4. Let it fully cure

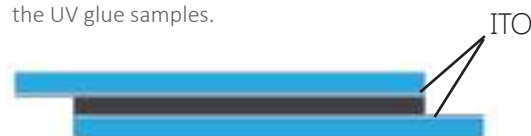
Fig89. Sample creation process method I and duration. Application of the vinyl is not illustrated but takes 3 minutes.



Because the major part of the phosphor mixture is already cured, applying the top electrode will not push around the mixture, preventing the air pockets that can be seen in previous samples (Fig85). Applying the top electrode is also easier as the cured mixture creates a hard surface which it can be pushed against. This surface can also be used to get the conducting surfaces as close to each other as possible without the fear of a short circuit.

This method is first tested with the standard ITO PET (125 micron) as top and bottom electrode which shows that using this method (cure first and apply the electrode later), results in a more even emission. The downside is that near the edges there is no or very low emission. This is likely due to the low relative per-

Fig90. Layer order and facing direction in the UV glue samples.





mittivity of the trapped air near the edges (permittivity approximately 1 (Fig4)), a cross section can be seen in Fig91. To try to circumvent this, a thinner stencil material is used. Instead of the 70 micron vinyl the 50 micron thick boeklon, a transparent protective cover for books, is used in an attempt to increase the brightness near the edges. The emission of the boeklon sample is slightly higher than the vinyl sample but still lacks edge to edge emission. Both samples can be seen in Fig92. It seems that ITO PET is too rigid to be able to push the air out of the corners.

Aluminium foil can also be used as electrode and is malleable enough to push the air from the corners. A sample using aluminium foil as the top electrode showed proper edge to edge emission and did not have the bright spot in the middle of the sample, which is visible in the ITO PET samples. It does however have some slightly darker spots (Fig93). For the final curing of the aluminium sample it has to be flipped because the UV light would otherwise not reach the glue. Using aluminium foil as an electrode also means it will be a single sided EL device. A sample using copper tape with a conductive adhesive layer somehow showed terrible performance and will therefore not be used Fig94.

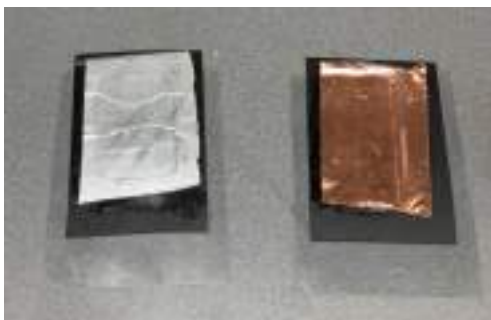


Fig91. Cross-section

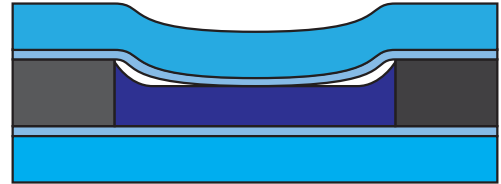


Fig92. Emission of the vinyl (left) en boeklon (right) samples. Notice the lack of emission near the edges.

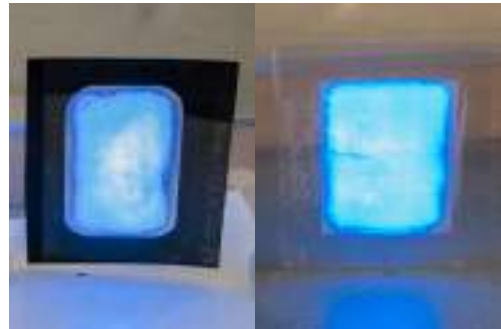


Fig93. Using aluminium as electrode. Top in a dark room, bottom with the lights turned on it is still clearly visible.

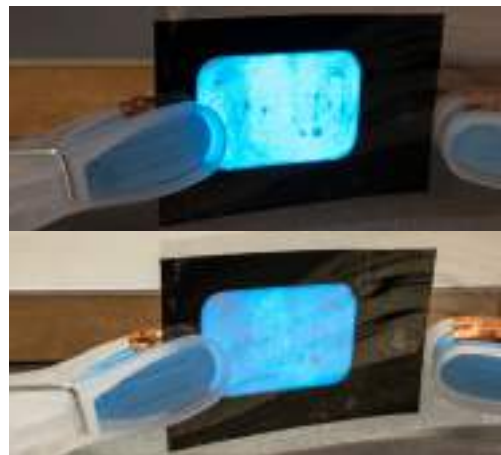


Fig94. Copper as electrode yield a low emission compared to aluminium. The top half is perception in a dark room, the bottom in a room with the light turned on.



Fig95. Bendable aluminium sample.



Fig96. Rear coverage with aluminium and copper.

## Application method II

*Two phosphor layers drying on air*

Building on the previous method, an additional step is introduced. Instead of applying one layer that dries in direct contact with the air, there are two layers applied that are dried in direct contact with the air, before applying the top electrode.

The first layer is dried in contact with the air before applying the second layer. The second layer is meant to fill up the gap that is left once the first layer has dried (Fig98). The method follows the following working order (Fig97):

1. Apply the phosphor mixture
2. Let it cure underneath an UV lamp
3. Apply second layer of phosphor mixture
4. Apply top electrode

5. Cure underneath an UV light

This method has been tested using the vinyl, Fig100, and boeklon, Fig99, which both provide samples with emission from edge to edge with the vinyl sample producing a low emission. Because the vinyl is thicker than the boeklon, it will create a thicker phosphor compared to the boeklon sample. This will cause a weaker electric field resulting in a lower emission. The boeklon still a lower emission near the edge although it is less than using application method I.

Fig98. The second layer is meant to fill the dent left by curing the first layer ▼

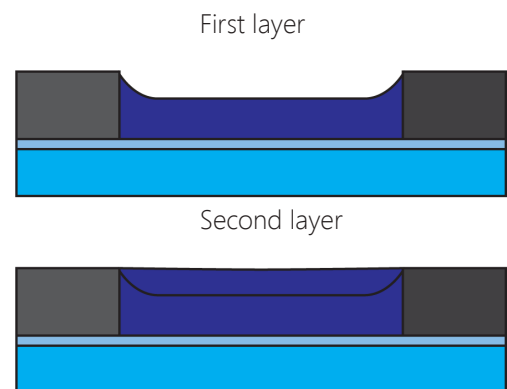
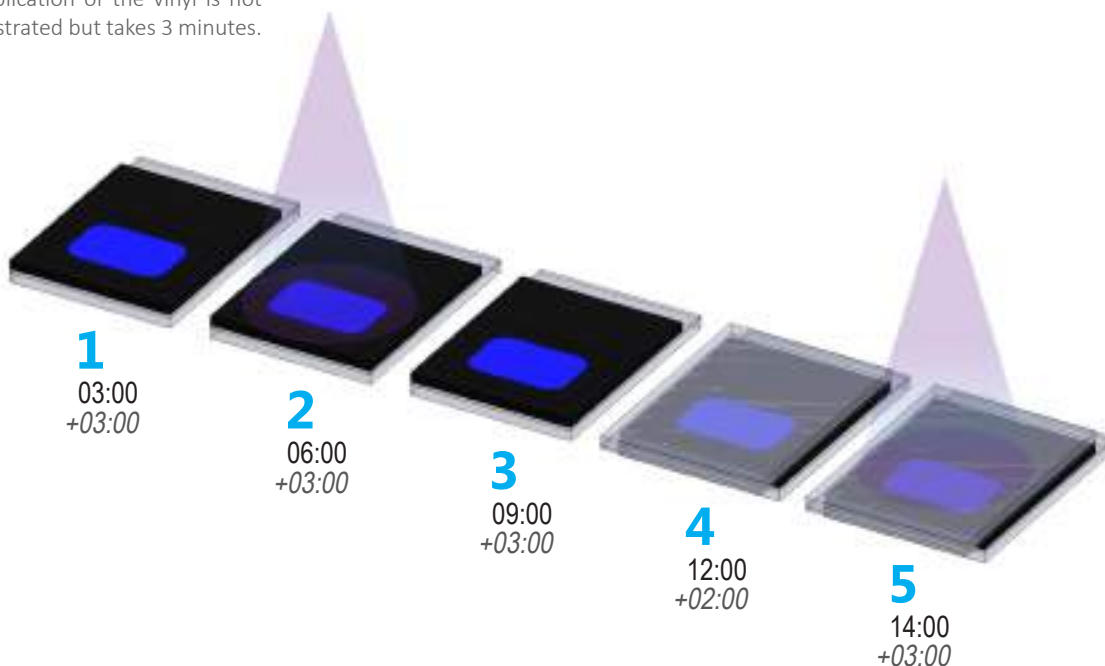


Fig97. Sample creation process method II and duration. ▼  
Application of the vinyl is not illustrated but takes 3 minutes.

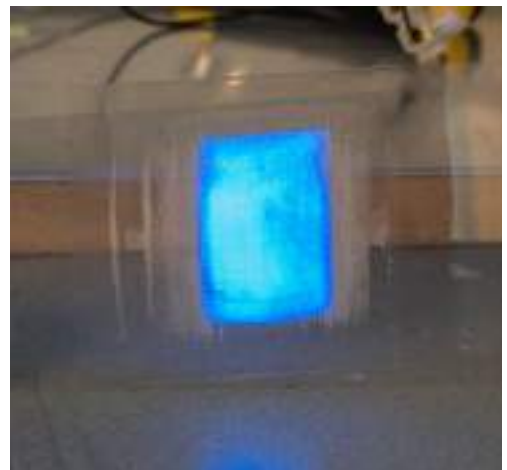


Some spots in the double phosphor layered samples measured even slightly thicker (after fully curing), than two layers of ITO PET and vinyl combined. Multiple samples have given the measurements but no good explanation of this effect can be given. A possible explanation can be that it is caused by the actual phosphor particles (average of 29 micron) in the second layer preventing the ITO PET to be pushed further down.

▼ Fig100. Application method II using vinyl



▼ Fig99. Application method II using boeklon





### Application method III a & b

*Phosphor on air - then one layer of glue behind ITO (remove vinyl)*

This final method is similar to method II because it relies on the application of two layers before the top electrode is placed. There are, however, two main differences. For method III a the following steps are taken( Fig101):

1. Apply the phosphor mixture
2. Remove surrounding vinyl and cure underneath an UV lamp
3. Fill with UV adhesive
4. Apply top electrode
5. Cure underneath an UV light

The thought behind it is that without the stencil material to attach to during curing, the edge of the phosphor layer will be level with the rest of the phosphor creating a more even layer. After the removal of the vinyl the phosphor is cured. Once the phosphor layer is cured, a second layer is applied that does not only goes on top, but also around the phosphor part. The top electrode can then be applied directly, pushing the top electrode as close to the phosphor as possible, followed by curing the sample. The EL device made using this method has sharp edges but as expected, there are some small air bubbles that decrease the output, Fig102. Placing ITO PET on top of liquid adhesive has already shown to be prone to capturing unwanted air.

Fig102. Sample creation process method III a

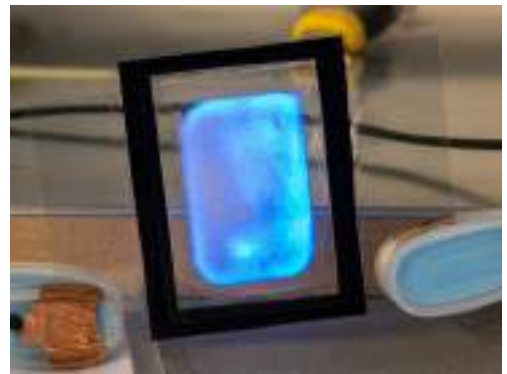
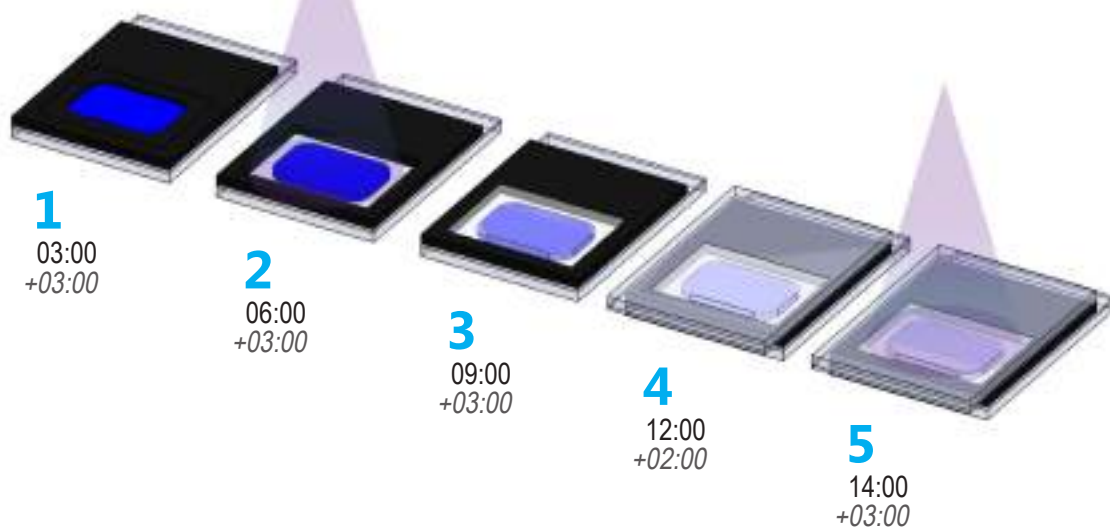


Fig101. Sample creation process method III a and duration. Application of the vinyl is not illustrated but takes 3 minutes.



Method III b is nearly identical but has an additional step (Fig103):

1. Apply the phosphor mixture
2. Remove surrounding vinyl and cure underneath an UV lamp
3. Fill with UV adhesive
4. Cure underneath an UV light
5. Apply top electrode
6. Cure underneath an UV light

This method adds the curing of the adhesive, filling before applying the top electrode, ending with a final curing session .

The first option has the advantage of getting the conductive layers closer together, the downside is that the liquid UV glue can cause air to get trapped beneath the electrode. The second option can prevent the larger air gaps underneath the top electrode but also increases the distance between the two electrodes since the cured adhesive prevents pushing the top electrode further down. The results of these methods, show

that the emission is higher when the top electrode is placed directly on top of the uncured UV glue. However this also causes air bubbles to get trapped, reducing emission at those spots. The sample with cured UV glue has a slightly lower emission, but has no air bubbles. The cured glue also enabled the removal of the surrounding vinyl with made the sample fully transparent (not counting the phosphor part).

Both samples suffered from small grains underneath the bottom electrode which caused a similar dark half in both samples. This means that regardless of the order in which the layers are applied, the working surface needs to be clean of dirt and dust.

Fig103. Sample creation process method III b and duration. Application of the vinyl is not illustrated but takes 3 minutes.



Fig104. Sample creation process method III a

### Curing time +10s

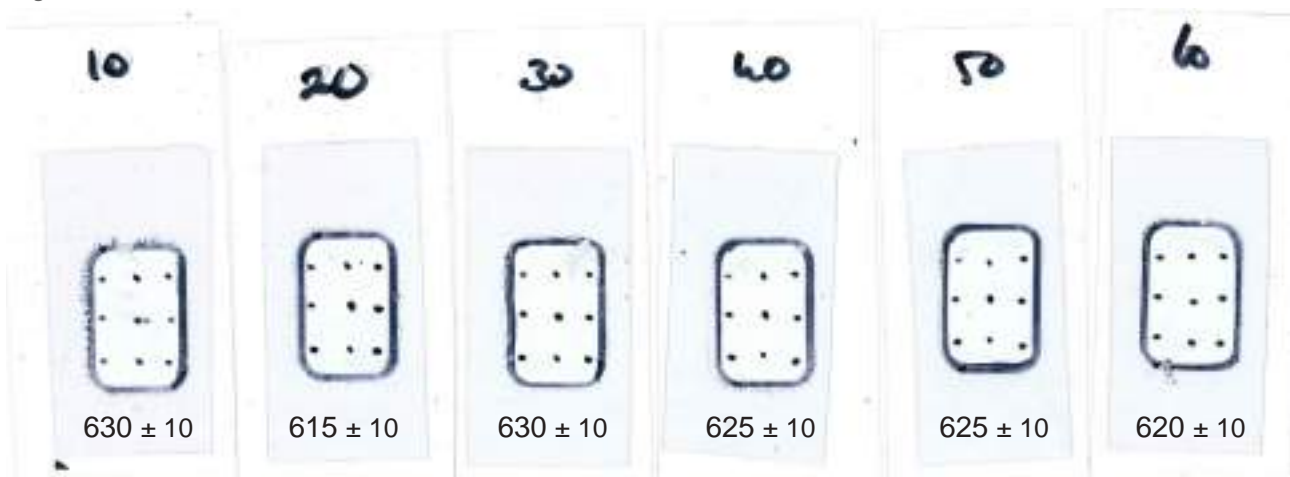
Because the outer layer does not cure fully when in contact with air, a small experiment is conducted to determine what happens when the top electrode is applied after increasing the curing time with increments of 10 seconds each time (Fig105). The focus will be on the thickness of the UV adhesive layer. Can this be decreased by lowering the initial curing time? How will the uncured glue spread near the edges, too much spreading reduces the sharpness of certain lines. The amount of air bubbles trapped beneath the top electrode will also be analyzed. Previous testing has shown that uncured glue causes air to get trapped between the two electrodes, which decrease output. Since each step cures the glue a bit further the amount of trapped air is likely to go down with each step.

Because the test is aimed on analyzing the behaviour of the glue, it is not mixed with phosphor and the ITO PET electrodes are replaced with transpar-

ent plastic sheet material. The first test is done curing the glue for 10 seconds before carefully applying the top plastic sheet and the testing stops at 60 seconds. Each sample is cured for an additional 120 seconds once the top sheet is applied to ensure proper curing. Each sample is measured in nine locations.

This resulted in 6 samples with an average samples thickness varying between 615 and 630 micron. Because the thickness of the used plastic varied between the 280 and 285, and is used twice (both top and bottom), the variation of the sample thickness is minimal. Thus the conclusion can be drawn that a short initial cure of the glue does not result in a noticeably thinner layer. The spreading near the edges became less as the curing time increased, which was expected to increase the average sample thickness. The amount of trapped air underneath the top piece of plastic also decreased, which might compensate for the reduced spreading of the UV adhesive in the longer cured samples.

Fig105. Six test samples with indication of initial curing time. The dots show the location where thickness is measured. The thickness is an average of the 9 measurements in micron.



## Conclusion

The application methods that have the highest potential are method I and method III, although both serve a different purpose.

If single sided light emission is sufficient, application method I with an aluminium foil rear electrode provides a good result. It is fast, it can be done within 15 minutes (since it requires the application of a single layer of phosphor that needs to be cured) and has a high light emission. Because the aluminium foil is also really thin it makes the device more flexible (compared to an ITO PET rear electrode).

If double sided light emission is required application method III-b has the best potential. Because the second layer of UV adhesive is cured in this method, the result can be more homogeneous than application method III a (less air will be trapped). Method III also has the added benefit of a transparent EL device. The down side of this method is the duration, it requires the application of two layers that need to be cured, which takes approximately 20 minutes. Nevertheless this is still significantly faster than the screen printing method.

Application method I



### Advantages

- Fast
- Thin
- High brightness

Application method III-b



### Advantages

- Double sided emission
- Transparent design

## U V - E X P L O R A T I O N

Multiple methods for creating single sided, double sided and transparent EL devices have been created. Using these methods a small exploration of the possibilities of EL is conducted. Because the main part of the project is aimed at finding a novel method for DIY EL device creation, the following part will be focused on exploring what is possible using the new method. It will start with mixing different phosphor powder and will further focus the capability of the new method regarding to recreate existing EL applications.



# Colour mixing

Since different colours of phosphors are available different types are mixed in different ways in order to experiment with the effects. The two colours that are chosen are the blue and yellow emissive phosphors. The other two are too similar in colour that mixing them would probably make it difficult to observe and determine the effects.

The three primary colours are blue, red and green (Fig107). This image shows that blue and yellow are each others opposites and if mixed in the right amount they will combine to create white light. Because the yellow phosphor emits less light in a similar adhesive/phosphor ratio compared to the blue phosphor the yellow phosphor is mixed in a 30 percent phosphor and 70 percent adhesive ratio. As can be seen in Fig106 this increased the brightness significantly although compared to the blue phosphor it is still less bright. It is unclear whether the re-

duced brightness is caused by a lower efficiency in converting the electric field into light or the difference in sensitivity of the human to the different wavelengths. Measurements can be found in appendix 7). Despite the lower brightness the decision is made to continue with these two ratios, 15 percent for the blue and 30 percent for the yellow phosphor. All samples are made using application method I using the aluminium rear electrode.

A mixture of 5 percent blue, 10 percent yellow and 70 percent adhesive creates, like expected, a more white emission. However, a blueish tint remains.

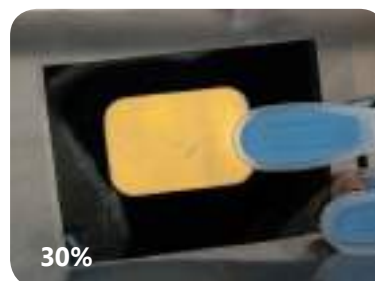


◀ Fig107. Additive colour mixing

Fig106. 15 percent blue phosphor and 30 percent yellow phosphor combine to create blueish white light ▼



~27 cd/m<sup>2</sup>



~5 cd/m<sup>2</sup>



~17 cd/m<sup>2</sup>



It is also tested what happens if the blue and yellow layer are deposited separately on top of each other, comparable to application method II. The method of application and the result is visible in Fig108 This was however not very fruitful. The sample with blue being applied first is just blue, no real difference, and the sample with yellow applied first has a low emission.

Inspired by the way TV screens are constructed, small pixels that are placed in close proximity that appear to be a cer-

tain colour when viewed from a distance Fig109, a final sample is made using thin lines of 15 percent blue and 30 percent yellow. The minimal line thickness that was possible to be made using this vinyl was 1mm. Thinner line makes it impossible to remove the separate lines, thinner lines causes the vinyl to brake, before applying the phosphor. This sample made it somehow look like the yellow phosphor is really dim while it is the

Fig108. Layer ordering and the results. ▼

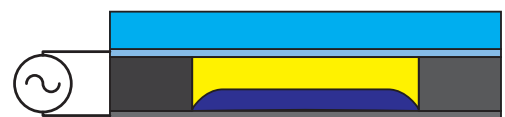
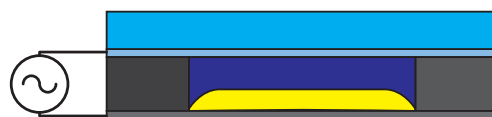
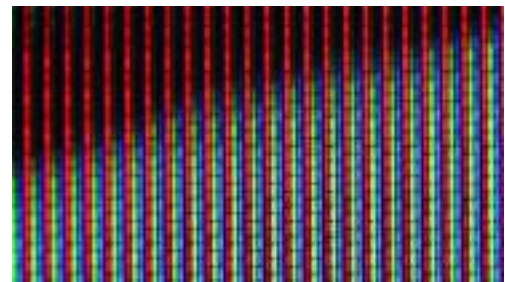


Fig109. Close up of the pixels on a TV ▼



same mixture that was used to create the yellow from Fig106. From a distance (approximately 3 meters) the colours shifts to a more light blue like the mixed phosphor. The test sample with the blue and yellow lines also doubled as a test to determine the effectiveness of two different methods of removing the vinyl. In the left half the vinyl was removed before curing took place and the right

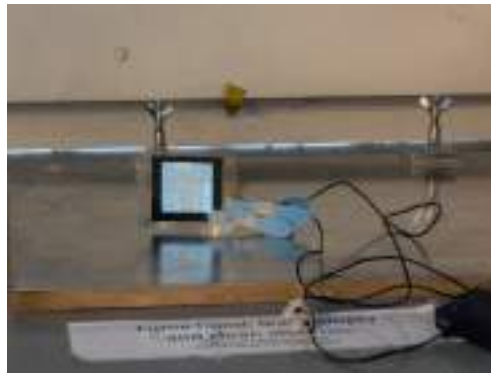
half was done after curing for a minute (Fig110). This shows that the part that had the vinyl removed after curing has much cleaner lines which is also visible in Fig112.

Concluding on the colour test the most easy and successful method is to simply mix two (or more) phosphor powders together in order to create a different colour. The other methods are either too cumbersome or ineffective to be used.

▼ Fig110. Close up of the yellow and blue lines



▼ Fig111. Yellow and blue lines from a distance



▼ Fig112. Shot at a steep angle this image clearly shows much cleaner lines in the right half of the sample.





## Flexible EL

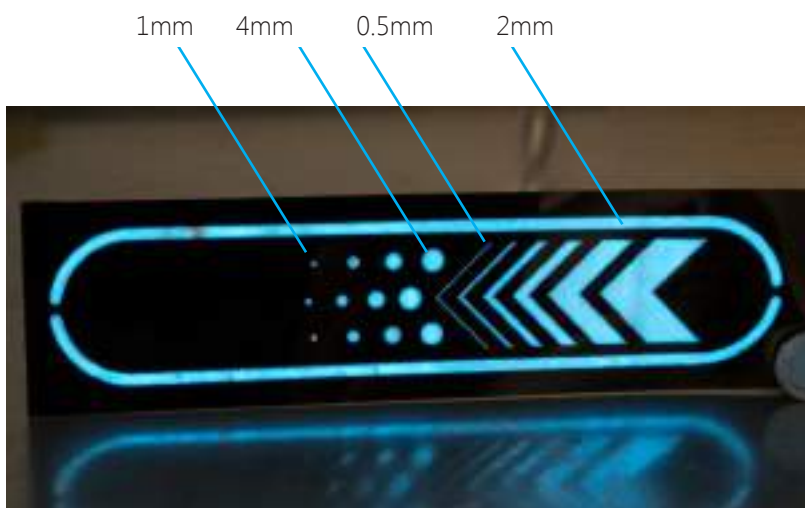
Because one of the advantages of EL is flexibility a more complex sample, compared to the square sample, using application method I is made. This can show how easy it can be to create a bendable EL device using only four materials. It is made out of different shapes with different thicknesses in order to test how well details of different sizes can be made with aluminium foil as rear electrode. The dimension of several details can be seen in Fig113.

This test shows that even details with a width of 1mm can be made using this method. However these small details are less bright than the larger structures. This can either be because the phosphor mixture is unable to be pushed into these small cavities as well as is the case

with the larger areas or the aluminium foil is not able to be pushed properly all the way up to the phosphor mixture before curing.

From start to finish, not counting the time that was required to gather the necessary materials, it took less than 10 minutes to create this sample. This definitely shows that this method is capable of producing fully functioning, highly flexible custom EL devices in a significantly shorter time than the current DIY methods. The sample shows high flexibility and continued to work after repeated bending Fig114.

▼ Fig113. Width of several details in this sample.

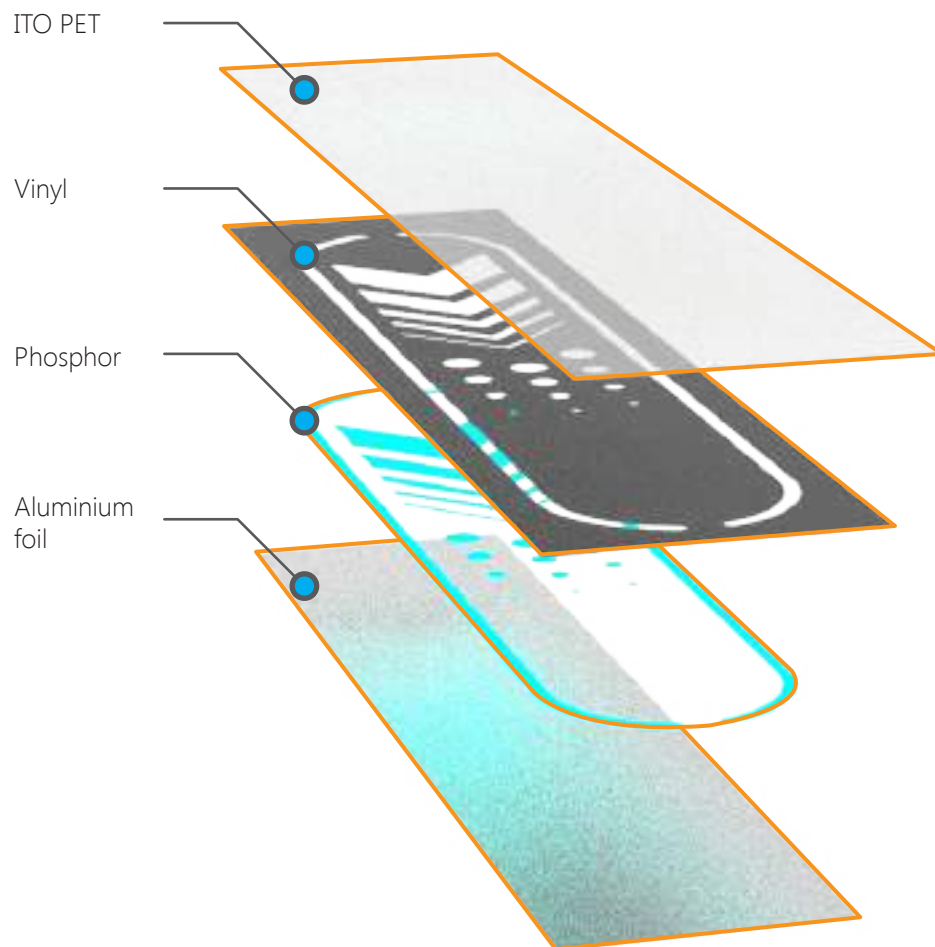


▼ Fig114. This construction method creates highly flexible EL devices.



# Flexible EL

Exploded view



# Touch panel

Because EL light emission only takes place when the electric field is strong enough creating an EL device that only light up at the location it is touched is relatively easy. As is visible in Fig117, by creating a structure that is able to keep the top electrode at a small distance from the phosphor layer when it is untouched the phosphor will not emit light when the power is turned on. This is partially caused by the distance and partially by the low relative permittivity of the air in between the electrodes. Pressing on the electrode will locally create a strong enough electric field causing the phosphor to emit light.

Early attempts at creating such a constructed using UV adhesive failed. This was caused by the oxygen inhibition of the top layer of UV adhesive. This meant it was still tacky and once the top electrode was pushed down it stayed down due to the adhesion with the slightly wet UV adhesive. Without a method to pry

the electrode of the phosphor layer the device kept emitting light at that location.

In order to overcome this problem the phosphor is cured for a short period of time after which a piece of household (LDPE) foil is placed on top and properly pressed down. This is then cured for an additional couple of minutes. Once cured the foil is cut to fit the device and is glued in places between the vinyl and the spacing layer, completing the construction with a piece of ITO PET on top. Although the LDPE foil adds 10 micron to the distance between the electrodes the influence on the emission is small as can be seen in Fig115 and Fig116. Attempts have been made to remove the LDPE foil once the UV adhesives was fully cured when ITO PET was used as an bottom electrode, due to the material properties it is difficult to bond with PE (permabond.com), but these attempts were unsuccessful. Small pieces of the

Fig115. Emission is clearly visible even with the added LDPE layer.

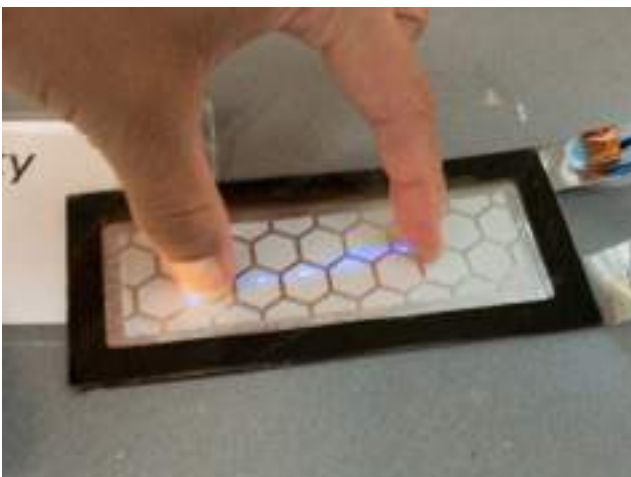


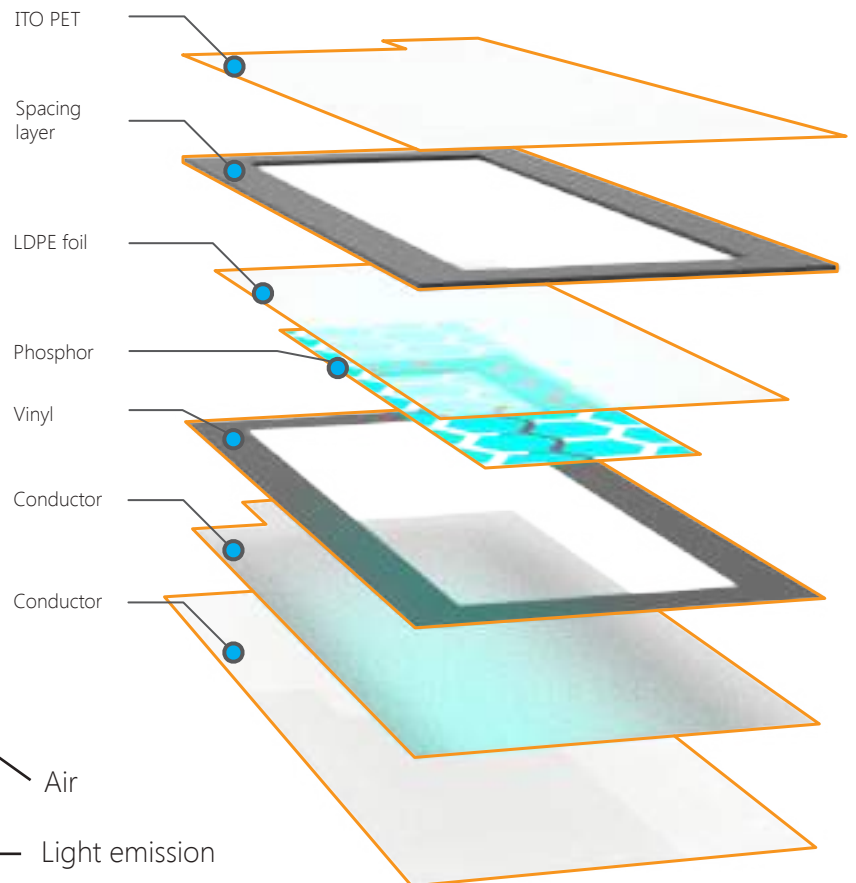
Fig116. Touching with three fingers creates lines between the touch points.



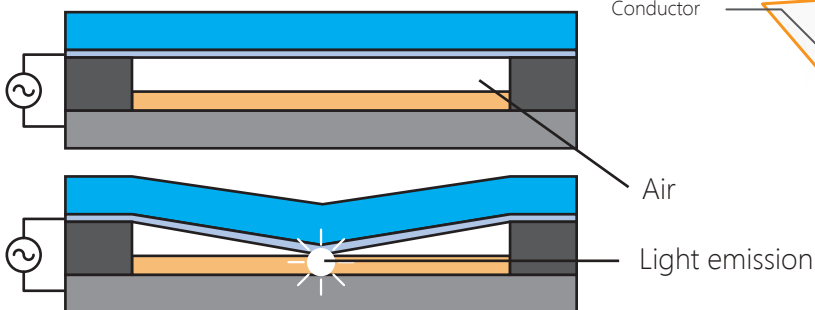
## EL touch panel Exploded view

phosphor mixture separated from the layer underneath.

In the end the main problem that needs to be overcome using UV adhesive for a touch panel is to prevent the top electrode from sticking to the adhesive once it is pressed down. Using a bottom electrode that UV adhesive adheres significantly better to than the covering material or by using a cover material that bonds extremely poor to UV adhesive it can be possible to remove this layer to further increase the output of the EL device.



▼ Fig117. Side view of this construction.



▼ Fig118. Final test sample for touch interaction.



## EL water interaction

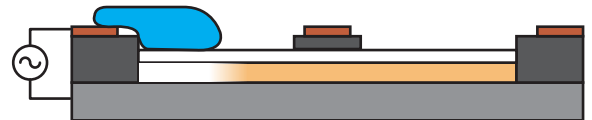
Because light emission in an EL device will take place at the location where two oppositely charged electrodes are placed in close enough proximity water can be used to shift these locations. Such a device does need a specific type of construction.

Using UV adhesive the first three steps of construction are the same as always, take an electrode, place a piece of vinyl with cut outs on top and spread the phosphor mixture on top. Instead of applying the top electrode as a final step a few extra steps need to be taken. First, like the touch EL device, a piece of LDPE foil is placed on top once the mixture has been cured for a short time and cured again followed by cutting the foil to size. It is possible to let the mixture cure in open air but this will result in a sticky surface (appendix 8). The next step

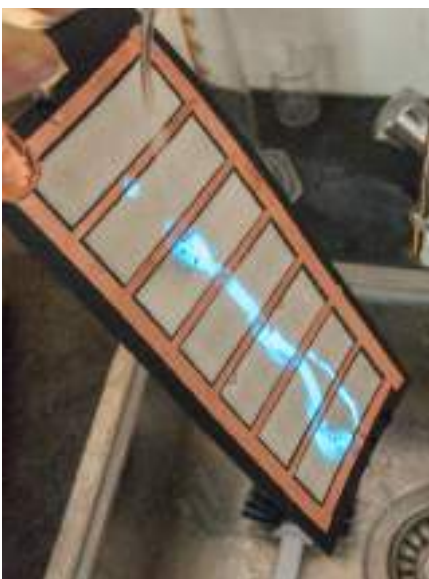
is to create a grid of conductive material that runs around the phosphor. The construction is finished by ensuring that the bottom electrode is insulated very well to prevent water touching it directly.

The emission happens once water, that has spread over the phosphor layer, also touches the grid, Fig119. This causes the water to get electrically charged which leads to only the phosphor that is directly underneath to emit light. The grid in the model that can be seen in Fig122, is made using adhesive copper tape but can be replaced by any other conductive material as long as the water can come into direct contact with it. A drop of water that is on top of the phosphor but is

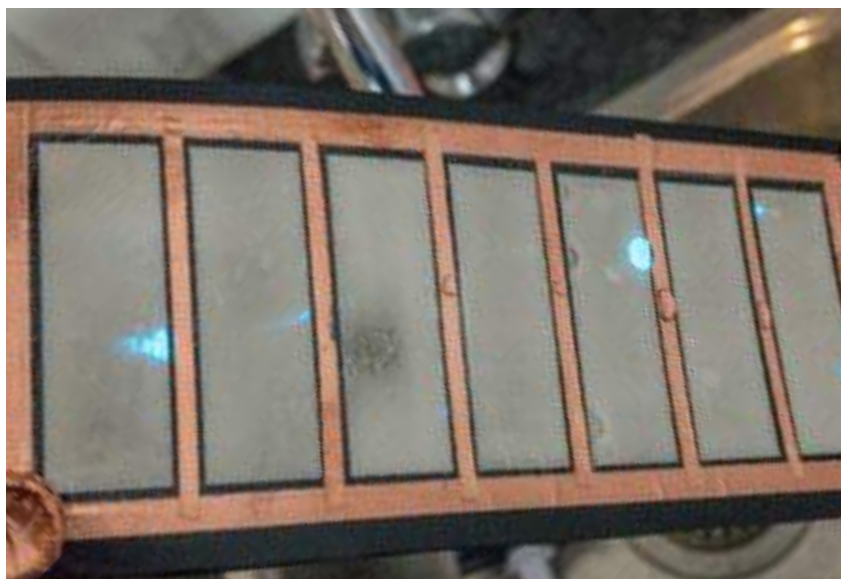
▼ Fig119. Only light emission where the water is.



▼ Fig120. Streaming water creates a light path



▼ Fig121. Emission where small drops still touch the copper grid.





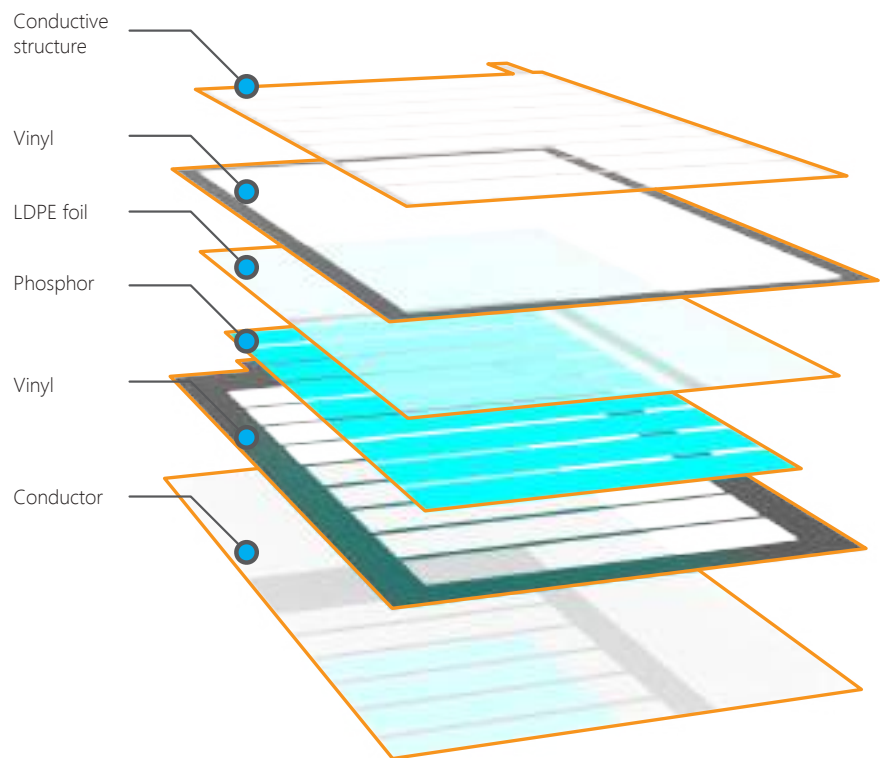
not in contact with the grid will not cause any light emission.

In this model the LDPE is also in place to fully cure the phosphor mixture but also acts as an extra barrier for the water to prevent it from reaching the bottom electrode. The phosphor mixture can come a bit loose from the vinyl when bend which could cause water to seep into these small gaps.

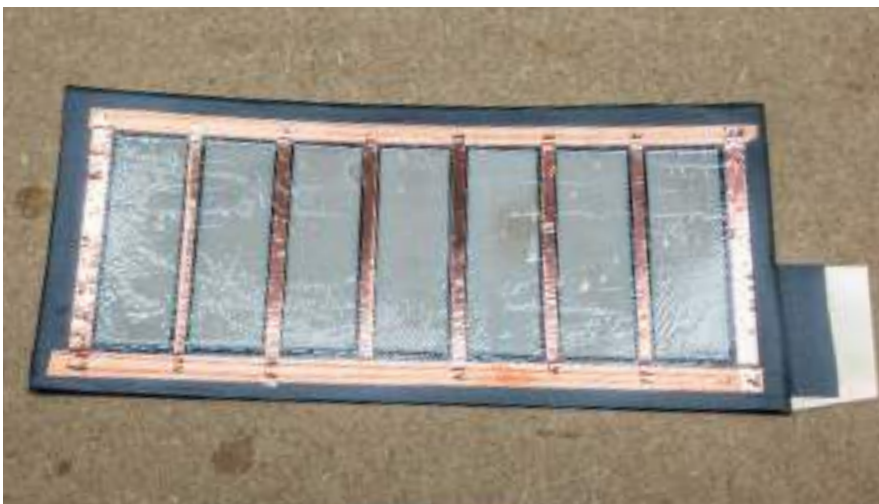
One model is been made where the phosphor is spread across an rectangle which has a piece of vinyl with aluminium foil on the bottom on top. This model did not have a layer of LDPE foil because the layer of phosphor was already an impenetrable barrier for the water. This caused the surface of the phosphor to be tacky to the touch and attracted small pieces of dust.

Improvements can be made on the material that is used to cover the phosphor layer and the material that is used to create the conductive grid. Copper tape does the job but is not effective in creating more complex structures.

## EL water panel Exploded view



▼ Fig122. Final test sample.



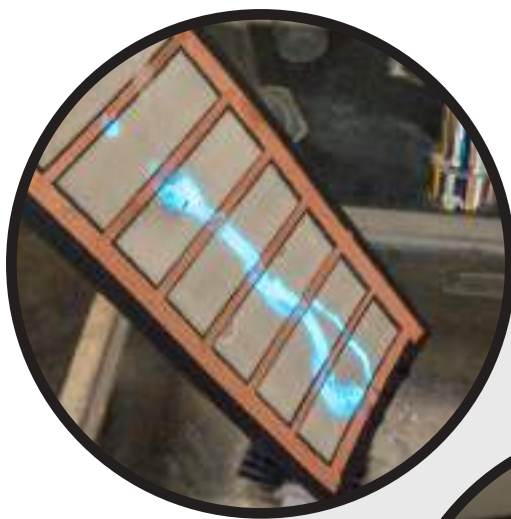
## Conclusion

The mixing of colours is difficult without contrasting colours. Only blue and yellow are available to test with. This showed another difficulty, they both have a different light output when the variables are similar (phosphor concentration and electric field strength). the only meaningful conclusion that can be drawn is that for mixing phosphors, the best and easiest method is to mix the powders before applying them to an electrode.

Flexible EL panels can be easily made using aluminium foil as rear electrode. The usage of aluminium foil also enable smaller details, although details smaller than 1mm will likely be too thin to be functional.

In the touch panel and water interaction EL the UV mixtures starts to show its downside. The oxygen inhibition make it more difficult to create these devices. It can be solved by placing a sheet of cling film to stop the oxygen inhibition. This is an extra step, make it more difficult to make a neat panel and makes the electric field slightly weaker. However, the application is not very difficult, does not take much time and only has a small influence on the light output.

These aspects show that EL panels made using UV curable adhesive can be as flexible as the screen printing method.







## U S E R   T E S T I N G

An important aspect of this graduation project is that the new DIY creation method is quick and easy to use. During the exploration and testing of different materials and methods, experience with the new application method is gained. This leads to a biased view on the practicality of the method and how easy it is to apply. This is why user testing is carried out, using students that have no prior knowledge of the project and no experience with the application technique.

# User test 1

The goal of the test will be to determine if the application of the phosphor/di-electric layer and the rear electrode is as easy and quick as expected.

This test is done using five students that will receive verbal explanation on how EL works and verbal instructions on how the application method works. During the application they will receive recommendations, based on their actions, on what to do or not to do in order to reach the best result possible.

The aspects that will be observed are how well the mixture is applied, how difficult this is for the participants and how well the rear electrode is applied. Both will influence the result of the output of the EL device.

Not the entire process of the new creation method will be part of the test. This would take up too much time and not all steps are equally relevant to the research. The list of steps of application method I are shown to the right, Fig123.

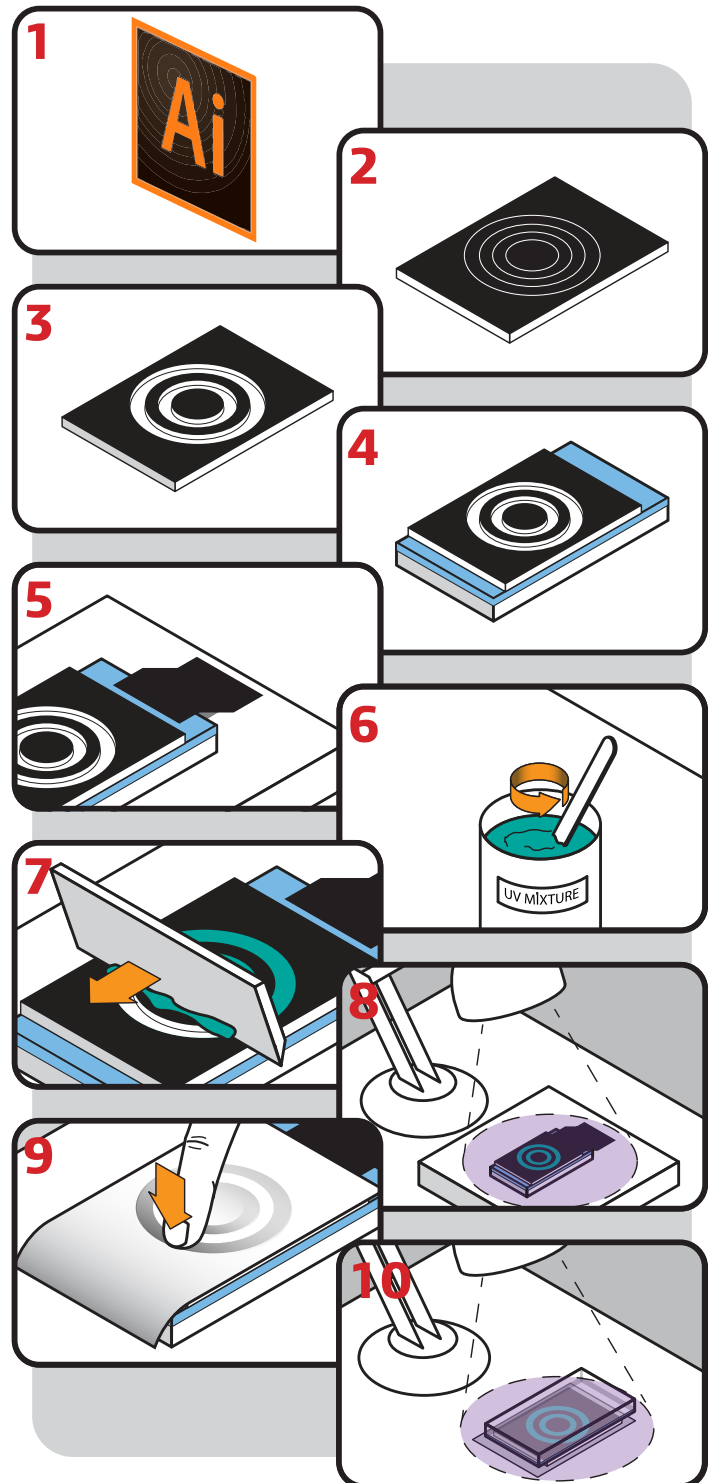


Fig123. General building sequence.

## Steps

1. Create design
2. Cut design from vinyl
3. Remove parts of the vinyl
4. Apply the vinyl on an electrode
5. Place the vinyl on the working area
6. Prepare the mixture
7. Apply the mixture on the vinyl
8. UV curing
9. Apply the rear electrode
10. UV curing

### Set-up

The first five steps do not need to be performed by the participants. These steps have little influence on the success of the new application method and are therefore not interesting to test. However, the application of the vinyl on an electrode can be seen as important step as applying it incorrectly, e.g. folded parts of the vinyl, can result in a sloppy device and possibly create a non working EL device. With the goal to test how well the phosphor and electrode can be applied, the decision is made to place the vinyl on the electrode for the participants. This will create a similar base for all participants, reducing variables that can influence the outcome. This will make it easier to compare the results. The vinyl cut out will be a TU Delft logo, approximately 10 by 4,5 cm. An error was made creating the vinyl. Since the light will exit through the ITO PET side the vinyl should have been mirrored be-

fore cutting it using the plotter. However, this will not influence the application method. The electrodes used will be ITO PET (vinyl will be placed on the ITO side) and aluminium foil as the rear electrode. The phosphor and glue will be mixed in a 50/50 weight ratio which will result in a 20/80 volume percentage respectively, this will be done for the participants.

A small cup will be used to store a small amount of the mixture, just enough for this design, and a box cutting knife to spread the mixture. This can be seen in Fig124 and Fig125.

### Results

The first four tests showed that creating the EL panel was not a problem. All panels light up, coverage is good and all show no major defects. In Fig126 can be seen that the coverage is not perfect, wrinkles caused by the aluminium foil show in the output, but for a first try it is a very satisfactory results. The win-

▼ Fig124. Participant applying the mixture.



▼ Fig125. Participant removing vinyl for double sided EL after curing the phosphor layer



kle effect of the aluminium foil can even be considered as a characteristic of this construction method and has a certain appeal to it. The excess phosphor mixture

Because of the success of the first four participants the last participant got a slightly different, more difficult variant of the application method. The last participant got to make a transparent and thus double sided EL panel. The result of this test was also successful as is visible in Fig126. Only small parts of the panel fail to light up and no malfunction occurred. After application of the phosphor layer the surrounding vinyl had to be removed after which small pieces of the phosphor layer started to peel, Fig127. The effect of the peeling can be seen in the letter "U" in the final panel.

## Conclusion

With direct guidance and proper instructions first time users are able to easily create a fully functioning EL device. Even the slightly more difficult double sided EL device was constructed without difficulty.

Fig126. The results of the first user test. The numbers correspond with the participant numbers. The first four images are mirrored for aesthetic purposes.



Fig127. Removing the vinyl caused local peeling of the phosphor layer.



## User test 2

The goal of the second test is to further determine the ease of application and how much time it actually takes from start to finish and to examine the clarity of the DIY guide that is created for this project.

This test is performed using 17 students from the master elective Lighting design. All students have no prior knowledge of the project or application method. The test will start at the same point in the process as the first test, with vinyl already in place. The main difference will be that

the instructions are not given verbally but by a DIY guide that is made for this project, the exact version handed to the participants is visible on the following pages. All participants are required to read it before starting the workshop. During the workshop verbal instructions are kept to a minimum, only steering when absolutely necessary (e.g. when way too much of the phosphor/UV mixture is used) and to answer questions if the guide is not clear enough. These questions will be used as feedback to improve the DIY guide.

### Materials

- |                             |                           |                   |
|-----------------------------|---------------------------|-------------------|
| 1. Work surface             | 5. EL pocket inverter     | 9. Aluminium foil |
| 2. Jars for mixture storage | 6. Vinyl shape on ITO PET | 10. Tape          |
| 3. UV curing adhesive       | 7. Clamps                 |                   |
| 4. Scissor                  | 8. Scraper                |                   |

▼ Fig128. Materials used during the workshop





### Set-up

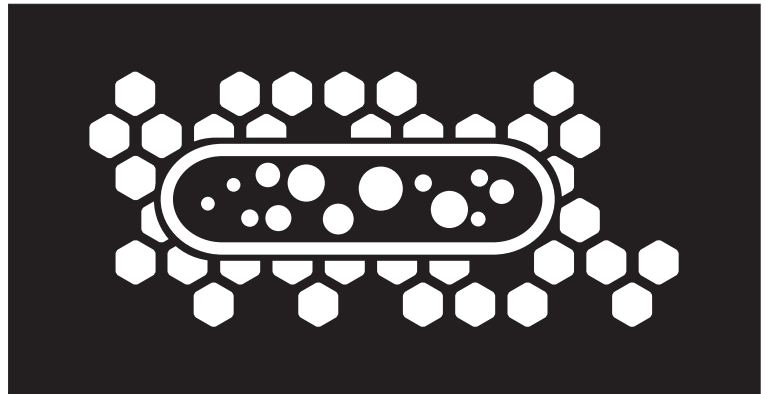
This time two different vinyl designs are used, Fig129, and spread evenly over the participants to determine the difference in application effectiveness on different types of shapes and line thicknesses for first time users. The important required equipment is visible in Fig128.

Like with the first user test in order to create an equal starting point for all participants the vinyl is already placed on the ITO PET.

The electrodes used will be ITO PET (vinyl will be placed on the ITO side) and aluminium foil as the rear electrode. The phosphor and glue will be mixed in a 50/50 weight ratio which will result in a 20/80 volume percentage respectively which will be stored in small weck jars.

The sessions will be recorded using a camera to further analyze the time that was required for the creation of the EL panels once the workshop is finished, Fig131.

Instead of box cutters as scraping tool, not safe enough for workshops with multiple participants, small strips of thin plastic are used. These are cut using a ruler to create a straight edge and glued to a thicker piece of plastic in order to make it more rigid. This is tested to be successful in creating an EL device, Fig130.



▲ Fig129. The two files used for cutting the vinyl in this test. The TU Delft logo is mirrored because the light will be emitted from the other side.



▲ Fig130. An EL device made using the self made scraping tool.



◀ Fig131. A still from the video made from the first group of participants.

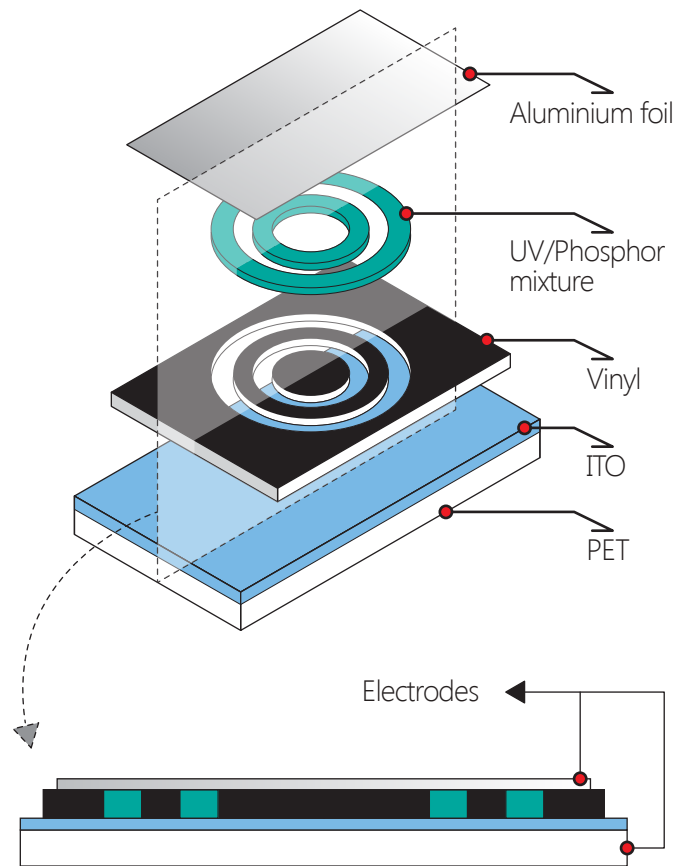


# DIY guide:

## Electroluminescence

Electroluminescence (EL) is the emission of light when phosphor particles are placed in a strong electric field. An electric field exists between two electrodes, with an opposite charge, when a non-conductive layer is placed between the two electrodes called the "dielectric". No current should flow from electrode to electrode directly as this will cause a short circuit and a malfunction in the EL device. One of the electrodes needs to be transparent in order to let the light out. In order to create a strong electric field you can increase the voltage or change the distance between the electrodes. This guide will focus on making

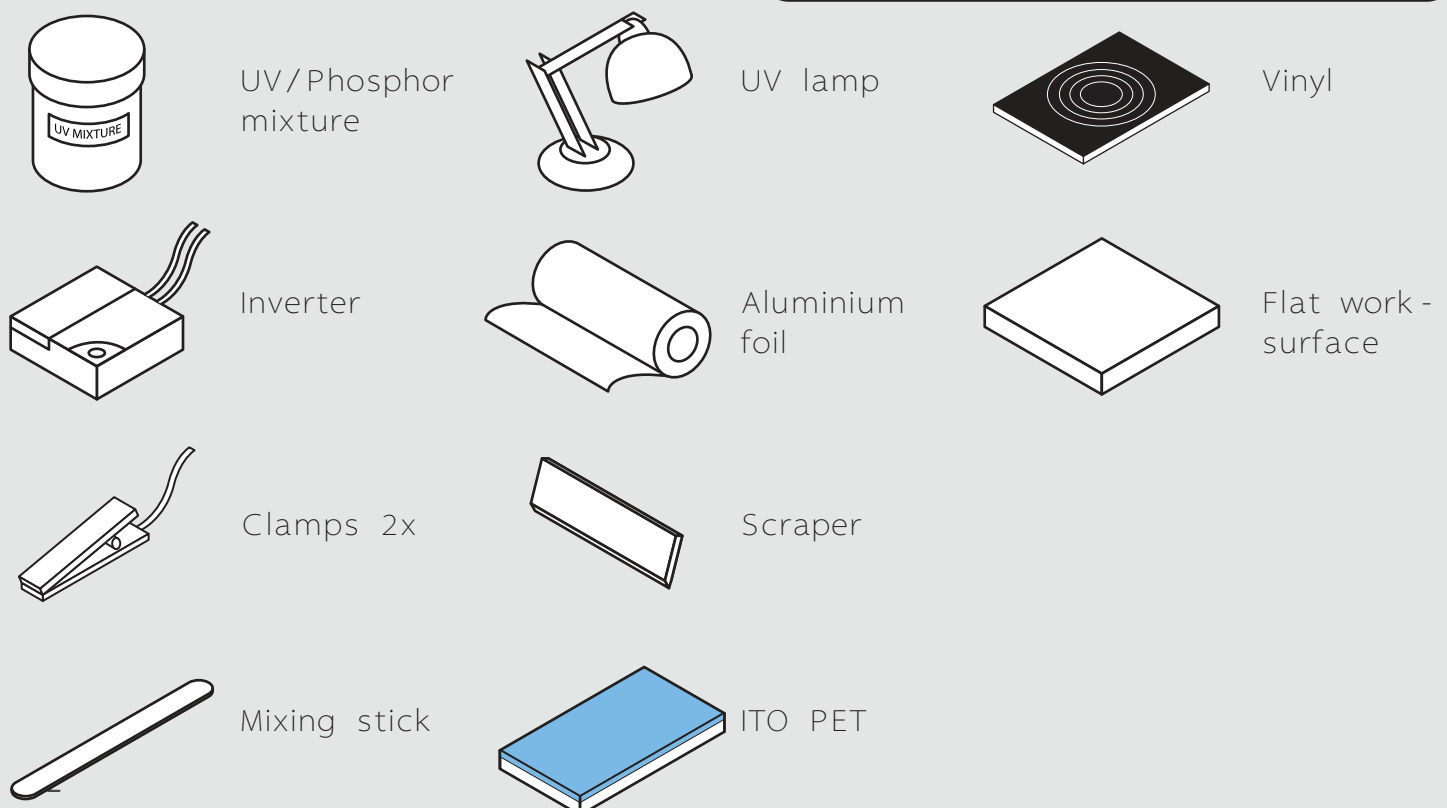
the distance between electrodes as small as possible. The electrodes used in this guide are aluminium foil and ITO PET. ITO is a very thin and delicate electrical conductive layer that is applied to a sheet of PET which is not visible by sight. The UV/phosphor mixture consists of phosphor powder and UV curing adhesive (only cures under the influence of UV light). The layers are ordered as such that the two electrodes are as close to each other as possible. The vinyl and UV adhesive will function as dielectric layers, insulating both electrodes. This workshop will start at step 3.

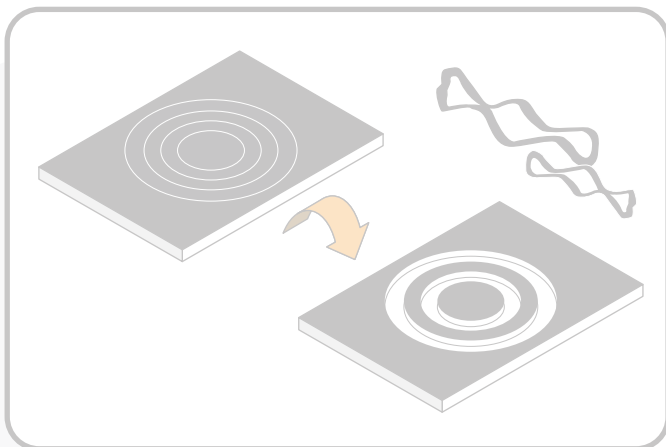


Be careful when handling the EL panel when it is on. You can get a shock if both electrodes are touched simultaneously.  
Wash your hands if the mixtures has gotten on your hands.



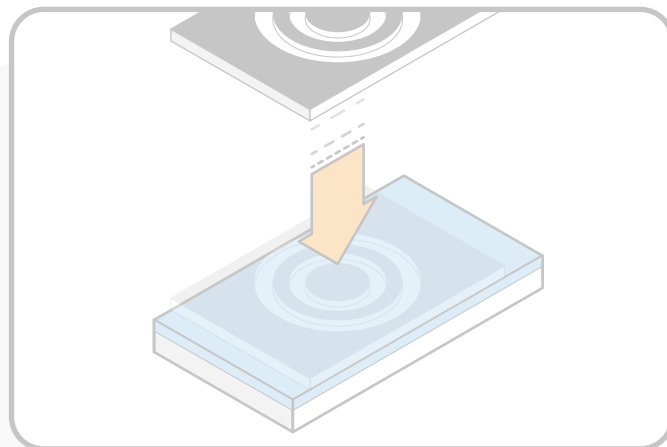
## Required equipment



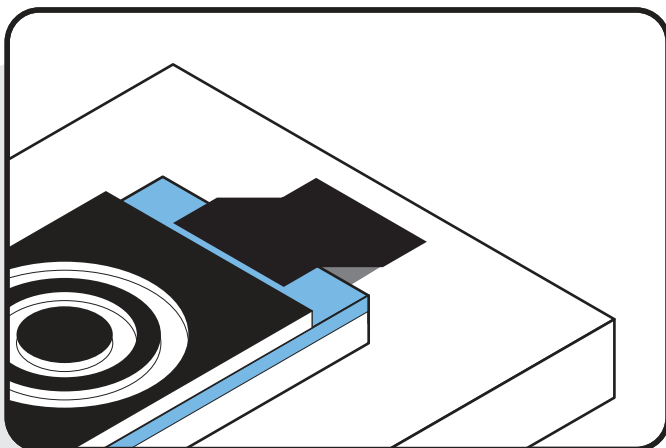


**1** Remove the parts of the vinyl that are not needed. These parts will be filled with the UV mixture.

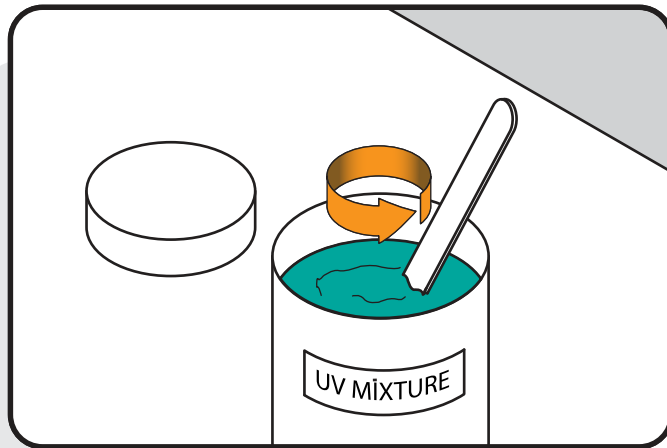
These steps are not needed during this workshop.



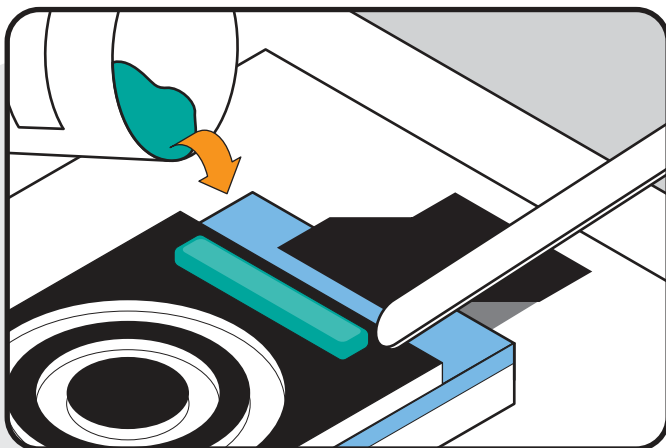
**2** Carefully place the vinyl on the ITO side of the ITO PET. If the cut-out part is complex a piece of transfer tape might be required.



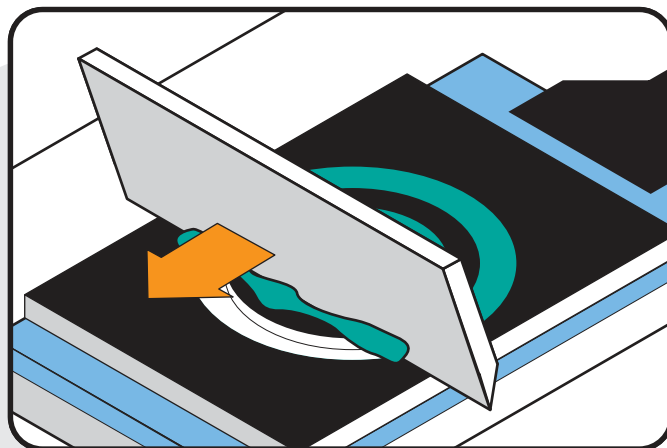
**3** Adhere the top side of the ITO pet to the (clean) working surface with a piece of tape.



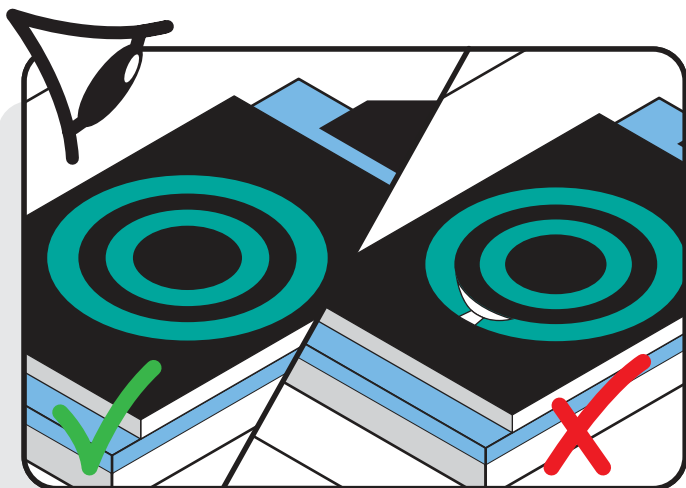
**4** Stir the UV/phosphor mixture properly right before application. Phosphor particles will start to sink to the bottom after a minute, this requires stirring to create a homogeneous mixture.



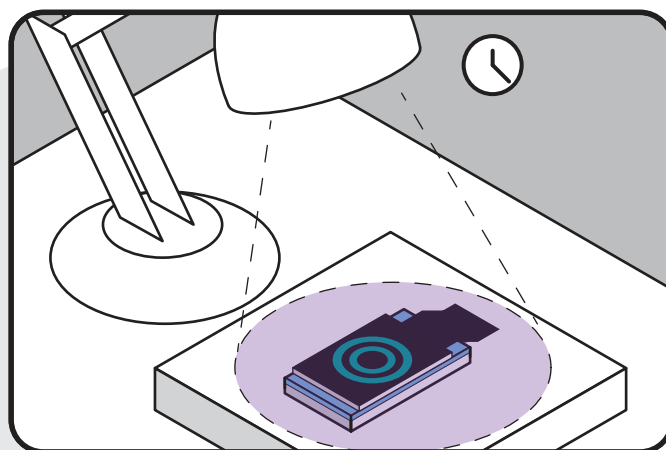
**5** Apply a line of the mixture above the cut-out on top of the vinyl.



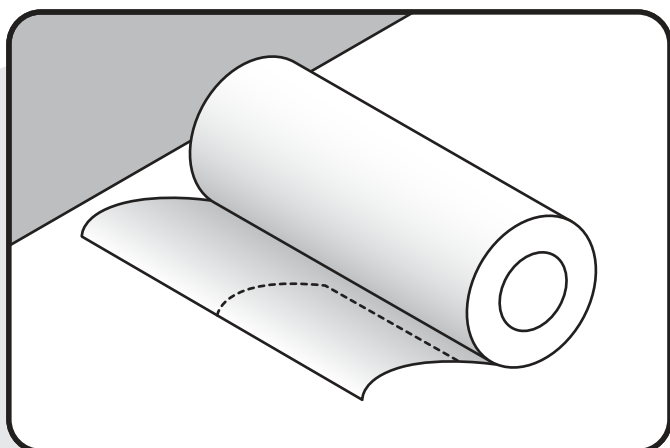
**6** Use the scraper, with medium pressure, to spread the mixture over the vinyl. If the coverage is insufficient repeat step 4, 5 and 6.



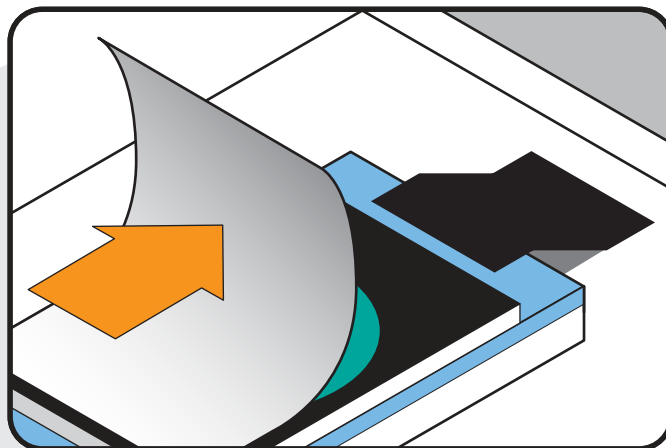
**7** Once the mixture is spread, perform a final visual check on proper coverage. Holes in the mixture layer can cause a short circuit.



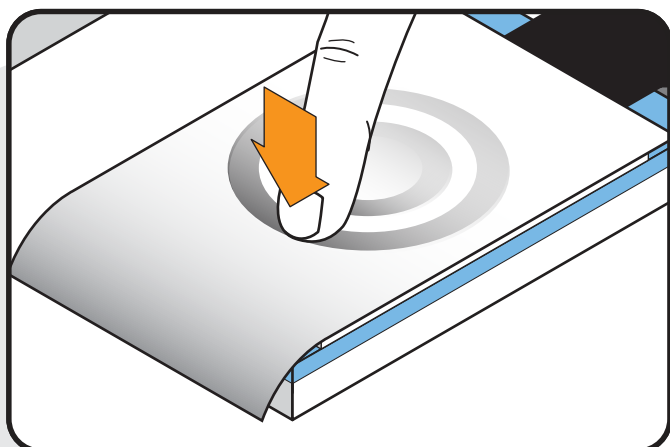
**8** Place the working surface underneath the UV lamp and let it cure for 1 minute. *UV adhesive that is in contact with oxygen will create a tacky outside layer. This effect will be used to bond the aluminium foil next.*



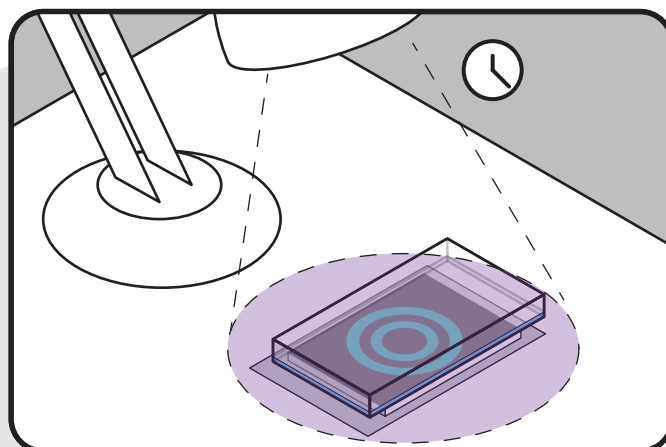
**9** While you are waiting cut a piece of aluminium foil large enough to cover the parts that are filled with the mixture.



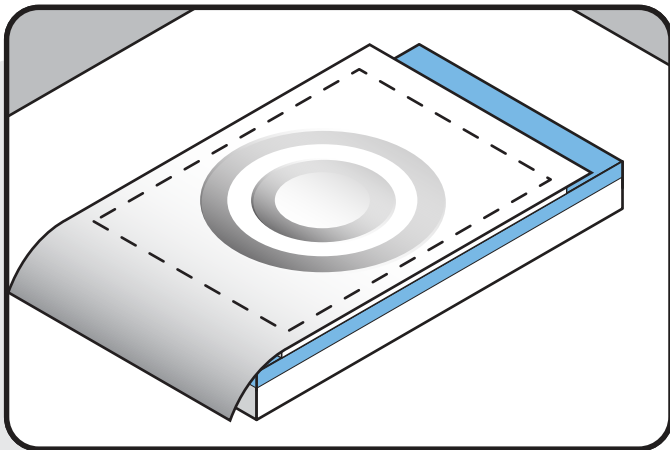
**10** Once the UV mixture is partially cured the piece of aluminium foil can be placed on top. Make sure that there is as little air as possible between the foil and the mixture.



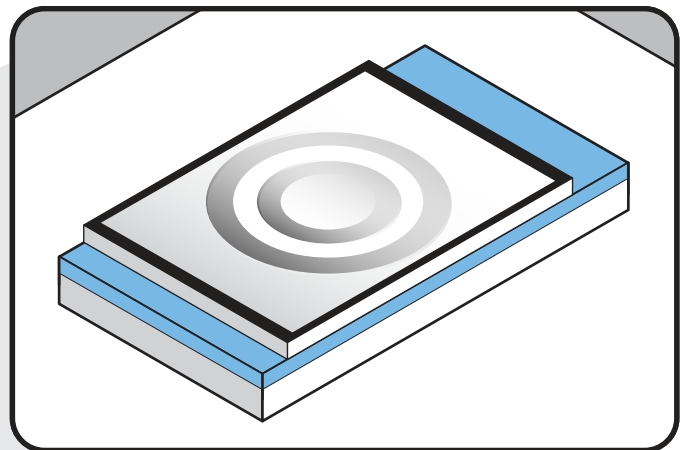
**11** Press down on the foil where the mixture is located using firm pressure. This is done to remove trapped air and decrease the distance between the electrodes which increases the electric field strength.



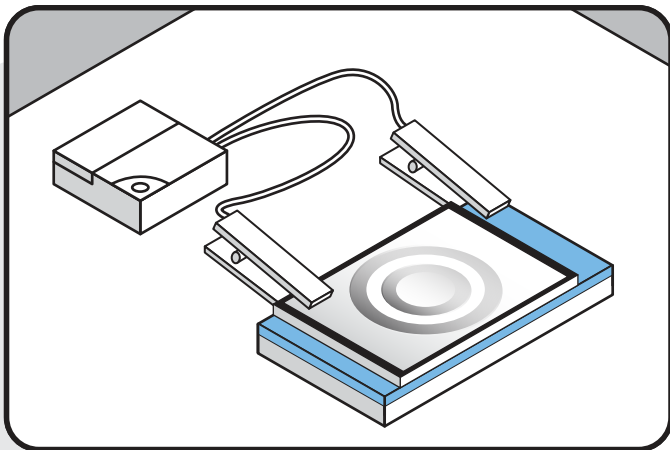
**12** Remove the tape that fixated the ITO PET and flip the material so the mixture can be seen through the ITO PET. Place it underneath the UV lamp for an additional 120 seconds.



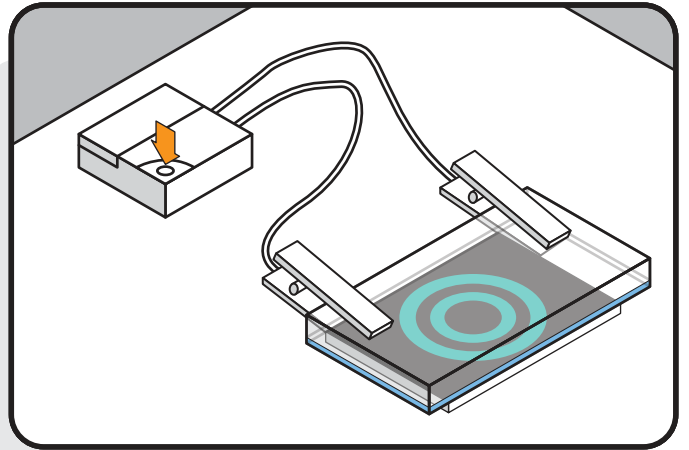
**13** Once the mixture is fully cured, remove the parts of the aluminium foil to the point that no part of the foil can touch the ITO side of ITO PET.



**14** After cutting the foil the EL device should look like this. If the aluminium foil is smaller than the vinyl no short circuit should be able to occur.

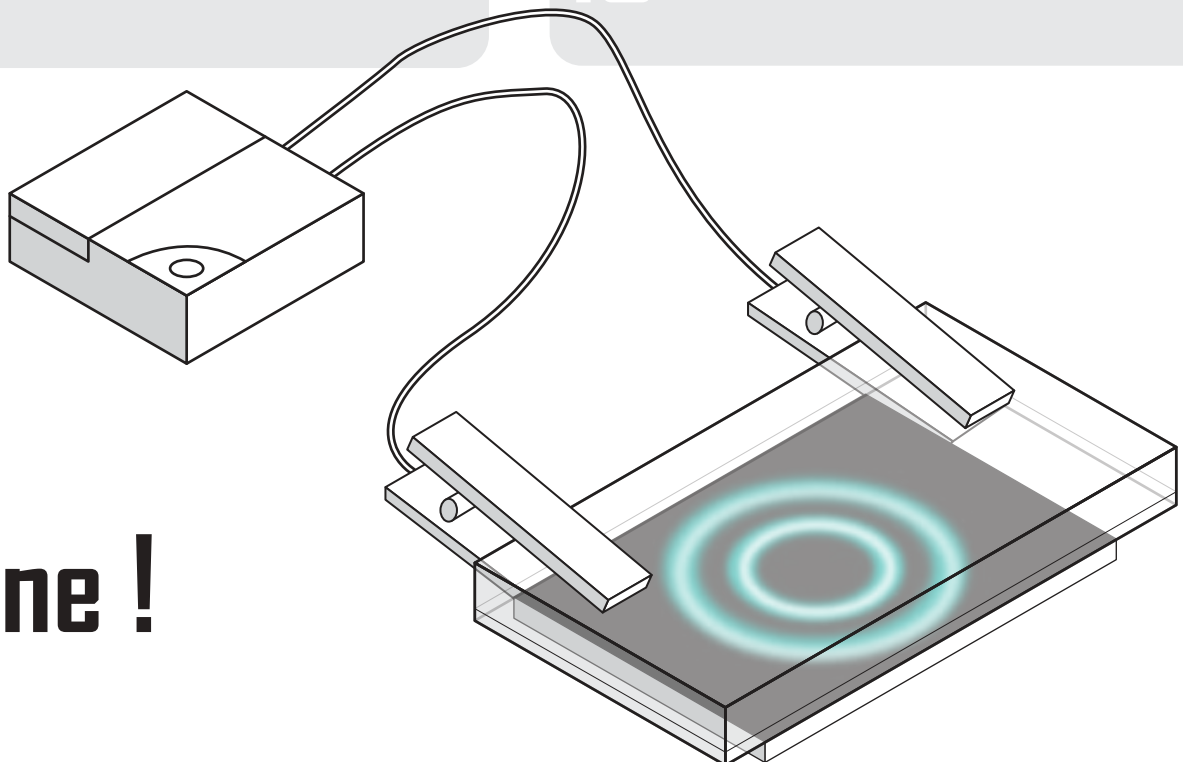


**15** Attach the clamps with the conductive side touching the two different conductive layers.



**16** Flip the device and turn on the inverter.

**Done !**



## Results

From start to finish, starting with applying the mixture to the vinyl and finishing with a panel that is emitting light, on average the participants took about 16 minutes. This is without reading the guide and stirring the mixture for the first time.

All panels lit up, with differences in success but no large malfunctions. It became clear that the small details in the TU logo version were difficult (1mm wide) for first time users but not impossible, Fig132. Fig133 shows lines of up to 0.5 mm are possible (with practice).

The coverage of the EL devices ranges from poor too to thick. Too thick led to low emission and a poor coverage gave a spotty result Fig133. All results can be found in appendix 9.

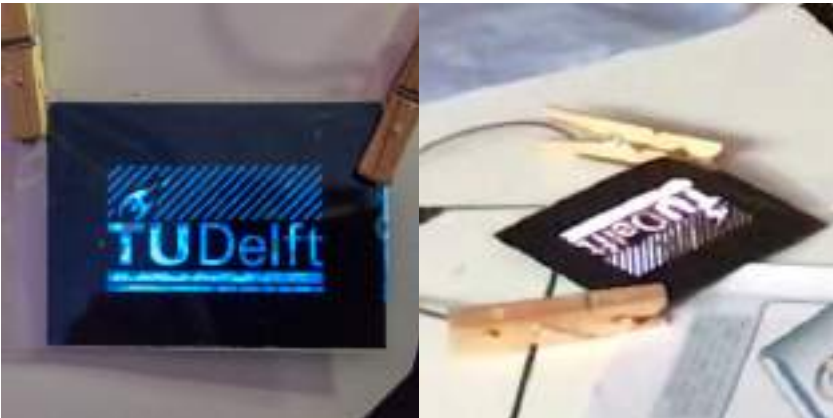
Even though the devices with a poor coverage had areas where no mixture was located this did not create a dielectric breakdown since the mixture that is in place, keeps the aluminium foil in place preventing it from touching the ITO layer.

After a couple of days a part of the samples showed degradation of the emission which is probably caused by insuf-

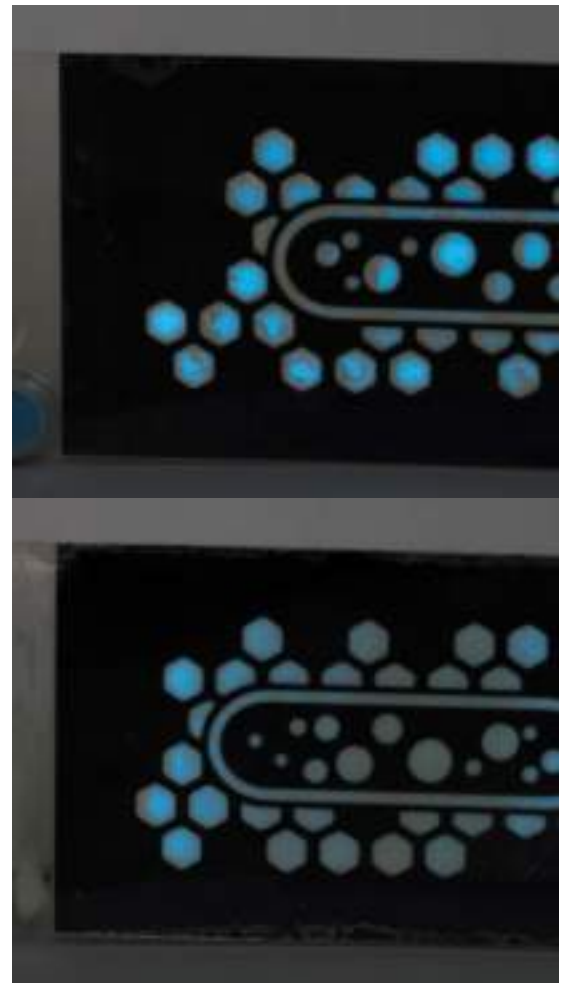
ficient removal of air when applying the aluminium foil. The image of one of the panels during the workshop compared to a couple of days later shows that the large areas started to decrease emission Fig134. When pressed on the ITO side when the panel is turned on shows that the mixture is still slightly liquid (the emission increases after it is pressed). This indicates that there was enough oxygen to prevent the mixture from fully curing causing the layers to separate slightly after a couple of days.

The only verbal corrective instructions

▼ Fig132. Coverage difference of the thin stripes. Left it is covered well and right only partly.



▼ Fig133. Bad coverage and spotty emission (top) and a too thick layer of phosphor (bottom).





that were given to the participants were to prevent the usage of too much of the mixture and to make sure the connectors were placed correctly. After a small introduction to the subject of EL and the written guide

### Conclusion

It can be concluded that without knowledge on the subject, application and working, all participants were able to create an working EL device within 20 minutes. The results are clearly less good than the first test but can still be considered an success.

The DIY guide is good but could use some more explanation at certain steps like the removal of the air bubbles which likely caused the quick degradation of multiple panels. A revised version can be found in appendix 10.

### Discussion

Because this workshop was part of an afternoon with different light experiments

the light in the room was dim. This made it more difficult for the participants to see if the different steps are done correctly, especially compared to user test 1 when the working area was properly lit. This can also be caused by the usage of a box cutter in user test one which is stiffer than the self made scraper which can make it easier to apply the mixture properly. The less than ideal conditions for creating an EL device show the effectiveness of the new method maybe even more.

It should also be noted that the decreased emission only occurred in the TU delft logo version. Why this only happened with this vinyl shape is unclear. There are different phosphors used in each test but this should not have influenced the ability of the mixture to bond. The EL device in Fig130 is made using one of the two phosphors used in this test and still works fine after three weeks.

▼ Fig134. Left are the samples during the workshop (taken from the video footage) and on the right are the samples after a few days. Clearly the brightness has gone down.



## User test 3

After finishing two users test that only focused on the new application method, a third and final test is carried out. This test will compare the UV method to the screen printing method. The focus will not only be on the time it takes, this will be the UV method, but also on the results. How do these to stand up to each other.

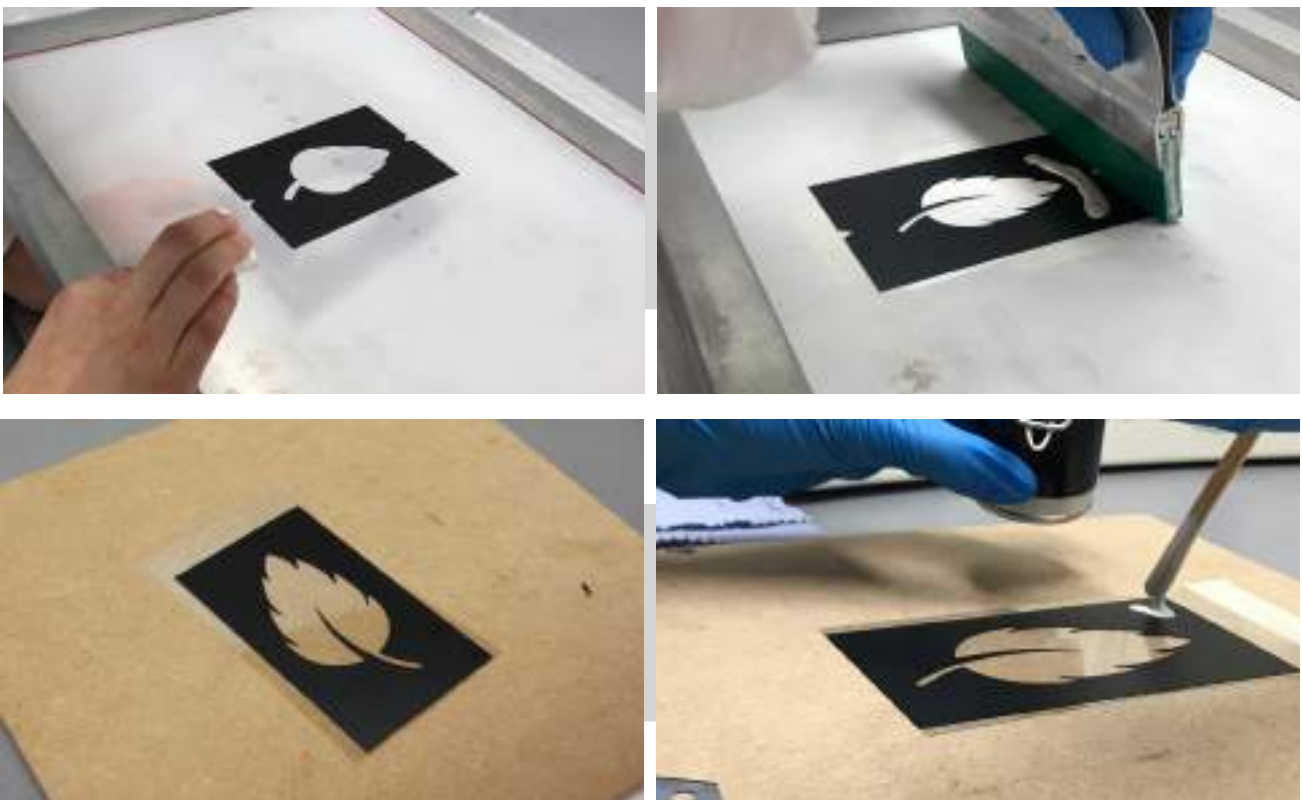
### Setup

This test will be carried out by a single participant. The participant has no experience with either of the EL creation methods. Both method are carried out in the chemical lab where proper lighting of the working area is present (this

was an issue during the second user test). All the required steps for this test will be carried out by the participant (Fig135)(except the design of the EL panel). Instruction for both methods are given beforehand. For the screen printing method, the guide created by Stan Claus is used and for the UV method the guide in this report is used. Both guides are supplemented by verbal instructed based on experienced gained on both method during this project.

In order to create an equal test setup, the design for the EL panel has the same shape and dimensions for both methods. For the screen printing method the shortest construction method is chosen.

▼ Fig135. Top, application using screen printing. Bottom, application using the UV method.





This means directly applying the phosphor on a piece of ITO PET. Using this method removes the need for applying the rear electrode, which reduces construction time. For the UV method the double sided method is used (method III-b). Similar phosphor colours are used for both EL devices.

### Results

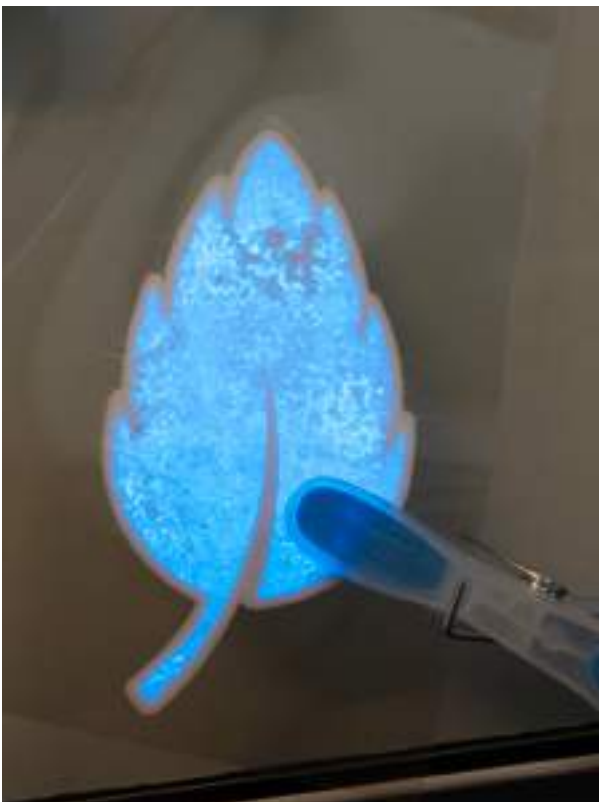
In Fig136 and Fig137 the results are visible. Both worked on the first try. The images do not properly capture the brightness. The screen printed panel is a small amount brighter. This is likely caused by the higher phosphor concentration of phosphor in the screen printing mixture (this can easily be increased in the UV mixture) and the higher relative permit-

tivity of the BaTiO<sub>3</sub> compared to the UV mixture. The time required for the screen printing was 115 minutes and for the UV method the total time was 19 minutes. The time for all the individual steps can be found in appendix 11.

### Conclusion

This test has shown that besides requiring less time than screen printing (up to eight times if both methods are used to create a single sided EL device), it can also deliver similar results. Some aspects can be considered to be slightly better. The light emission is more homogeneous and the edges of the emissive area are sharper compared to the screen printed sample.

▼ Fig136. Results using screen printing. The dark spots are caused by bumps left in the dielectric layer after removing the screen printing mesh.



▼ Fig137. Results using the UV method. Dark spots are caused by small particles on the working area.



## D E M O N S T R A T O R

Since the main part of the project consists of developing the new construction method for DIY EL, which has been properly validated, the ideation phase of the final demonstrator will be relatively short. Combining ideas that are collected during the project with ideas that are generated during brainstorming sessions held with students, will lead to a final demonstrator that shows of important visual properties of electroluminescence.

# Ideation

## Brainstorm workshop

Part of the second user test is an ideation session. The ideation session is held after the EL panel workshop. This sequence is chosen to familiarize participants with EL before they are asked to generate ideas. Each ideation session has two groups that are given five minutes to generate ideas on a given property of EL, flexibility and water interactivity, and are free to combine this main property with the other properties of EL. Both groups will start with a different property. One group will have flexibility and the second group will use the water interactivity as the main property. Although the water interaction will not be a part of the final demonstrator this property has been chosen to motivate the participants. People that see the water interaction generally have a positive reaction to this effect. This aims to activate the participant into generating more unique ap-

plications that can be adapted to fit the final demonstrator.

Ideas are written or drawn on post it notes and placed on a large sheet of paper. After five minutes the two groups exchange their sheet of paper and are given an additional five minutes for idea generation. During these five minutes they can elaborate on the ideas of the other group or add their own ideas to the sheet using the main property that is linked to the sheet of paper.

Once the user testing is finished the sheet of paper are collected and processed to remove post it notes that are not relevant to the project, technically not feasible and ideas that are double. The remaining ideas are filtered further based on how well they fit the properties that will be integrated into the demonstrator (appendix 12).

▼ Fig138. One of the two brainstorm sessions.



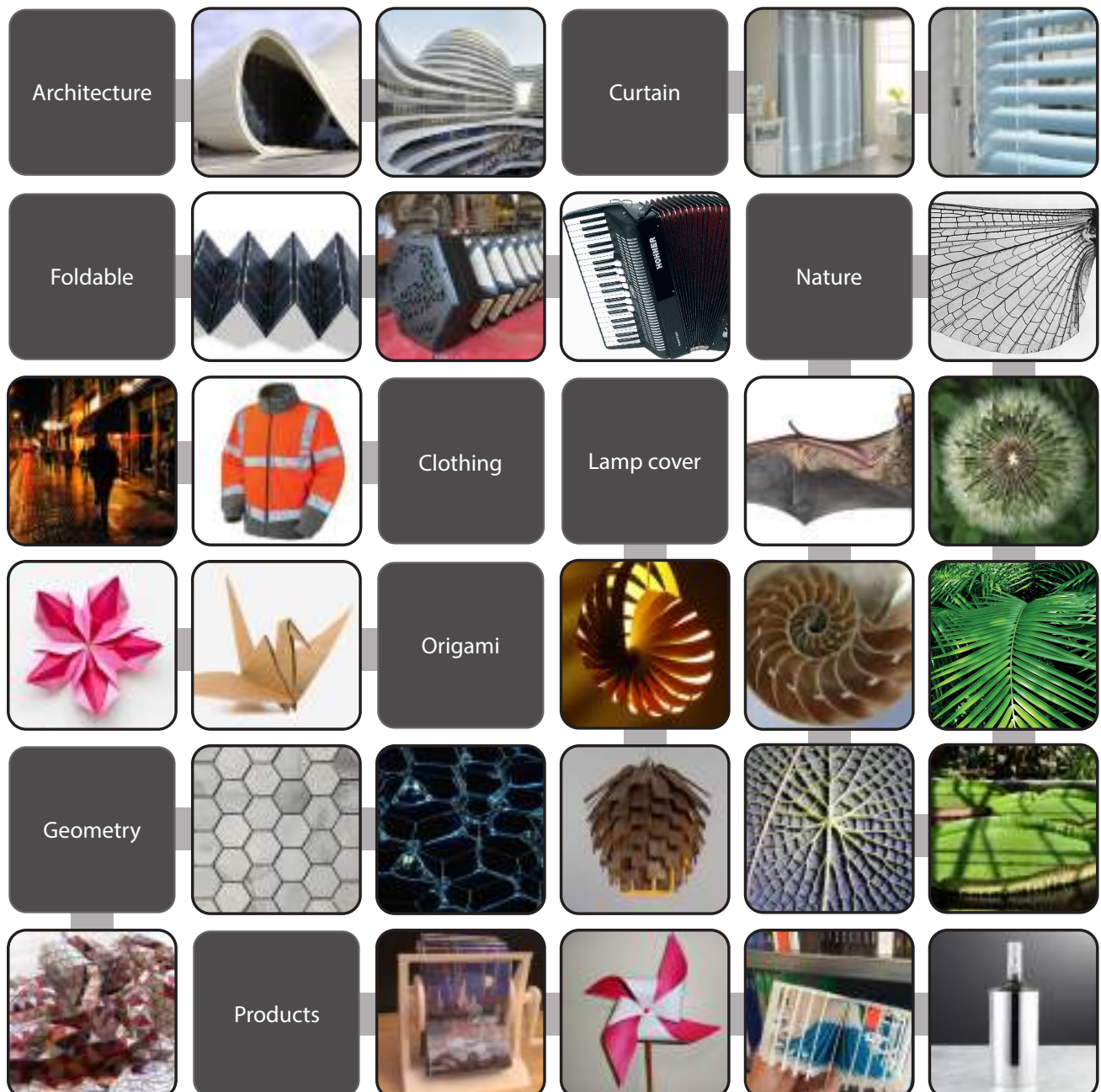
## Inspiration

Using the ideas from the workshop and ideas that are collected during the project, an inspiration board is made. This will be used to further the direction of the final demonstrator. The important visual aspects of EL are:

- Thin panels
- flexibility
- transparency
- double sided light emission

The aim is to combine all four properties into a single demonstrator.

The inspiration page consists out of products and shapes in architecture and nature that have the potential to show of multiple or all important visual properties of EL.

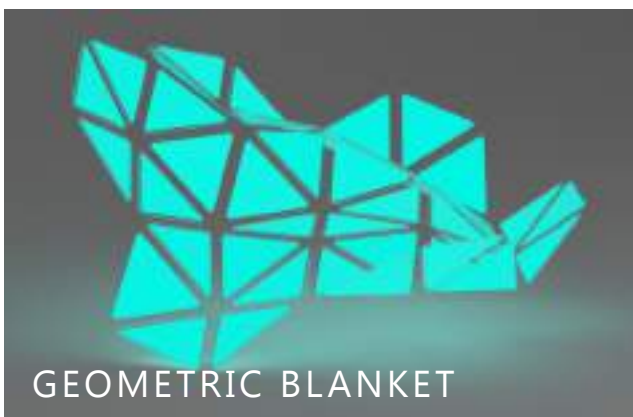




# Concepts

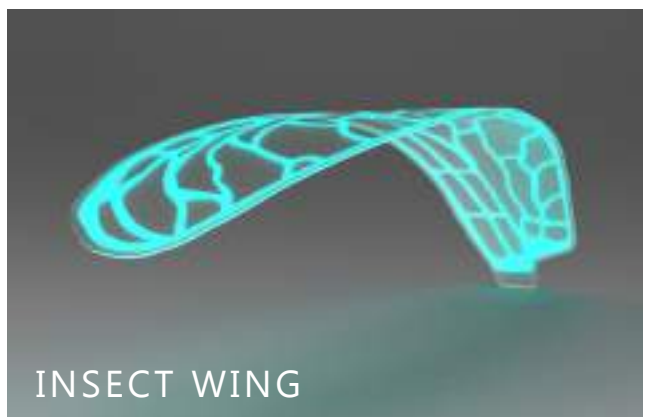
The scale of the demonstrator should be the size of something that can be placed on a desk or put in a windows sill. This means the concepts need to be relatively small. This is mainly due to material and time restrictions. The remaining phosphor powder stock might not allow a large demonstrator and the demonstrator still has to be build in the remaining time. However it should still be large enough to clearly showcase the main properties of EL.

A Harris profile is made of the three concept. The criteria that are include are: flexibility, thinness, transparency, double sided light emission and expected build time.



## Concept 1

A large collection of individual triangles that need to be linked to each other. While a single EL panel cannot take on 3d-curved shapes, this construction focuses on being able to just that.



## Concept 2

As an fragile, thin and transparent part of an insect , this would provide an good opportunity to show of transparent and the thin properties in the final demonstrator.



### Concept 3

Fragile in nature, leafs offer a good opportunity to demonstrate the thin qualities of EL. It is also possible to play with day and night cycles. Charging during the day and slowly starting to emit light once the sun goes down.

## Concept choice

Looking at the five aspects in the Harris profile (Fig139), the first concept will take too long to build. Linking all the triangles can be difficult. And although it can take on 3d-curved shapes the individual panels do not really show off the flexibility. Rather the construction of triangles shows this aspect.

The wing and the leaf are closer together. Both have great potential in showing the thin and double sided properties of EL. While the building time of a leaf based demonstrator is likely to take less time, the transparency and the expected reaction to the looks of an insect model have lead to the insect wing to be developed into a full demonstration model.

▼ Fig139. Harris profile

	Geometric blanket					Insect wing					Leafs			
	--	-	+	++		--	-	+	++		--	-	+	++
Building time														
Flexibility														
Thinness														
Double sided emission														
Transparency														



### Wing type

Insects come in many shapes and sizes and so do their wings (Fig140). From bee wings and moth wings to wings of a dragonfly. Each with a different structure of the veins that run through them. Not all wings are transparent, with make them less favorable for the demonstrator. The goal is to represent the wings as close to an actual wing as possible.

The final direction for the type of wing is the dragonfly wing. They are large, look very fragile and can be highly transparent. Ideal properties for the demonstrator to convey.

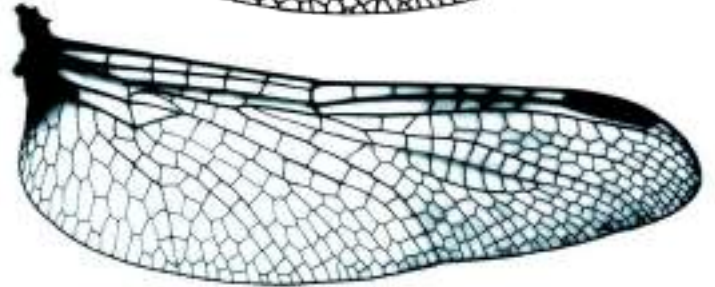
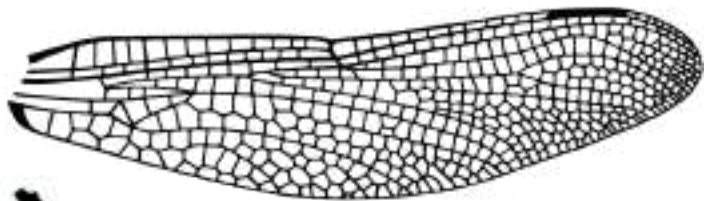


Fig140. From top to bottom, bee wing, moth wing, dragon fly wings.



### Wing modeling

Dragon fly wings have a high vein density. This can become a problem during the creation of the model. Four wings have to be made and using the method for creating transparent EL panels, is not practical if the actual vein structure is replicated. All the parts that are showed in red (Fig141) need to be manually removed once the phosphor layer has cured. Without counting it is easy to see that will take a lot of time. For this reason a new design is made that follows the outlines of a dragonfly wing, but has a lower veins density.

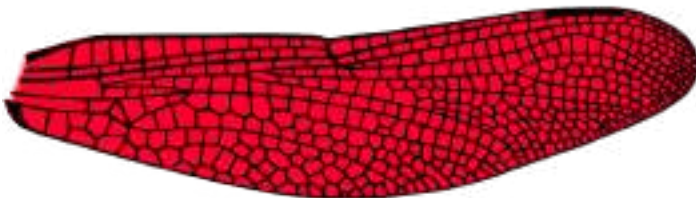
The design is first made on paper (Fig142) after which it is scanned and imported into Adobe Illustrator (Fig143). From there it is turned into a vector

based image, which is used to create the Solid Works model (Fig144). The same illustrator file will be used to cut the shape into a sheet of vinyl.

The Solid Works model allows the creation of different models to determine the final design without actually building anything yet. The models are exported to Keyshot to quickly make renders of the expected output.

### Dragonfly body

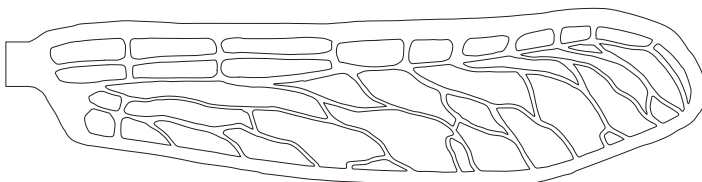
In order to pull as much attention to the wings as possible, the body of the dragonfly model will be made from transparent acrylic sheet material. This will be laser cut and should fit together like a puzzle. Using a transparent glue the pieces will be held together. This should



▲ Fig141. The black parts represent the phosphor part. The red indicates the pieces of vinyl that have to be removed.

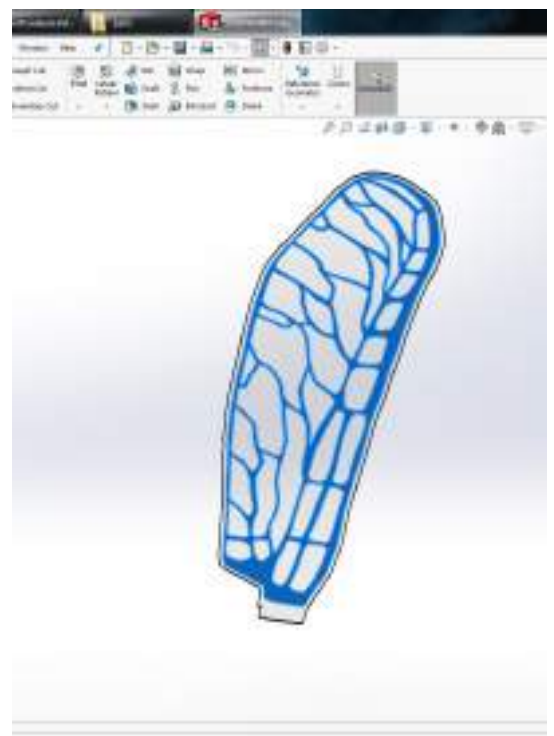


▲ Fig142. Wing design on paper



▲ Fig143. Wing design in Adobe Illustrator

▼ Fig144. Vector images can be imported to Solid Works and turned into 3D bodies.



make the model strong enough to carry the wings.

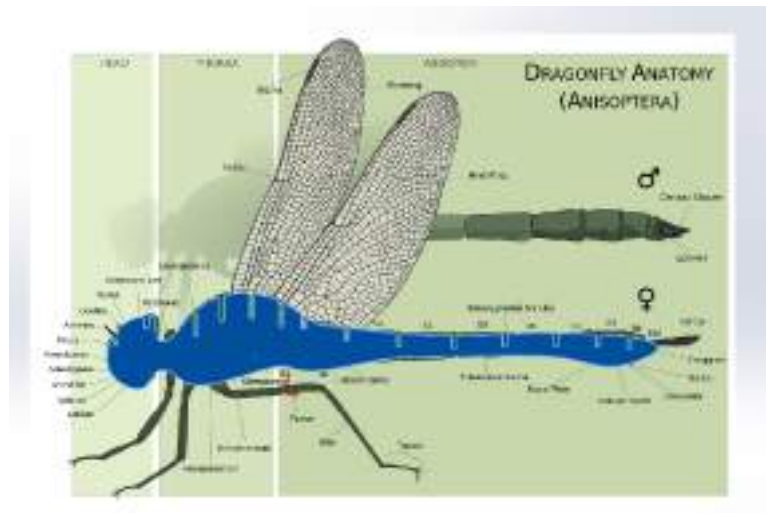
The design of the body is based on the outline of a dragonfly illustration (Fig145). In order to give the model more volume, the body parts are represented by disks that are placed perpendicular to the main body part. Since the tail of the type of dragon fly the body is based on normally has ten sections, the final model will have a similar construction (Fig146).

The construction of the dragon is also designed with the placement of the wings in mind. By creating cut outs the wings should have support (Fig147). Unfortunately the wings on a single side have to be placed close together which means additional support is needed underneath the wings (Fig148). The outlines of the supporting structures are displayed in orange. The locations at which glue is applied to keep the wing in place is indicated by red.

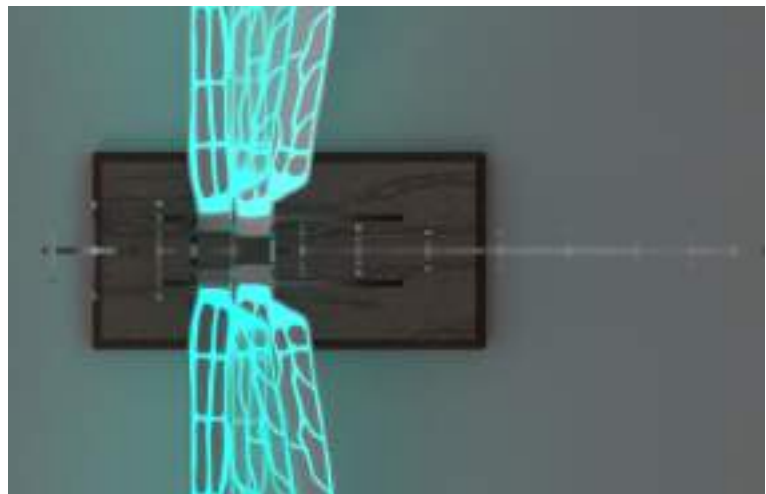
▼ Fig148. Supporting structures underneath the wings (made black to make them stand out more).



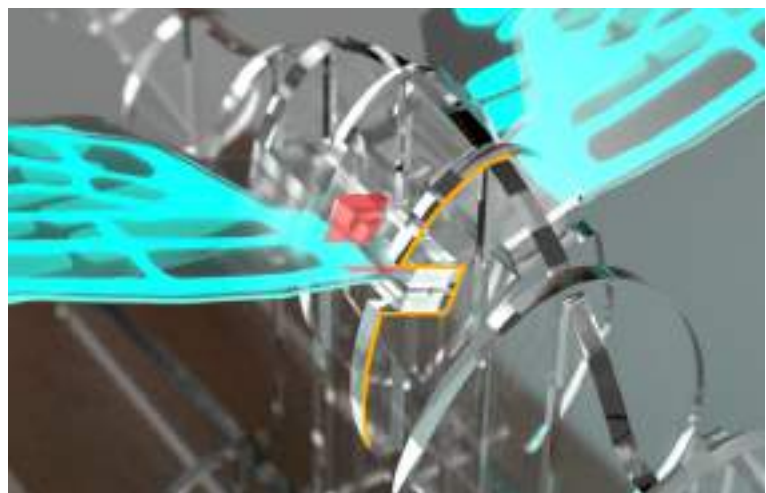
▼ Fig145. An imported image in Solid Works allows for accurate tracking of the side view of a dragonfly.



▼ Fig146. 3D model of all the main parts.



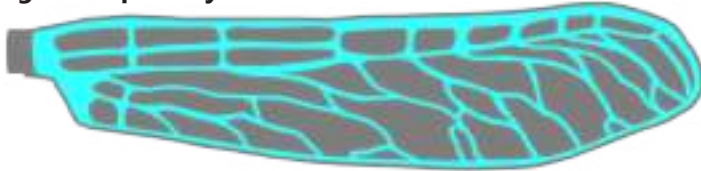
▼ Fig147. Cut out in one of the panels to support a wing.



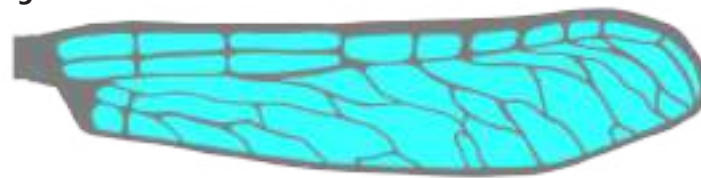


▼ Fig149. Vector images can be imported to Solid Works and turned into 3D bodies.

### High transparency



### High emission



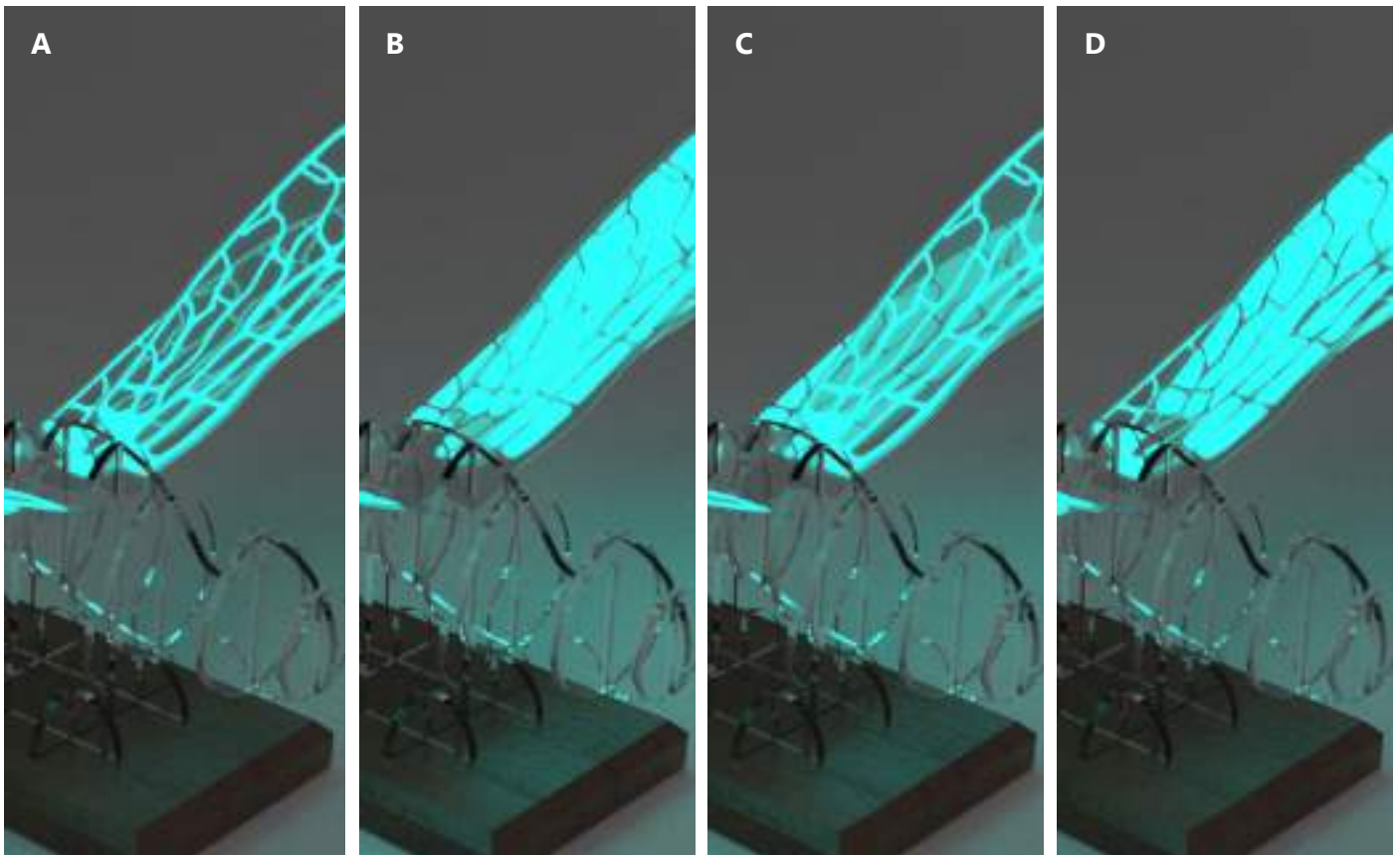
### Wing types

The 3D model of the wing allows to easily invert the phosphor and transparent parts of the wing (Fig149). This means one wing will be more transparent, while the other will emit more light. Using these two different wings all the possible configurations are modeled and rendered (Fig150).

- A Two transparent wings
- B Two high emission wings
- C High transparency wings on top, high emission on the bottom
- D High emission on top, high transparency on the bottom.

Option C is chosen for the wing configuration. The high emission wing will be more visible through the top wing. This will make the transparency of the top wing more pronounced.

▼ Fig150. Four different configurations of the wings.



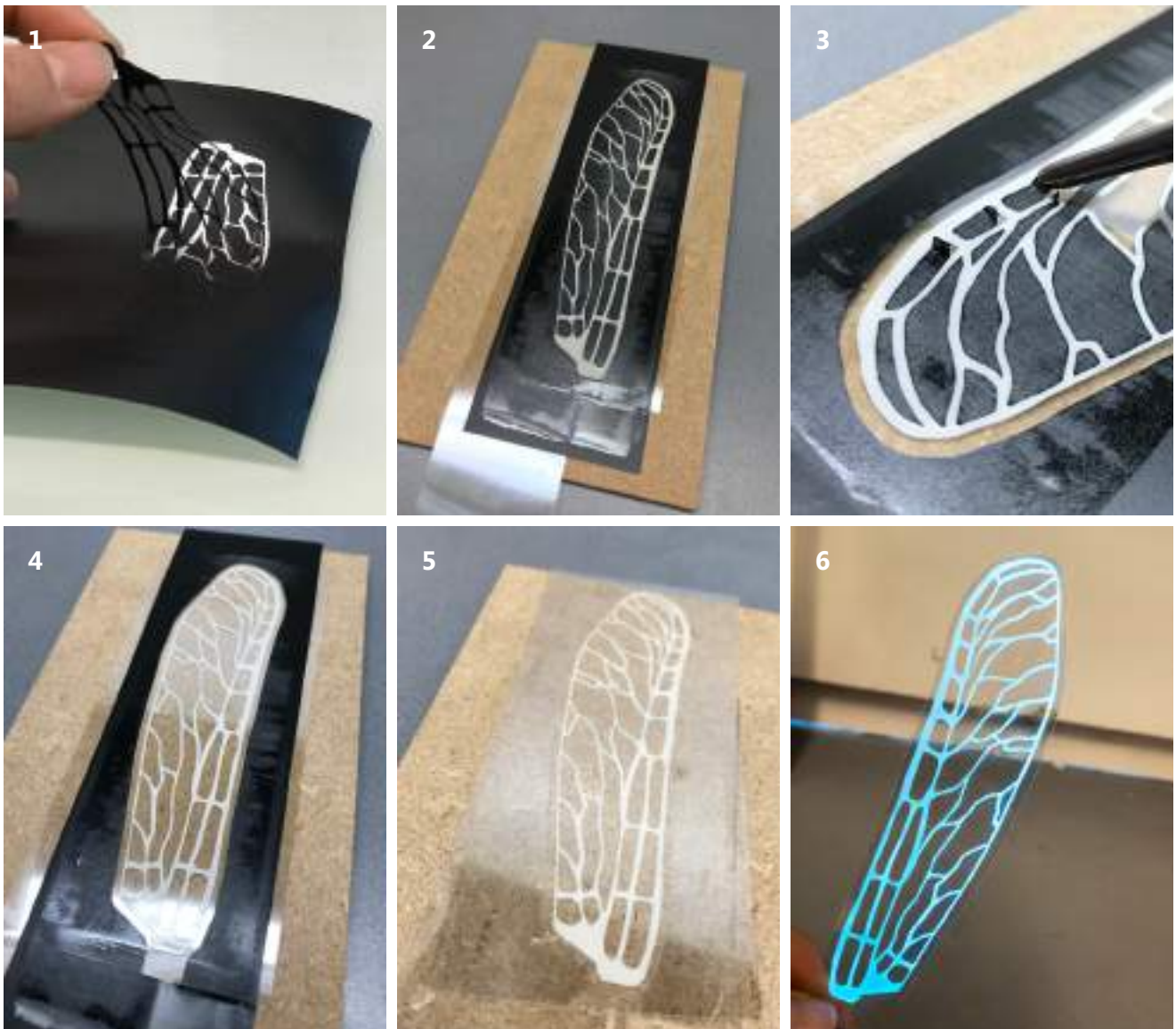
### Building the wings

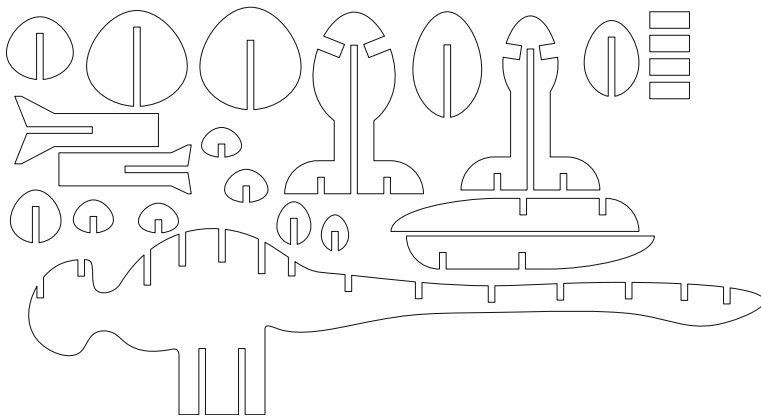
The construction of the wing follows method III-b. In Fig151 the main steps for the building are shown. Image three shows the removal of all the pieces of vinyl where the wing will be transparent. It shows why copying an actual dragonfly wing design would require the removal of many, tiny pieces of vinyl. After filling this space with the clear UV glue and curing it for a minute, the surrounding vinyl is removed. Then top piece of ITO

PET is then placed on top and the wing undergoes a final cure of two minutes. This should properly bond the different layers. Cutting off the redundant parts near the edge of the wing, produces a highly transparent result.

The small connections to the top and bottom electrodes are very fragile which resulted in multiple malfunctioning wings. By being more careful, this problem is solved and functioning wings can be produced.

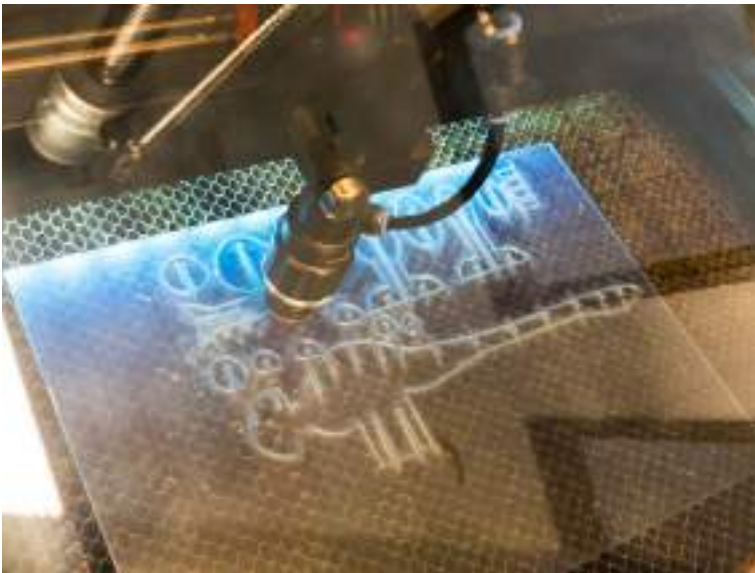
▼ Fig151. Four different configurations of the wings.





▲ Fig152. Illustrator file based on the SolidWorks parts.

▼ Fig153. Laser cutting the individual parts.



## Building the body

Using the files from SolidWorks, which are already made to scale, an illustrator file can be made that can be sent to a laser cutter (Fig152 and Fig153).

Initially the parts did not fit together properly. The slits that need to slide over each other were too large. This is caused by the digital file that has slits of 2mm which resulted in actual gaps slightly larger. The acrylic that is used is 2mm thick. Making small test parts, a digital slit size of 1.6mm has shown to provide a tight fit.

Once the parts are cut they slide into place, fixated by a small drop of super-glue (Fig154).

▼ Fig154. Dragonfly model



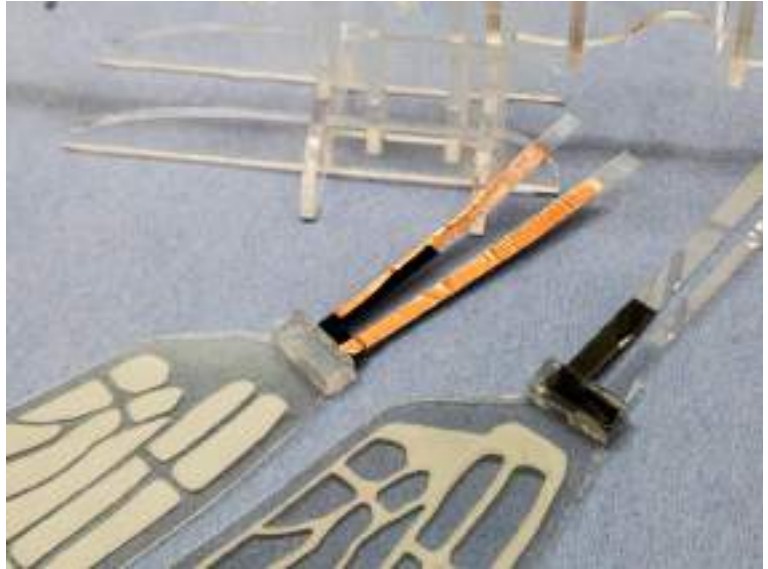


### Make it fit

The pieces of ITO PET that connect to the wings need to fit inside the model. This means cutting them to be only 3-4 mm wide. This is where the fragility of the ITO PET started to show again. Like the first test wings, once the connectors were cut to size, they started to fail again (the two types of wings can be seen working in Fig155). An attempt was made to fix this by wrapping copper tape around the pieces of ITO PET (Fig156). This did not help and with little time left I was unable to finish the model in time. Using the existing wings and an UV lamp an indication of what it should have looked like can be seen in Fig157. The UV light causes the phosphor particles to look like they emit light.

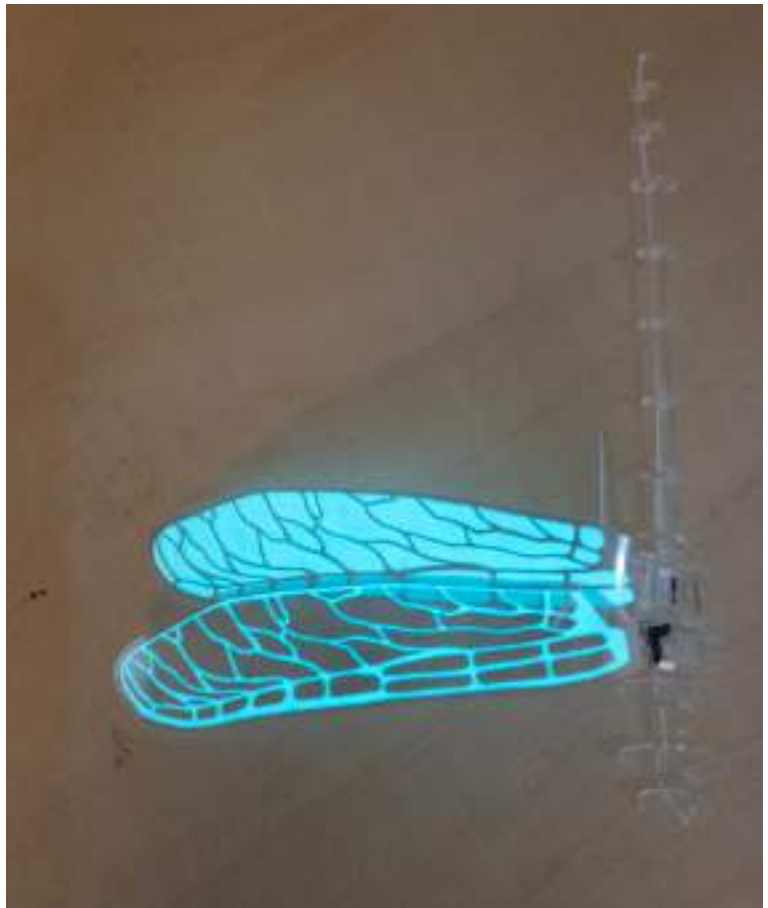
An render of how it should have looked like can be found in appendix 13.

▼ Fig155. The two different types of wings in working condition.



▲ Fig156. Copper on the connectors in an attempt to fix the malfunctioning wing.

▼ Fig157. Using an UV lamp to illustrate the attempted effect.



# Conclusion & Recommendations

## Conclusion

With the project goal in mind, create a method for DIY EL that takes fifteen minutes or less, it can be said that this goal has been reached. Providing two different methods, single or double sided emission, the quickest version can be done in twelve minutes. The other still only takes about twenty. User testing has validated this method, in both speed and success rate.

Comparing this to the screen printing method the results are similar. However the screen printing method does still have certain advantages over the new method, like tactile experience. The new method relies on at least one layer of ITO PET which has a smooth surface compared to the rougher, and thinner, layer of PEDOT:PSS used when screen printing. Concluding, it is best to look at the new method as an addition to the existing application techniques, as it lowers the barrier for student and designers to explore the possibilities of electroluminescent materials, and opens the door to the different properties of the other application techniques.

## **Recommendations**

While the new method works, improvements are still to be made. A short list of aspects that were not explored during the project, but might provide positive results, will be discussed.

### **Different UV adhesives**

Different adhesives have different properties. Trying out different adhesives with varying dielectric properties might increase the output.

The TP 1000N adhesive in the final part of the project has a low viscosity which creates difficulties when storing the mixture in a container. After a few days the phosphor powder collects on the bottom and forms a clay-like substance. Mixing it with the adhesive is possible but takes a lot of effort. This might be solved by using a UV adhesive with a higher viscosity.

### **Thinner vinyl**

In order to increase the output, or lower the required voltage, thinner vinyl could make it possible to make the layer of the UV mixture even thinner. The size of the phosphor grains should be taken into account but vinyl of 40-50 micron should be able to work. The boeklon used during testing is 50 micron thick but could not be put in the vinyl plotter.

### **Transparent Vinyl**

In order to create transparent panels, a layer of transparent vinyl could offer an solution. The current method for transparent panels relies on the removal of the redundant vinyl. This has to be taken into account during the design of the illustrator file and adds time to the creation process. Using transparent vinyl could remove the need for both steps, which reduces the total time required.

# References

## Papers

Kim, D., Kim, H., & Yoon, G. (2005). Effect of substrate and tackifier on peel strength of SIS (styrene-isoprene-styrene)-based HMPSAs. *International Journal of Adhesion and Adhesives*, 25(4), 288-295. doi:10.1016/j.ijadhadh.2004.10.001

Kim, J., Bae, M. J., Park, S. H., Jeong, T., Song, S., Lee, J., Han, I., Yoo, J., Jung, D., Yu, S. (2011). Electroluminescence enhancement of the phosphor dispersed in a polymer matrix using the tandem structure. *Organic Electronics*, 12(3), 529-533. doi:10.1016/j.orgel.2010.12.020

Larson, C., Peele, B., Li, S., Robinson, S., Totaro, M., Beccai, L., Mazzolai, B., Shepherd, R. (2016). Highly stretchable electroluminescent skin for optical signaling and tactile sensing. *Science*, 351(6277), 1071-1074. doi:10.1126/science.aac5082

Medling, S., Bridges, F., & Carter, S. (2013). Local degradation of electroluminescent emission centers in ZnS:Cu,Cl phosphors. *Journal of Luminescence*, 134, 251-254. doi:10.1016/j.jlumin.2012.08.037

Swart, H., Greeff, A., Holloway, P., & Berning, G. (1999). The difference in degradation behaviour of ZnS:Cu,Al,Au and ZnS:Ag,Cl phosphor powders. *Applied Surface Science*, 140(1-2), 63-69. doi:10.1016/s0169-4332(98)00356-0

## Books

Brockmann, W. (2009). *Adhesive bonding: materials, applications and technology*. Weinheim: Wiley-VCH.

Yen, W. M., Shionoya, S., & Yamamoto, H. (2007). *Phosphor handbook*. Boca Raton: CRC Press/Taylor and Francis.

## Other

Basics of light and lighting [PDF]. (2015). Philips

Ganslandt, R., & Hofmann, H. (1992). *Handbuch der Lichtplanung*. Wiesbaden: Vieweg.

Processing Guide for DuPont Luxprint® Electroluminescent Inks [Pdf]. (2012, May). Dupont.

Dielectric Properties of Polymers [PDF]. (2005). Zeus Industrial Products, Inc. .

Relative permittivity and dielectric breakdown (CES Edupack 2017).[2017]. Retrieved from software.tudelft.nl

## Internet

About UV-curing resins. (n.d.). Retrieved September 10, 2017, from <https://www.threebond.co.jp/en/technical/seminar/ucuringvresin.html>

Dielectric Constants at 20°C. (n.d.). Retrieved September 25, 2017, from <http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/diel.html>

EL delamination. (n.d.). Retrieved July 10, 2017, from <http://www.enactiveenvironments.com/exploring/el-construction/>

EL and Water. (n.d.). Retrieved September 12, 2017, from <http://www.enactiveenvironments.com/exploring/el-and-water/>

EL Paint Starter Kit - 4oz. (n.d.). Retrieved September 01, 2017, from <http://www.ellumiglow.com/electroluminescence/el-paint/el-paint-starter-kit-4oz>

EL Wire 2xAA Pocket Inverter. (n.d.). Retrieved June 02, 2017, from <https://www.cytron.io/p-ps-el-2aa>

Electromagnetic spectrum. (2017, June 16). Retrieved June 20, 2017, from [https://en.wikipedia.org/wiki/Electromagnetic\\_spectrum](https://en.wikipedia.org/wiki/Electromagnetic_spectrum)

Indium tin oxide coated PET 639303. (n.d.). Retrieved August 16, 2017, from <http://www.sigmaaldrich.com/catalog/product/aldrich/639303?lang=en&ion=NL>

Petrovan, B. (2013, April 30). Diamond Pixels: Galaxy S4's unique subpixel arrangement gets a close up. Retrieved September 27, 2017, from <http://www.androidauthority.com/galaxy-s4-display-diamond-pixels-199926/>

Relative permittivity. (2017, September 19). Retrieved September 20, 2017, from [https://en.wikipedia.org/wiki/Relative\\_permittivity](https://en.wikipedia.org/wiki/Relative_permittivity)

# A p p e n d i x



## Materials and equipment

This list contains all important materials and equipment used during this project.. All materials that have been acquired for this project through the manufacturer have the website added. All other materials were already available at the faculty of have been bought through regular channels (webshop or physical store).

### **MATERIALS**

#### **Phosphor**

Shanghai Keyan Phosphor Technology Co.,Ltd.

[www.kpt.net.cn/](http://www.kpt.net.cn/)

D310B

D417B

D512B

D611B

#### **ITO PET**

Mianyang Prochema Commercial Co.,Ltd.

[www.itopop.com](http://www.itopop.com)

80 micron (120ohm)

25 micron (150ohm)

Sigma-Aldrich

ITO PET 125 micron (60ohm)

#### **UV adhesive**

Loon outdoors UV Wader repair

Bison Glass glue

Generic LOCA glue - TP 1000N

#### **Double sided tape**

Tesa

[www.tesa.com](http://www.tesa.com)

Tesa 5338 (consumer tape)

Tesa 4972

Tesa 4959

Tesa 4900 PV9

**3M**

467MP - 200MP

Teraokatape

[www.teraokatape.co.jp](http://www.teraokatape.co.jp)

7054 (6 micron)

7072 (5 micron)

#### **Conductive tape**

**3M**

Electrically Conductive Adhesive

Transfer Tape 9703

#### **Silicone**

Smooth-on

Smooth-On Dragon Skin 20

**Double sided silicone tape**

PPI tapes

[www.ppiadhesiveproducts.com](http://www.ppiadhesiveproducts.com)

RD-449

#### **Hot melt foil**

Thermoweb

[www.thermowebonline.com/](http://www.thermowebonline.com/)

iCraft Hot Melt adhesive

PPI tapes

RD-461

Biederman GmbH

[www.biedermannngmbh.com/](http://www.biedermannngmbh.com/)

Digimount

Fusion Plus

Fixmount ultra

#### **Hot melt powder**

Intercol

[www.intercol.eu/adhesives/](http://www.intercol.eu/adhesives/)

HMA powder for PET

### **EQUIPMENT**

UV Lamp

Philips Studio HB 311 (HP 3205)

Containing 5 TL lamps

TL44D25/09N

Vinyl cutter

Roland GS-24

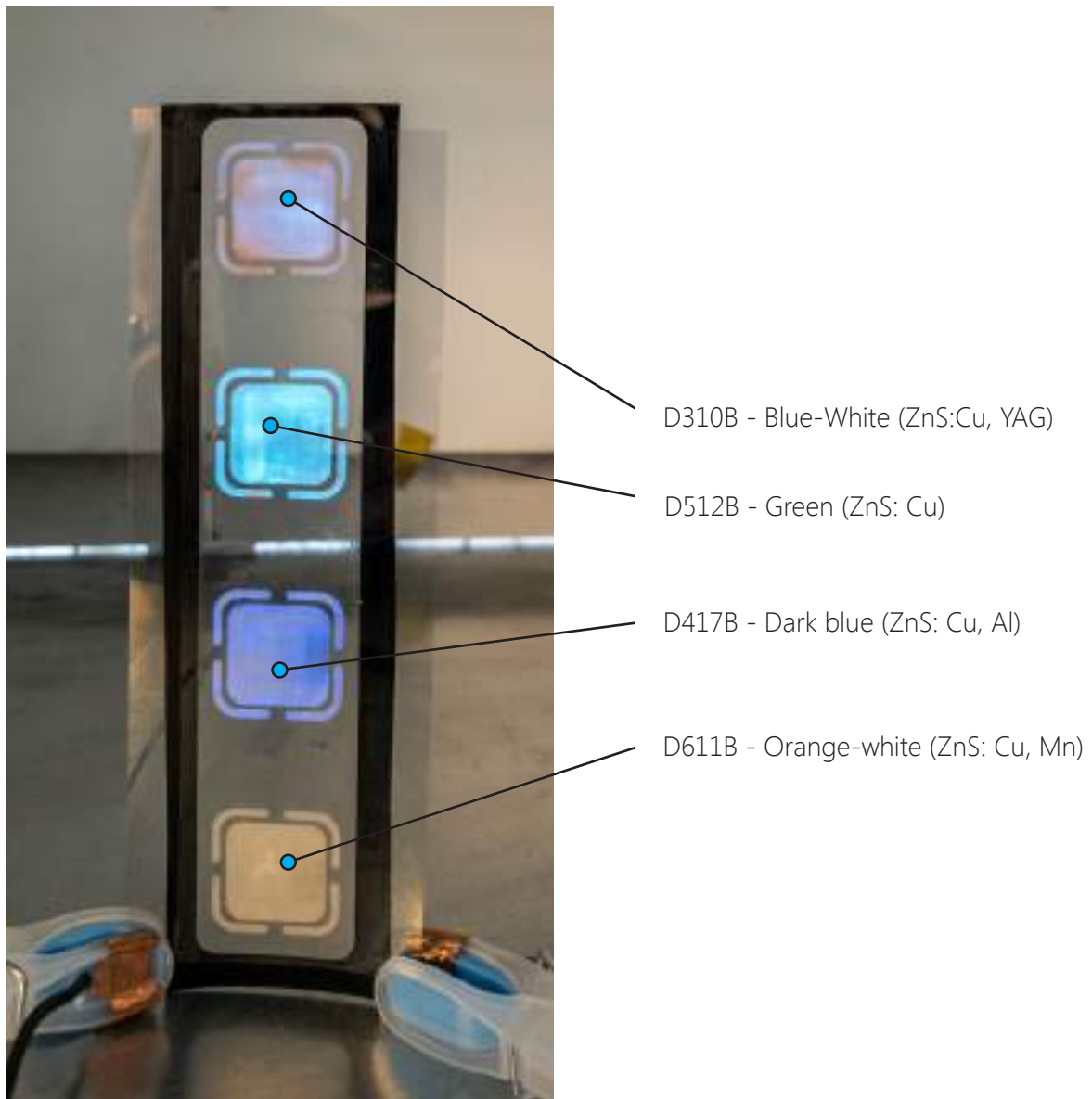
Length gauge

HEIDENHAIN-METRO MT 1281

## Appendix 2

### Colours

The colour indicated by the manufacturer does not all match with the actual colour. The 310 and 417 do match but the 'green' 512 is more a bright blue and the 'orange-white' 611 is a dim yellow.



## Appendix 3

### Testing ultra thin double sided tape

By the time the ultra thin double sided tape of Teraoka arrived, which measured 5 and 6 micron thick, the project had already reached the phase where the UV curable adhesive was tested. Creating samples using the UV mixture was easy and without the samples used in the initial double sided tape test, the samples used for this quick test were made using the UV mixture.

The samples were made from a single layer of the mixture placed directly on top of the ITO. A layer of the double sided tape was then placed on top followed by a piece of ITO PET with the ITO facing the tape. A similar setup as the original test.

This showed that the tape, due to the extreme thinness, could perfectly function as dielectric layer. The lack of emission in the middle of sample (Fig141) was caused by the uncured UV adhesive (caused by oxygen inhibition). The uncured adhesive caused poor adhesion of the tape to the phosphor layer, it also caused air to get trapped underneath. By creating a small sample (Fig142) and pressing this against a piece of glass (Fig143) the sample did emit light in the centre. During normal condition it did not.

Although it can work for the dry layering concept, at the time of the project the UV mixture was chosen to continue with which made the tape to be left for what is was.

Fig141The first test sample shows large areas without emission.

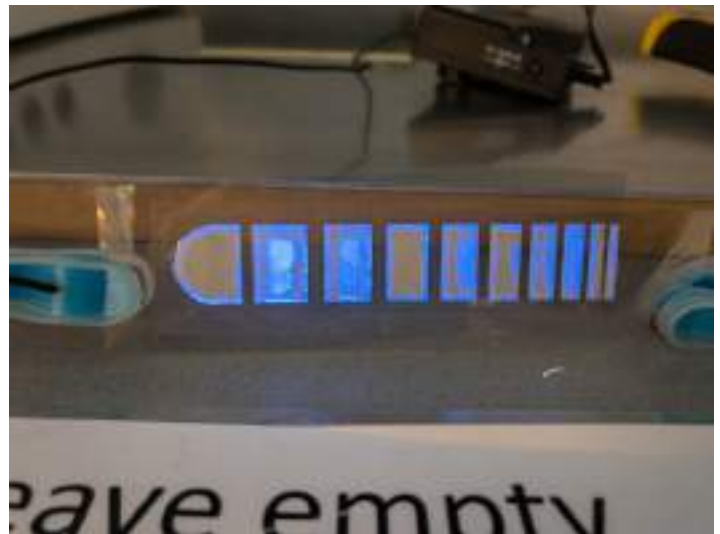


Fig142Test sample 2.



Fig143Sample 2 pressed against a piece of glass.



## Appendix 4

### Silicone sheets

In a first attempt to create thin sheets of silicon a screen printing mesh was used. After mixing the two parts of the dragon skin 20 mixture it was spread across a standard screen printing mesh and applied to a sheet of plastic. Once cured, it was able to release from the plastic easily (Fig144).

However, the layer was very difficult to handle. It started to stick to everything it came into close contact with and also easily stuck to itself.

Besides the difficult handling, this method destroyed the screen printing mesh, the silicone could not be removed with the equipment available.

---

Fig144Thin sheet of Dragon Skin 20 made using a standard screen printing mesh.



## Appendix 5

# Hot melt adhesive sheet

Hot melt adhesives, HMAs, are produced in different forms. In this test thin sheets are used. Used in different industries, e.g. clothing or electronics, to laminate substrate creating thin structures this principle might also be applicable for use in EL devices. Besides bonding the different layers, also working as dielectric, it might also be usable as medium for the phosphor particles. This can decrease the amount of layers that are required since the HMAs can potentially double as dispersion medium and adhesive. Because of HMAs consists mostly out of thermoplastic polymers there are many different types of HMAs and like all

adhesives not all HMAs are suitable for bonding every type of substrate. Manufacturers advise customers to test their HMAs on the substrates it will be used on.

Because of the potential application of HMAs, solely adhesive/dielectric or maybe functioning as dispersion medium as well, and the unclear factor of how well different HMAs will bond with the substrates, multiple tests will be done using different sheets of HMA.

First the bonding strength of the different HMAs to the ITO side of the PET ITO sheets will be tested. Next one of the HMAs will be tested on how it can be used as medium for

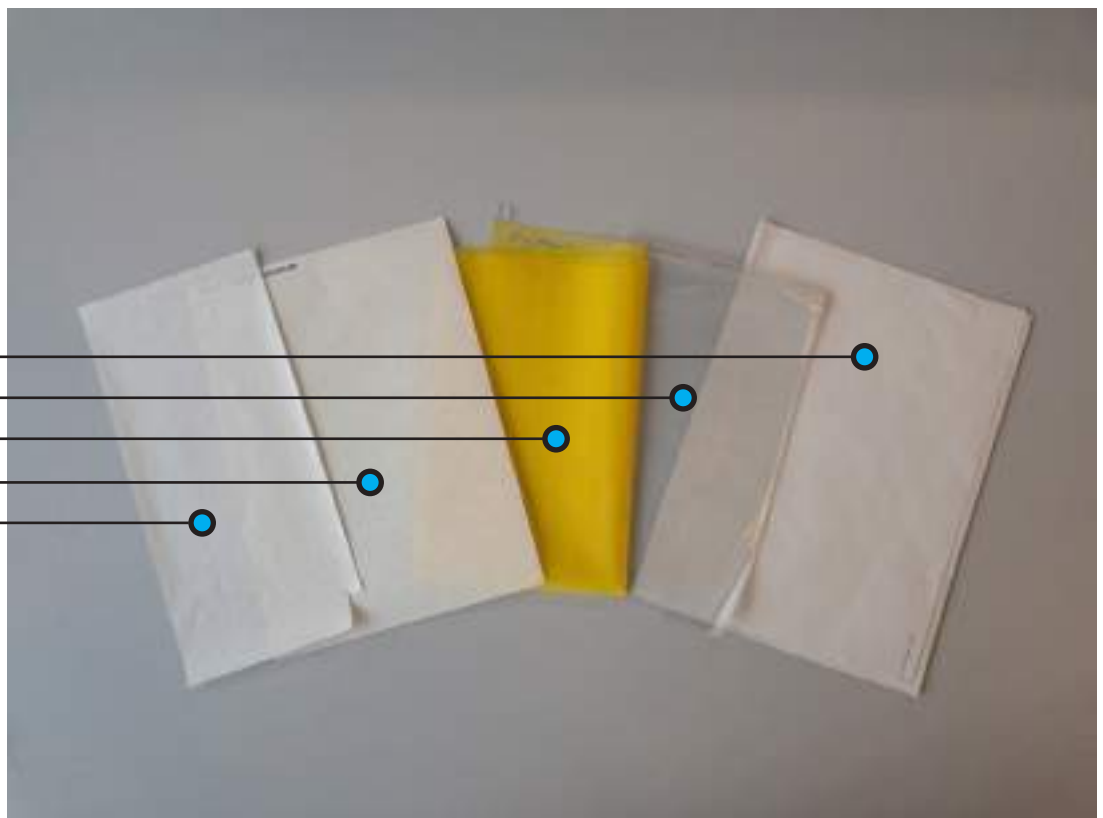
the phosphor particles to adhere to.

### Materials

Acquiring the different types of HMAs in sheet form turned out to be more difficult than expected. Because of the electric field getting weaker as layers increase in thickness thin sheets of HMA are necessary, this meant that the maximum thickness of the sheets was 50 micron. Searching for companies that produce thin sheets of HMA led only to European companies that require a minimal order quantity (in the order of multiple hundreds square meters if product) since they often were a special order product which meant that they are

Fig145Five different types of HMA sheets side by side.

Fixmount Ultra  
Fusion Plus  
DigiMount  
RD-461  
iCraft



not in stock and are produced on request only. Asian producers seem to produce many different types of thin sheets of HMAs, searching with alibaba.com, but shipping from Asia takes days and shipping small packages costs a minimum of 50 dollars. These factors are far from ideal and therefore the Asian manufacturers were a back up in case nothing was found. Luckily, after multiple long searching sessions, multiple companies based in Europe were found that produce a form of HMA. Although finding them was not easy as they could not be found by searching for 'hot melt adhesive' because the companies does not sell them as that. For example the company Biedermann Gmbh sells them as heat mounting films and the company PPI does so as heat activated transfer adhesive tapes. Both companies were kind enough to send samples of multiple HMAs. Finally a commercially available HMA was found sold by therm-o-web. In total five different HMAs are tested on their ability to bond to both sides of the ITO PET sheets, Fig145.

#### HMAs used

- iCraft Deco Foil Hot Melt Adhesive
- PPI RD-461
- Biedermann Fixmount Ultra
- Biedermann Fusion Plus
- Biedermann Digimount



Fig146Preparing the samples. Keeping track of the PET side by writing a P on that side. When placed on top of each other both P's should align indicating both an ITO and PET side are facing the HMA.

#### Heat source - Iron

- Tefal FS4020 - 1200W

#### **HMA sheet test procedure**

Each of the HMAs is tested by cutting off a small piece and placing this between two layers of ITO PET, Fig146. One layer will have the ITO side face the HMA and the other layer will have the PET side face the HMA. A piece non stick parchment paper, supplied with the iCraft HMA, is placed on the top and one at bottom of the sample. This is done to prevent the surface of the iron to directly contact the sheet of ITO PET and to prevent molten HMA from contacting the iron.

The iron is set on high setting heating it up to just above 200C. It is then placed on top of the sample with firm pressure for 60 seconds. After each test the sample is measured on

overall thickness. The samples are bend to test flexibility. Finally the two sheets of ITO PET are pulled slightly apart to test on how easy the construction will de-laminate. This test is done to quickly determine if the HMAs provide a poor, acceptable or good bonding properties the PET and ITO.



Fig147Delamination of Digimount, showing poor adhesion to ITO.



Fig148Right: Measurements of different HMAs as given by the manufacturer and own measurements followed by the measurements of the samples once they were cooled down.  
 Fig149Down: Bonding of HMAs to PET and ITO

Adhesion to:	PET	ITO
iCraft	+	+
RD-461	-	-
Fusion Plus	-	±
Fixmount Ultra	-	±
Digimount	±	±

### Adhesion test results

Measurements of the sample before and after the heating took place are shown in Fig148.

Non of the samples were very easy to bend. Not much force was applied since the samples still needed to be tested on how well the HMA adhered to the PET and ITO.

Testing all samples on how well the HMA bonded to the PET and ITO has given two types of results. It either bonded well with one of the two surfaces and not so good with the

	iCraft	RD-441	Fusion Plus	Fixmount Ultra	DigiMount
Specified Thickness	-	25	50	50	50
Measured Thickness	50~120	20~25	45~50	80~100	40~45
Sample Thickness	315~340	280~290	310~320	335~350	295~315
Heated HMA Thickness	55~80	20~30	50~60	75~90	35~55

other or it bonded with both types of surfaces. The latter can go from adhering better to ITO or better to PET. None of the HMA bonded about equally to both surfaces, results are noted in Fig149. Images of how the lack of bonding or partial bonding looked like can be seen in Fig147 and Fig150.

### Adhesion conclusion

Looking at the thickness of the HMAs after heating the minimum thickness remained approximately the same. Only the iCraft seemed to become thinner, this is likely due to the highly

textured surface of this material. The maximum thickness for most HMAs is increased, this can be because air gets trapped between the HMA and the ITO PET adding to the overall thickness.

Bendability was not good. This can be because the sample is to small to bend properly and using thinner PET will probably also improve bendability.

Only the adhesion of the iCraft and Digimount have potential in being used for EL devices. The other HMAs did not provide a good bond to both ITO and PET and in the case of the RD-441, it bonded well with the PET but the bond with the ITO was really bad.

### Adhesion discussion

Measuring the HMAs before heating might not be accurate. Some



Fig150Two different HMAs bonding to both or one surface.

of the HMAs were a bit soft which can cause the measurement device to cause the surface to be dented slightly, due to the force of the device being focused on a small area, causing the measurement to be lower than it really is. This effect will be less pronounced after it is heated since the layer of ITO PET will distribute the force over a larger surface area reducing indentation of the HMA. An extra sample that was longer showed improved bendability. Thinner PET was not tested.

### Phosphor addition procedure

This test was performed with the iCraft Deco Foil as this was the first material available for testing. The other sample materials took a few weeks to arrive. The principle of phosphor adhering to the HMA is likely to be also applicable to the other sheets of HMA and looking

at the bonding properties only the DigiMount is similar but is not significantly thinner.

Two methods of using the HMA as medium for the phosphor and one method to decrease the layer thickness are tested.

The first uses a layer of HMA covered with phosphor powder on top of which another piece of HMA is placed. This is heated, iron set to high, and put under pressure for 60 seconds. Just like the adhesion test the sample is placed between Two pieces of parchment paper. This is meant to bond the two layers of HMA trapping the particles in the middle. This single sheet is then placed between two pieces of ITO PET, with the ITO side facing the HMA since the HMA can double as dielectric, and heat is while applying pressure.

The second test uses a single layer of HMA that is covered with phos-

phor powder. This is heated using the iron on the high setting and put under pressure for 60 seconds to try to press the particles into the HMA. The rest of the procedure follows the same directions as the first test. This test is followed by a small third test to find out if the thickness of the HMA layer can be decreased by creating space for the molten HMA to flow to. This is done by creating a sample using the single layer method and cutting this in rectangular pieces that are placed slightly apart. These are heated and put under pressure like the first and second test.

### Phosphor addition - results

Using two layers of HMA to encapsulate the phosphor yielded a unusable sample, Fig151. Only on the edge of the small electrode a few particles emitted light. This is likely because increased pressure on the edge of

Fig151Left: Method one for using HMAs to trap phosphor particles, distance between the electrodes at the emission center is 75 micron.

Fig152Right: Second method for using HMA to trap phosphor particles, distance between the electrodes at the brightest emission center is 55 micron.



the electrode caused the HMA to be pushed to the outside where it can flow more freely. This decreases the layer thickness causing the electric field to be higher at that location.

The second test, using a single layer, gives a sample that emits a small amount of light over the entire surface, barely noticeable, and again a higher output near one of the edges due to decreased layer thickness, Fig152.

The third test showed the highest output with, again, the highest output near the edges. Not all of the space between the pieces of HMA has been filled causing an inhomogeneous emission across the sample, Fig153.

### Phosphor addition - conclusion

It has been shown that using HMA as medium and dielectric can be used to create working EL devices. However the emitted light is inhomogeneous and making the HMA flow evenly has shown to be difficult. The hot melt on the edges of the samples has more space to flow causing higher emissions near the edges and lower in the middle, both in the second and third test a clear dark spot can be seen in the middle. Beside the unequal spreading of the HMA one side of the sample has a higher output which shows the difficulty of making the layer flow evenly using an iron.

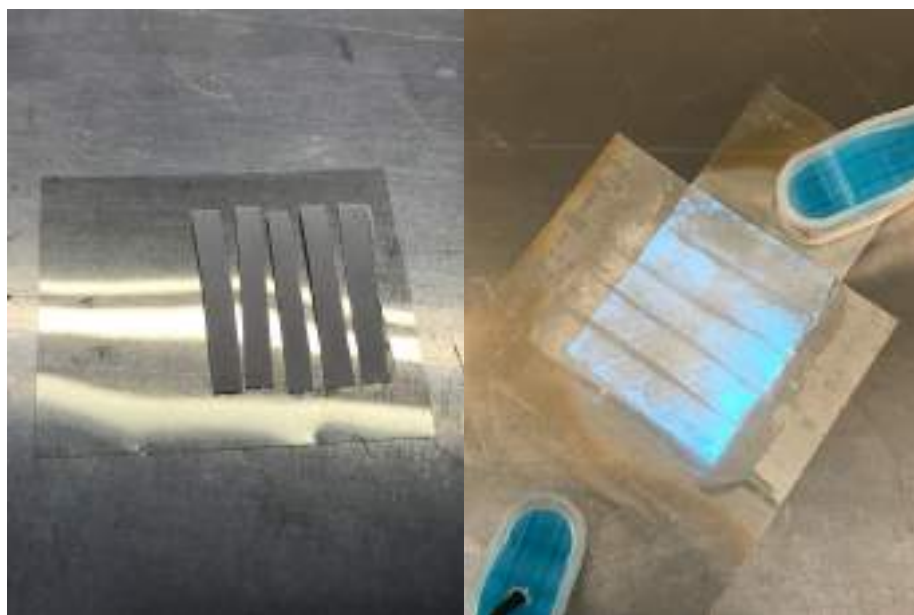


Fig153 Preparation and testing of the final sample. The strips are cut and placed between two pieces of ITO PET and heated until the HMA stopped spreading.

### Phosphor addition - Discussion

Using the iCraft HMA was not ideal since it is the thickest HMA but thinner HMA will probably behave very similarly, flowing more freely near the edges creating a lower output in the middle. Recreating this test using one of the 50 micron HMAs would probably result in a slightly higher output as the electric field will be stronger.

Using the sheet of HMA for detailed custom EL devices is probably not ideal. Once heated the edges of the HMA layer will start flowing to the outside losing detail in the process. However if a (thin) HMA can be found that has good adhesion properties to ITO this method has potential for being used in simple shapes.



Fig154 Applying heat over a longer period of time improved the output but the centre remained significantly darker than the edges.

## Appendix 6

# UV curing adhesive

Searching for materials that can be used to mix with the phosphor and need an external activator led to testing with UV curing materials. These materials remain liquid as long as they are not exposed to high levels of UV radiation. Once exposed to sufficient levels UV radiation the material start to harden immediately. Some can reach their hardened state in a matter of seconds.

This all means the phosphor can potentially be mixed and stored for future use and directly applied when necessary. Because the application method used with the HMA powder was successful the decision was made to use this for this experiment as well. Another method of applying the mixture could be using screen printing but since the goal of the

project is to move away from screen printing this is not tested.

Because UV curing adhesives can be easily bought two different brands of adhesive were acquired, tested and compared on their respective performance, Fig53 .

### Materials used

The two UV curing adhesives that are used in this experiment are:

- Bison Glass glue
- LOON UV Wader repair

These are chosen for the different properties the manufactures claim the products have, Fig155.

The Bison glue is actually meant for mending broken glass. They state it will fully harden in 5 minutes (or less depending on the intensity of the UV light and using a lamp that emits between a wavelength of 250 and 350nm). It is also readily available at local hardware stores.

The LOON UV wader repair is meant

to quickly close holes in waders (watertight boots that can reach up to the chest) and should harden within 15 seconds. According to the manufacturers website it should be 'soft and pliable' once hardened.

Because the two materials have different purposes, one fixes broken glass ( a stiff material) and the other closes holes in clothing (a flexible material), they will probably have different properties making it interesting to examine the results and determine the practical application when it comes to EL.

### Curing speed and bonding quality

Although the curing times are given by the manufacturers the time it takes when placed between two pieces of ITO PET is determined by simply applying a small drop on top of a substrate and place it underneath an UV lamp for 10, 60 and 300 seconds, Fig156. The difference between each step is noted to determine if change is still taking place.

Fig155Left: The two different tubes of UV adhesive

Fig156Right: Three of the six samples partially prepared for testing (blue protective foil was removed before the samples were placed underneath the lamps)





Both types did not seem to be fully cured after 10 seconds. After 60 seconds both types seem to have fully cured since the step to 300 seconds resulted in no further change.

Next the bonding properties of each adhesive to PET and ITO is tested. This is done by making three samples for each adhesive, Fig58. The samples are placed in an ITO-ITO, ITO-PET and PET-PET configuration. They are then placed underneath the UV lamps for 60 seconds taking into account that the ITO and PET might (partially) absorb UV radiation. Bonding properties are tested by manually pulling the samples apart. This showed that the Bison glue bonded well with the ITO but poorly with PET. For the Wader it was the opposite, providing a better bond with the PET than with ITO. The Wader also showed to be a bit more flexible as can be expected based on the manufacturers description.

### Test setup

Because the Bison glue has a lower viscosity it, making it easier to mix with the phosphor powder, and overall slightly better bonding performance the tests are done using this adhesive. When spreading both mixtures behaved similar as can be seen in Fig37.

The test setup is similar to that of the

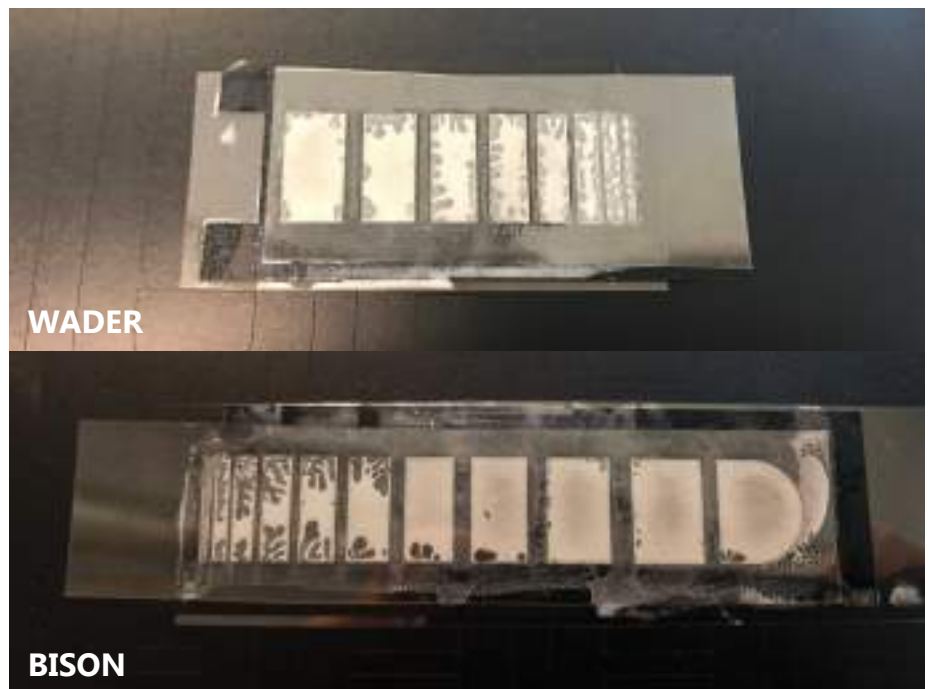


Fig157 First samples made using the Wader and Bison solution, similar spreading.

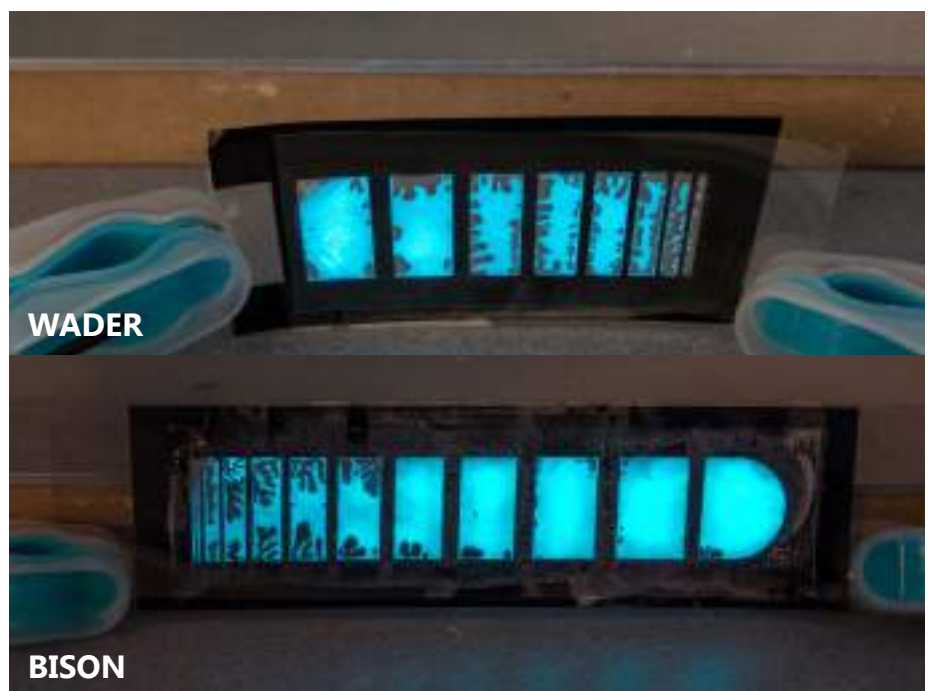


Fig158 First samples made using the Wader and Bison solution, similar output.

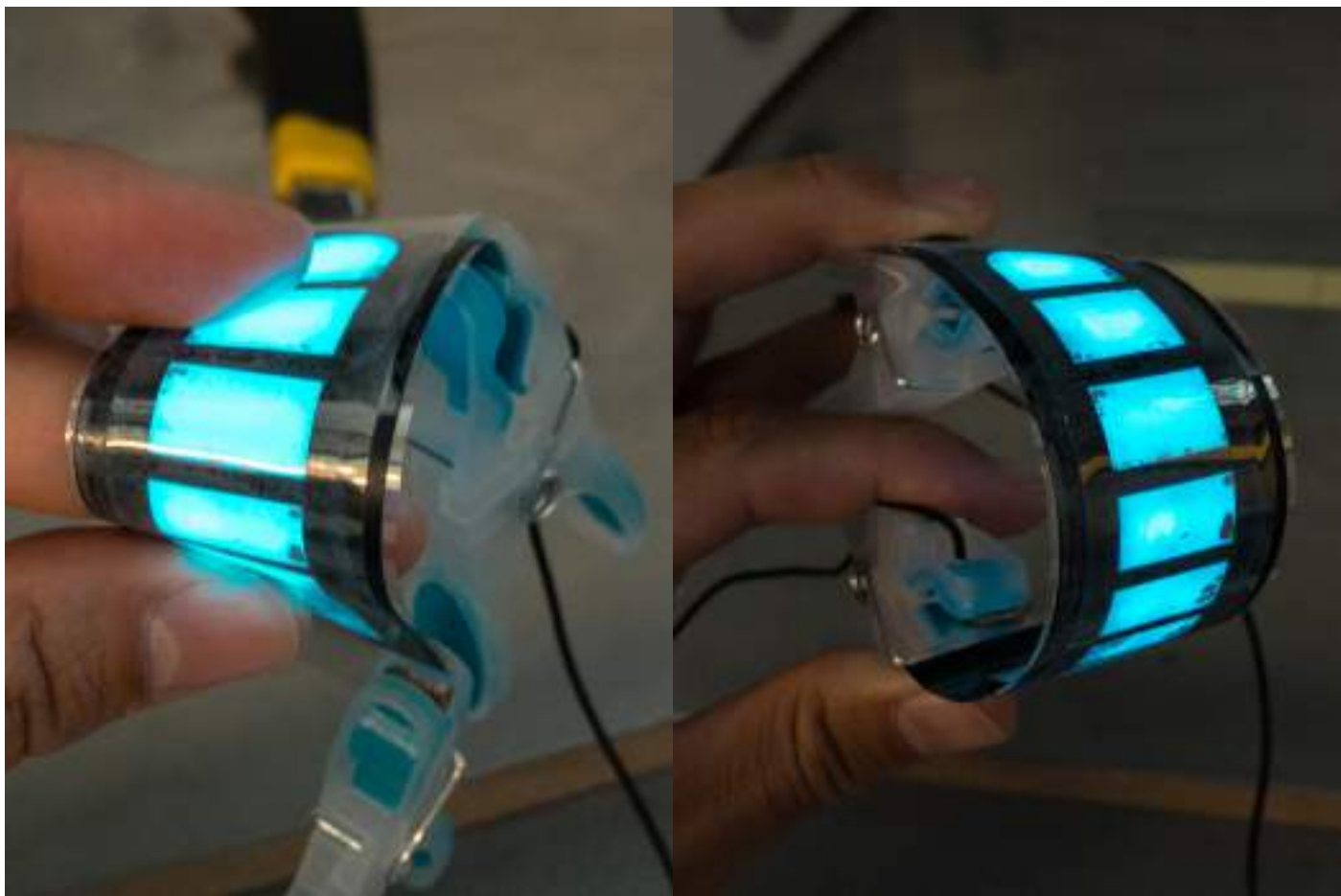


Fig159Left: Test sample immediately bendable after curing for 60 second. Right: Same sample still bendable and no delamination after two days.

test with HMA powder. First testing the properties as dielectric by placing the same pattern cut from vinyl on top of the ITO side of a strip of ITO PET. Adding a small amount of the mixture which is spread to properly cover the cut-outs removing any excess material. Place another strip of ITO PET on top, ITO facing down and let it cure underneath the UV lamp for 60 seconds.

If this does not work the 25 micron ITO PET will be used in order for the PET layer to function as dielectric. Like with the HMA powder the test will be performed after trying to remove the vinyl without disturbing the mixture deposit.

### Test results

The first test already showed that using the UV glue as dielectric is effective. After curing for 60 seconds it immediately was usable as a bendable EL device, Fig159, providing sufficient light output (the wader was tested on this as well and provided similar results, Fig158). Bending the sample in the short axis direction seemed to cause no malfunctions in the device. However not all sections were covered properly. Notable were the smaller sections that clearly were not covered with the mixture properly. Sections 1 to 6 showed bad coverage. The other sections only had small holes where no adhesive was present after curing, Fig158.

Looking beyond the holes in the emissive layer it can be seen in Fig86 that the centres of the larger sections are putting out more light than the edges. Holding this sample against the light, power turned off, shows that the parts that emit the most light are also more transparent than the parts near the edges. This is because the thickness of the mixture is approximately 40 micron thinner in the centre.

Another similar test was done while more generously applying the mixture to a part that only has the smaller sections while also replacing the regular PET ITO sheets (130 micron) with the 25 micron PET ITO to see





Fig160Bison sample turned on and held against the light. It is clearly visible that the brighter parts are more transparent. Measurements showed that these parts are also significantly thinner.

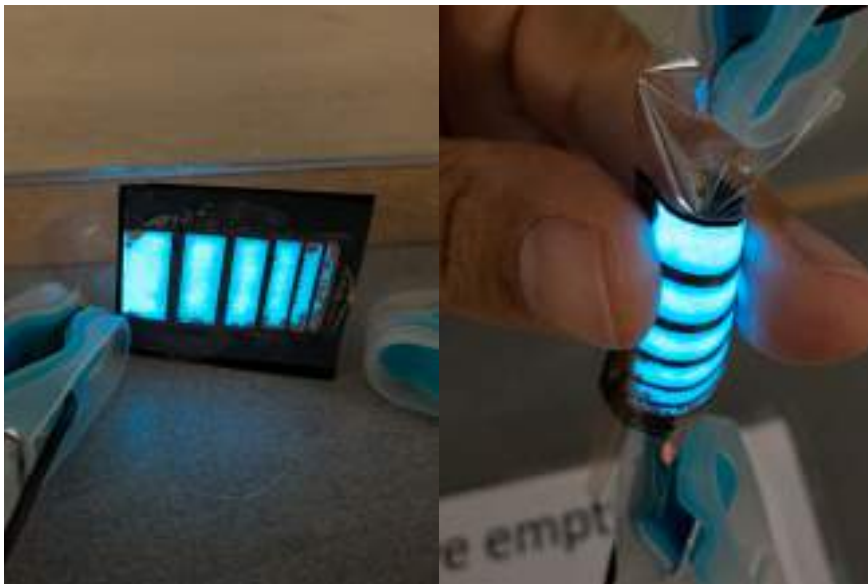


Fig161Bison sample turned on and held against the light. It is clearly visible that the brighter parts are more transparent. Measurements showed that these parts are also significantly thinner.

what effect this had on the ability to bend. This led to a sample that had better coverage on the small sections, although the 1 mm section still had a bad coverage. This sample also had a significantly larger ability

to be bend in any direction without malfunctioning as can be seen in Fig161.

Both samples were tested two days later to see if the bond between the layers had deteriorated like the HMA

powder samples but they appeared to function the same as the day before.

Even though the UV glue can be successfully used as dielectric the second test, using the PET as dielectric was performed to see the difference in light output, moreover the distribution since the first method has slightly brighter centres.

After removing the vinyl the mixture that was left showed very clear and tight lines which could potentially enable fines details, Fig162. This was undone once the second ITO PET was placed. Everything got pushed to the sides almost fully combining the smallest four sections, Fig163. On the larger sections it is also clear that air got trapped between the mixture and the ITO PET. The output is low compared to method one and the brightness is reversed, i.e. the edges are slightly brighter. The test is not repeated with the vinyl still in place because the assumption is made this will lead to similar results as the first test only with a lower output due to the added 25 micron thick PET layer.

## Conclusion

The output of the sample that use the adhesive as dielectric have a sufficient output although the spreading should be better to prevent empty spots inside the lighting areas. Using the thin ITO PET made the entire device very flexible.



Fig162 Removing the vinyl left the deposited untouched. Providing clean straight lines.

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Fig163 The top part of the sample does not emit light because the top piece of ITO PET was cut to narrow. The top part is above the red line.

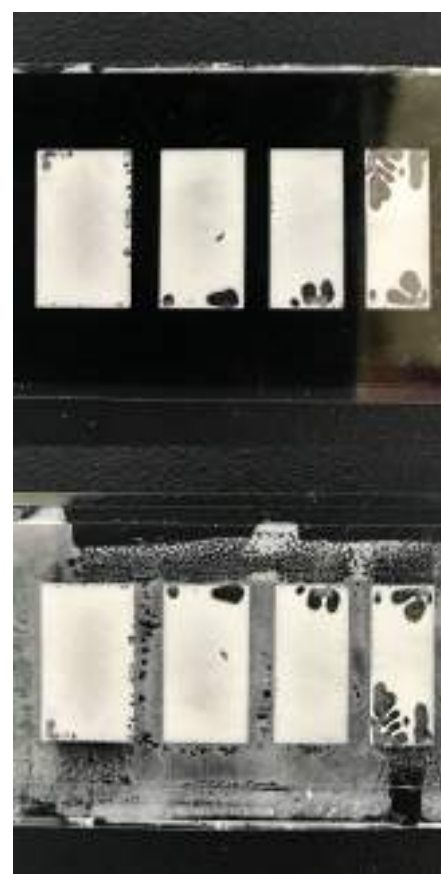
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Using the ITO PET of 25 micron as dielectric layer did create a working EL device but the output is very low and not really usable.

### Discussion

If an easy solution can be found to create a better distribution of the phosphor mixture using the first method, preventing holes in the light emitting areas, this method has a high potential as a quick and easy method of creating EL devices. A downside right now is that it is not suitable for transparent EL devices. Using transparent vinyl (or another material) for creating the stencil could be used to create transpar-

ency. However this would create a new challenge in using this method while keeping the area surrounding the cut-outs clean. When making the samples this was not a focus point as can be seen in Fig164.




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Fig164 Front and back of the first sample.



## Appendix 7

# Light measurement

The human does not have the same sensitivity for different colours. This means that two light sources with a different colour, that emit electromagnetic radiation with the same amount of energy, can have a different perceived brightness.

This effect is mainly caused by the sensitive to different wavelengths of the different cones (the cells that are responsible for registering different colours) in the human eye (Fig166). The perceived brightness of different colours changes slightly as the environment becomes dark enough.

This is caused by the rods (the cells responsible for low light vision), that have a slightly different sensitivity to different wavelengths compared to the cones.

In order to make the difference in brightness between the different colour samples more concrete, the brightness will be measured using a luminance meter (Fig165). This is a tool that allows the measurement of light emitted from a source and convert this to a value that corresponds with the sensitivity of the human eye.

The measurements are used as an indication of the difference between the different samples. They are not meant to measure the exact output of each sample. This is why the following setup will be sufficient.

All samples are placed in an upright position on a matt surface to decrease light scattering which improves the measurement (Fig167). This position enables the luminance meter to be aimed as perpendicular as possible to the sample (Fig168). A circle is visible when looking through the luminance meter. This is an indi-

Fig166General sensitivity to colour of the human eye in a bright environment (black) and in a dim environment (green) ([https://en.wikipedia.org/wiki/Luminosity\\_function](https://en.wikipedia.org/wiki/Luminosity_function)).

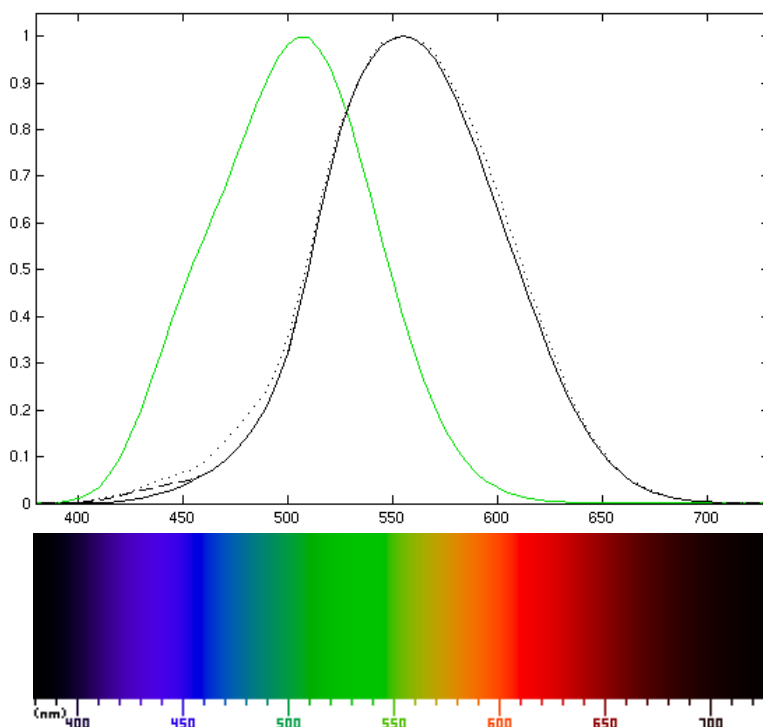


Fig165Minolta luminance meter LS-100.



cation of the area that will be measured. Since all samples have the same dimension, the circle will be aligned to fit on the sample as is visible in Fig170.

During the measurement the value fluctuated slightly. The highest reading on each sample is written down (Fig169).

Results

The results show that the blue phosphor has an output that is significantly brighter than the yellow phosphor

even though the yellow phosphor has a double concentration.

Conclusion

Mixing with the yellow phosphor will be difficult since the output of the yellow phosphor is very low. Mixes that require only a little amount of yellow should be fine. If more yellow is required the ratio of yellow and the other colour(s) will shift towards the yellow, which will lead to a lower output. Without a measurement of the exact spectrum of each sample it

is difficult to determine if the yellow phosphor is less efficient in converting the electric field into light, or that the human eye is less sensitive to the light that is emitted by the yellow sample.

Fig167General setup for the luminance measurement.

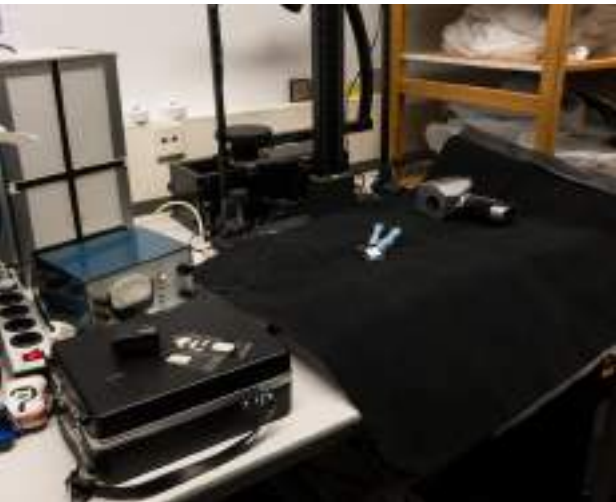


Fig168Schematic of the measuring setup

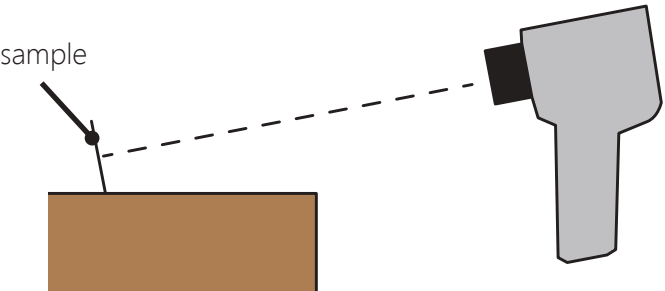


Fig169General setup for the luminance measurement.

Sample	Phosphor volume percentage	Luminance in cd/m2
Blue	15	26.9
Yellow	30	5.4
50/50 mix	22.5	16.8

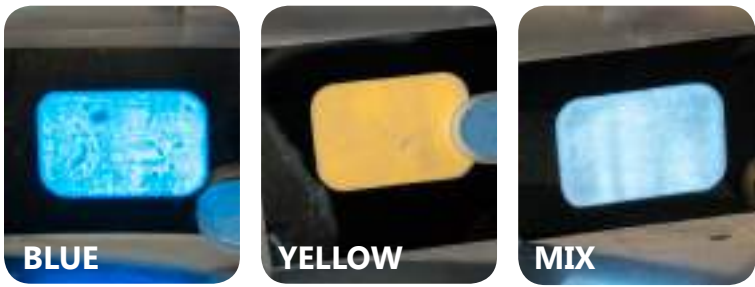


Fig170Measured area per sample, indicated by the orange circle.



## Appendix 8

### Water interaction sample

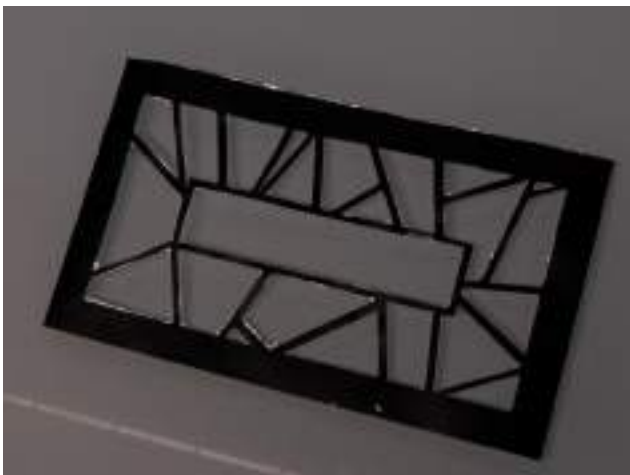
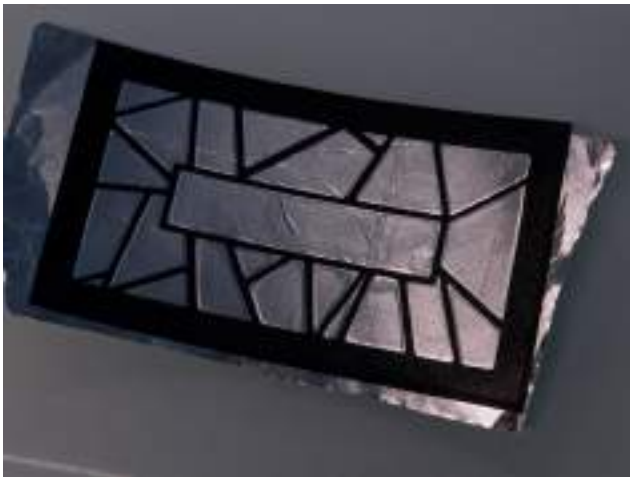
Constructed by creating a large rectangle of the UV mixture and letting this dry while in contact with air.

A piece of aluminium foil is attached to a piece of vinyl that already has cut outs through which light can be emitted. Initially the aluminium foil covers the whole piece of vinyl but only those parts that are covered by the vinyl remain, the rest is care-

fully removed. This is placed on top of the still sticky surface of the partially cured layer of UV mixture. The sample is flipped and cured again to bond the two parts together.

The thin layer of aluminium foil between the vinyl and phosphor layer is enough to charge the water that come into contact causing emission.

Fig171 Placing and removing excess aluminium foil. When turned on from the back emission can be seen where aluminium foil is located. Water that touches the grid



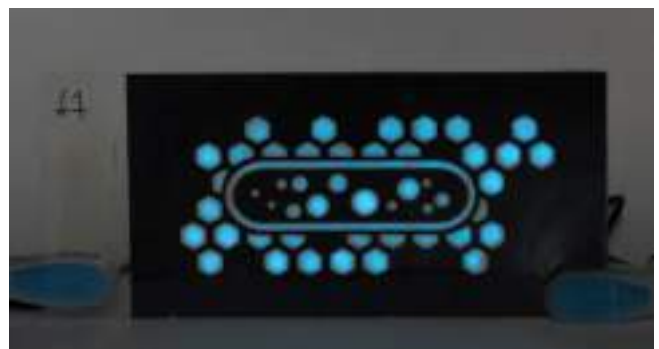
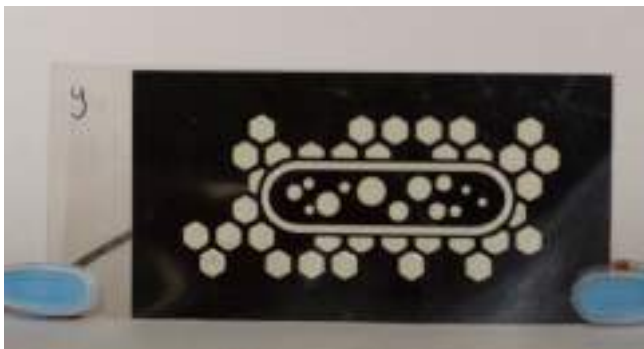


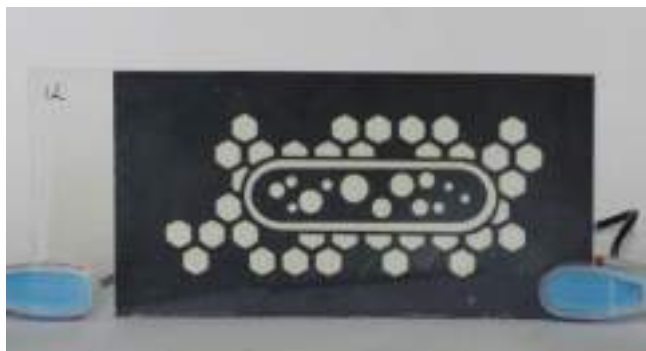
Appendix 9  
Workshop

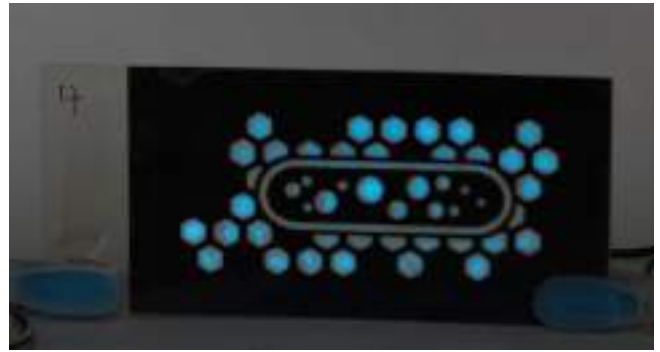
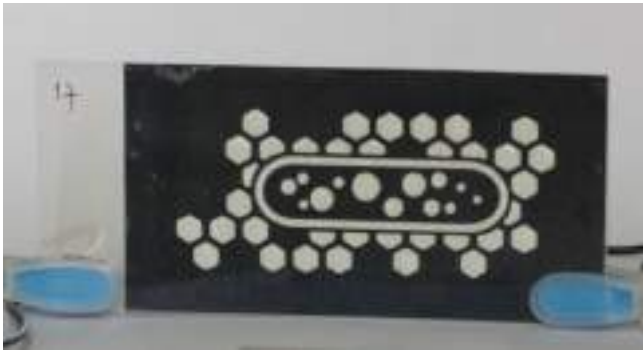
Off

On







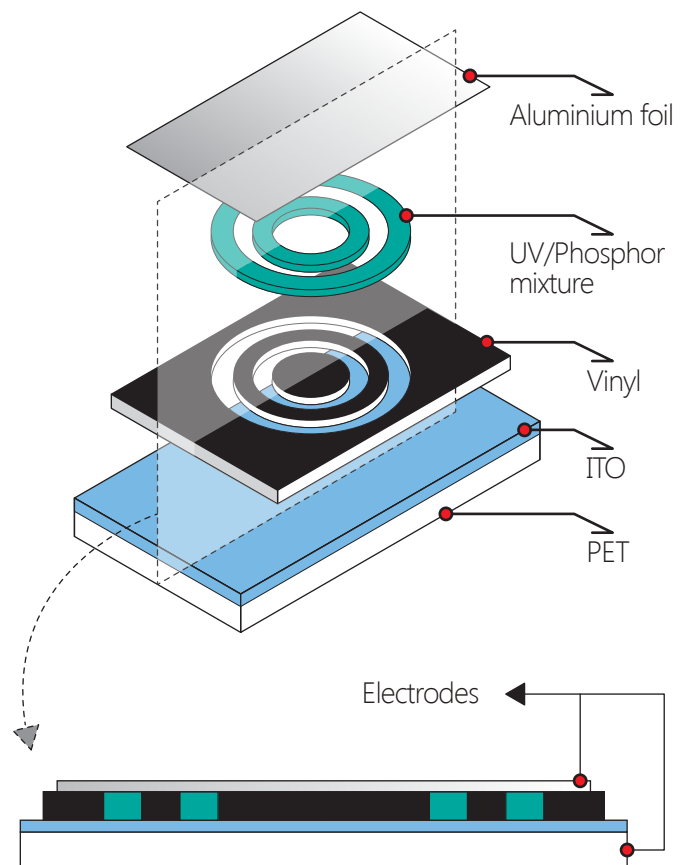




# DIY guide: Electroluminescence

Electroluminescence (EL) is the emission of light when phosphor particles are placed in a strong electric field. An electric field exists between two electrodes, with an opposite charge, when a non-conductive layer is placed between the two electrodes called the "dielectric". No current should flow from electrode to electrode directly as this will cause a short circuit and a malfunction in the EL device. One of the electrodes needs to be transparent in order to let the light out. In order to create a strong electric field you can increase the voltage or change the distance between the electrodes. This guide will focus on making

the distance between electrodes as small as possible. The electrodes used in this guide are aluminium foil and ITO PET. ITO is a very thin and delicate electricaly conductive layer that is applied to a sheet of PET which is not visible by sight. The UV/phosphor mixture consists of phosphor powder and UV curing adhesive (only cures under the influence of UV light). The layers are ordered as such that the two electrodes are as close to each other as possible. The vinyl and UV adhesive will function as dielectric layers, insulating both electrodes. This workshop will start at step 3.



Be careful when handling the EL panel when it is on. You can get a shock if both electrodes are touched simultaneously.

Wash your hands if the mixtures has gotten on your hands.



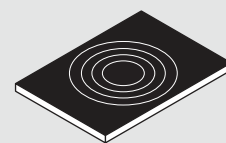
## Required equipement



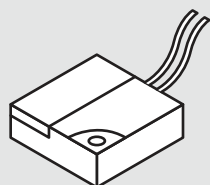
UV/Phosphor mixture



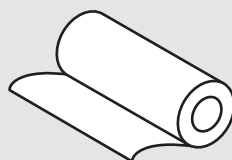
UV lamp



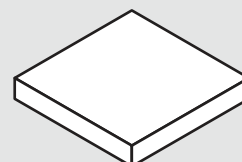
Vinyl



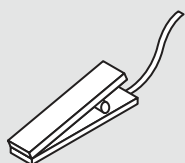
Inverter



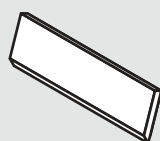
Aluminium foil



Flat work-surface



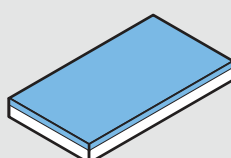
Clamps 2x



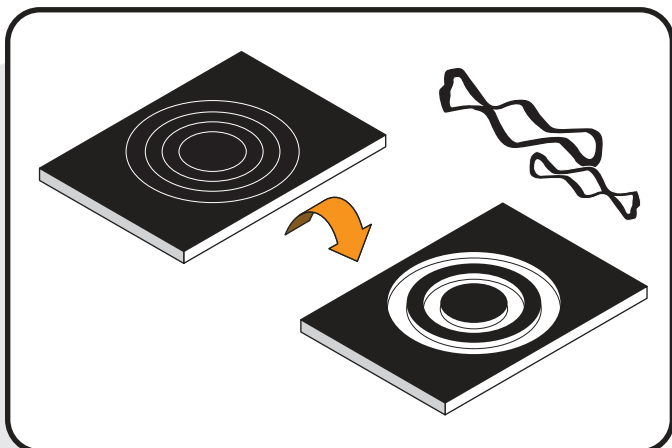
Scraper



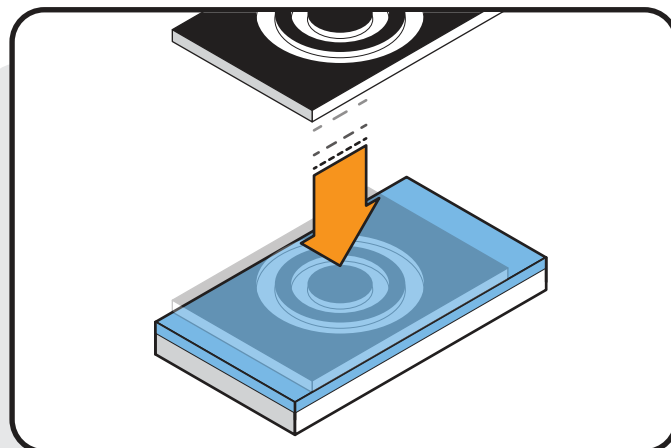
Mixing stick



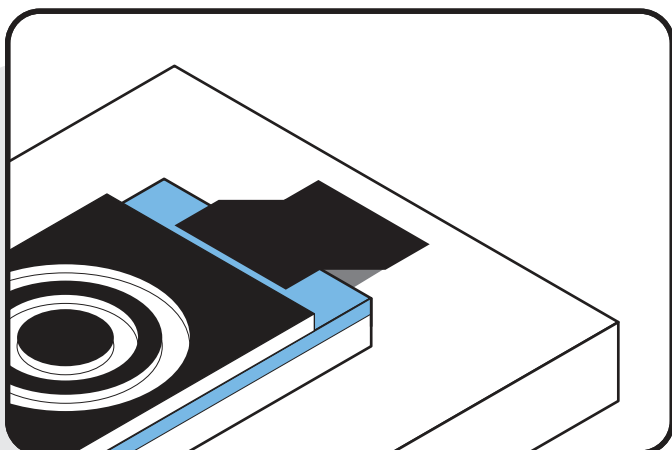
ITO PET



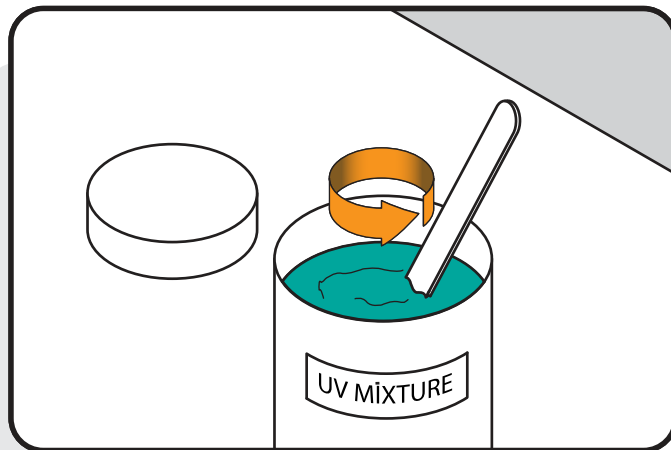
**1** Remove the parts of the vinyl that are not needed. These parts will be filled with the UV mixture.



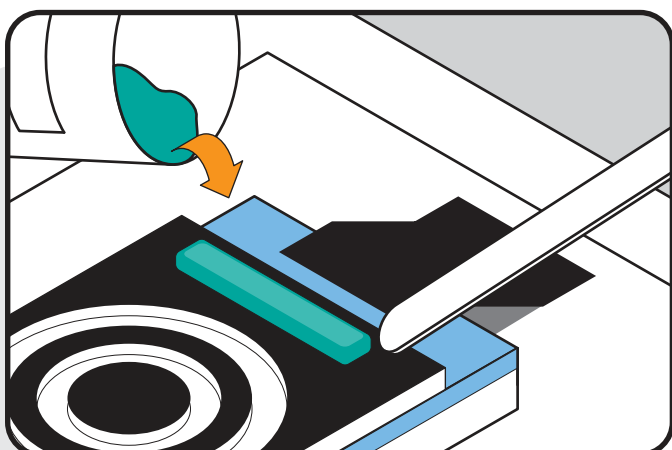
**2** Carefully place the vinyl on the ITO side of the ITO PET. If the cut-out part is complex a piece of transfer tape might be required.



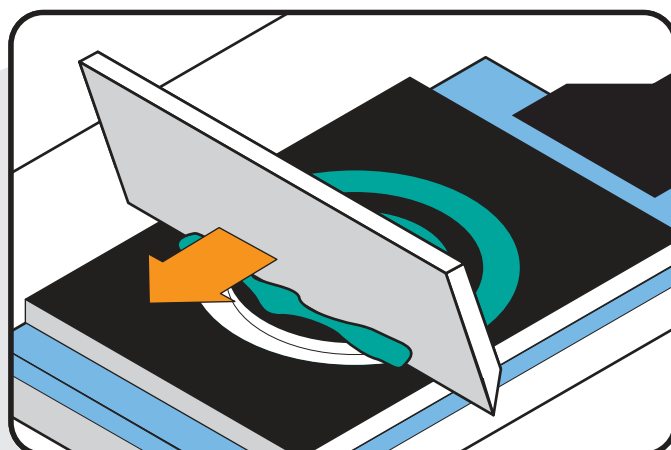
**3** Adhere the top side of the ITO pet to the (clean) working surface with a piece of tape.



**4** Stir the UV/phosphor mixture properly right before application. Phosphor particles will start to sink to the bottom after a minute, this requires stirring to create a homogeneous mixture.

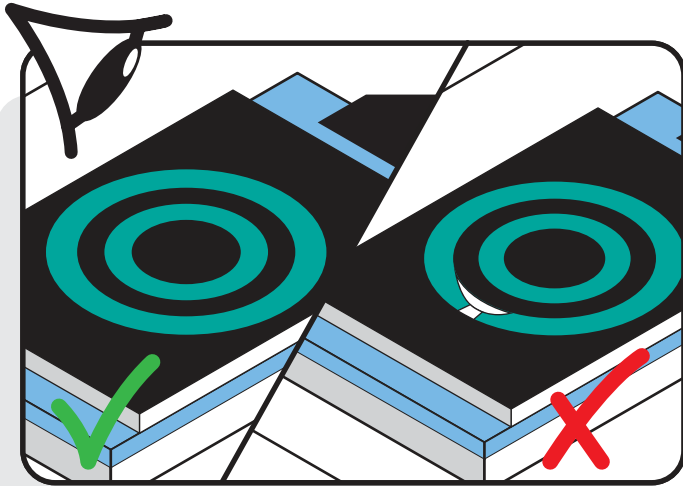


**5** Apply a line of the mixture above the cut-out on top of the vinyl. Be careful not to apply too much. More can always be added later.

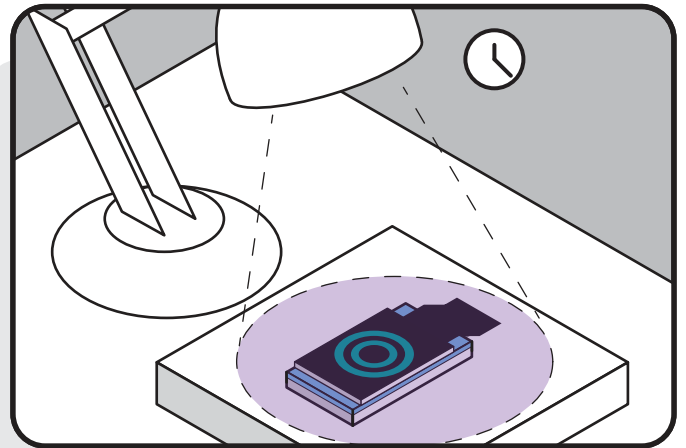


**6** Use the scraper with enough pressure, to spread the mixture over the vinyl. If the coverage is insufficient repeat step 4, 5 and 6.

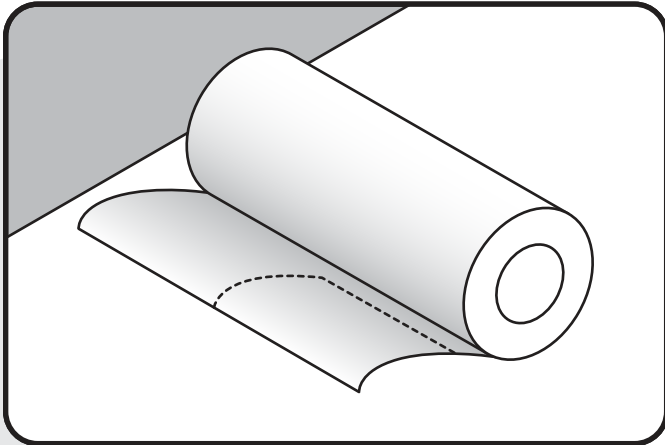




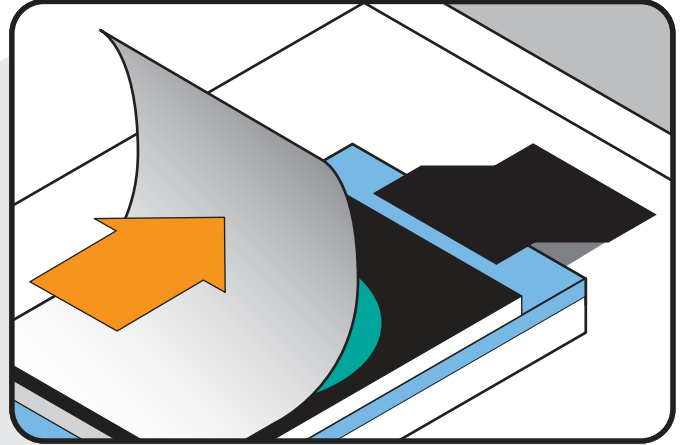
**7** Once the mixture is spread, perform a final visual check on proper coverage. Holes in the mixture layer can cause a short circuit.



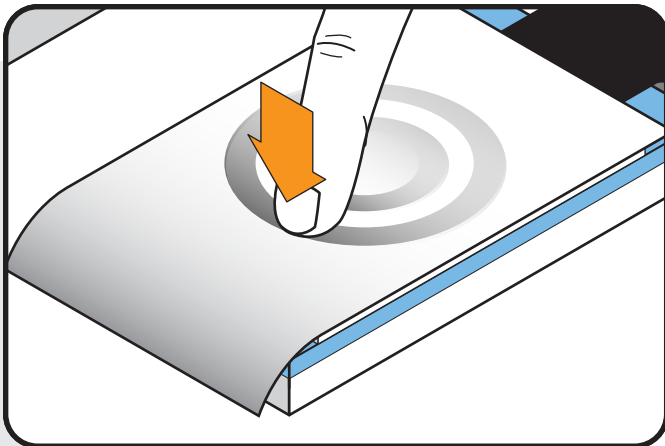
**8** Place the working surface underneath the UV lamp and let it cure for 1 minute. *UV adhesive that is in contact with oxygen will create a tacky outside layer. This effect will be used to bond the aluminium foil next.*



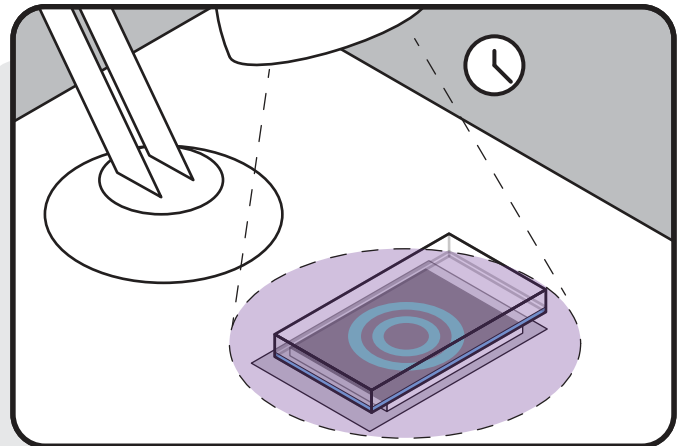
**9** While you are waiting cut a piece of aluminium foil slightly smaller than the piece of vinyl, but large enough to cover the parts that are filled with the mixture.



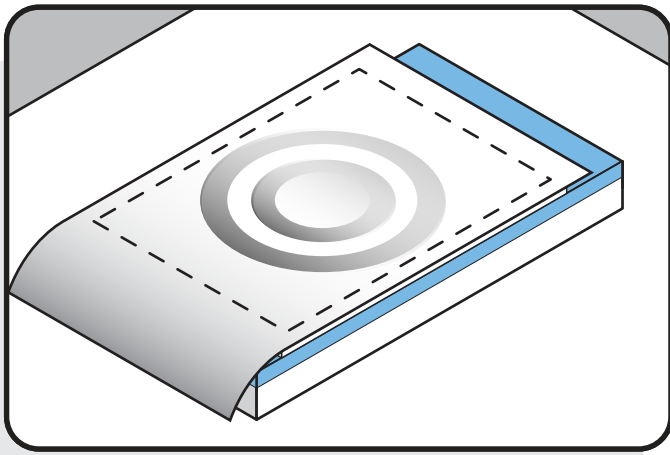
**10** Once the UV mixture is partially cured the piece of aluminium foil can be placed on top. Make sure that there is as little air as possible between the foil and the mixture.



**11** Press down on the foil where the mixture is located using firm pressure. This is done to remove trapped air as much as possible. This is important in order to reach good emission.

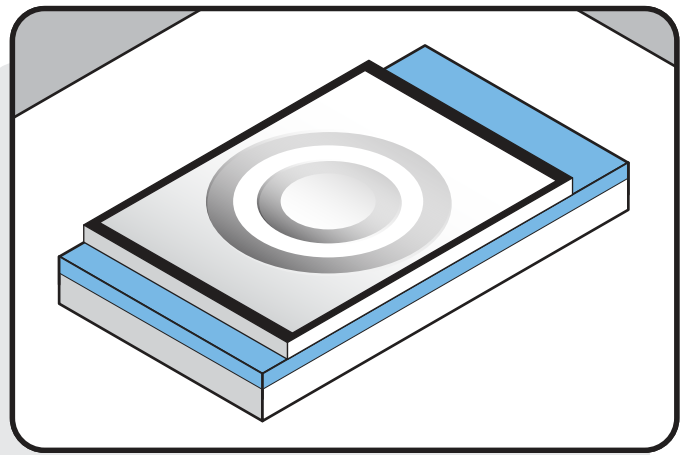


**12** Remove the tape that fixated the ITO PET and flip the material so the mixture can be seen through the ITO PET. Place it underneath the UV lamp for an additional 120 seconds.



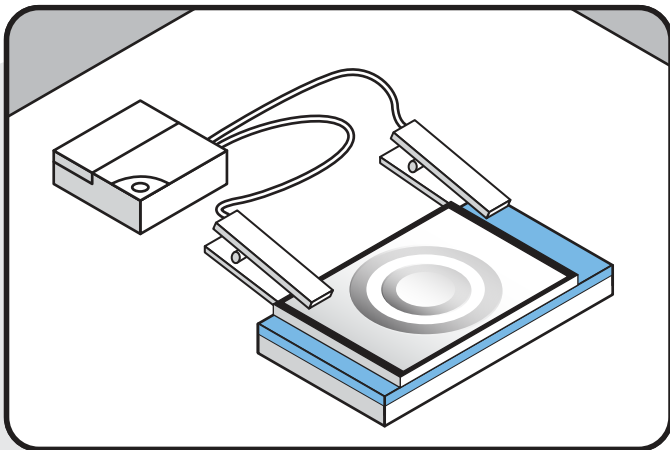
13

Once the mixture is fully cured, remove the parts of the aluminium foil (if this is needed) to the point that no part of the foil can touch the ITO side of ITO PET.



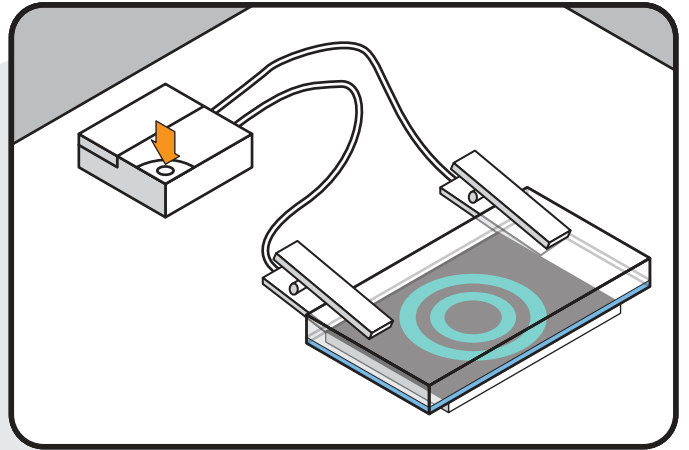
14

After cutting the foil the EL device should look like this. If the aluminium foil is smaller than the vinyl no short circuit should be able to occur.



15

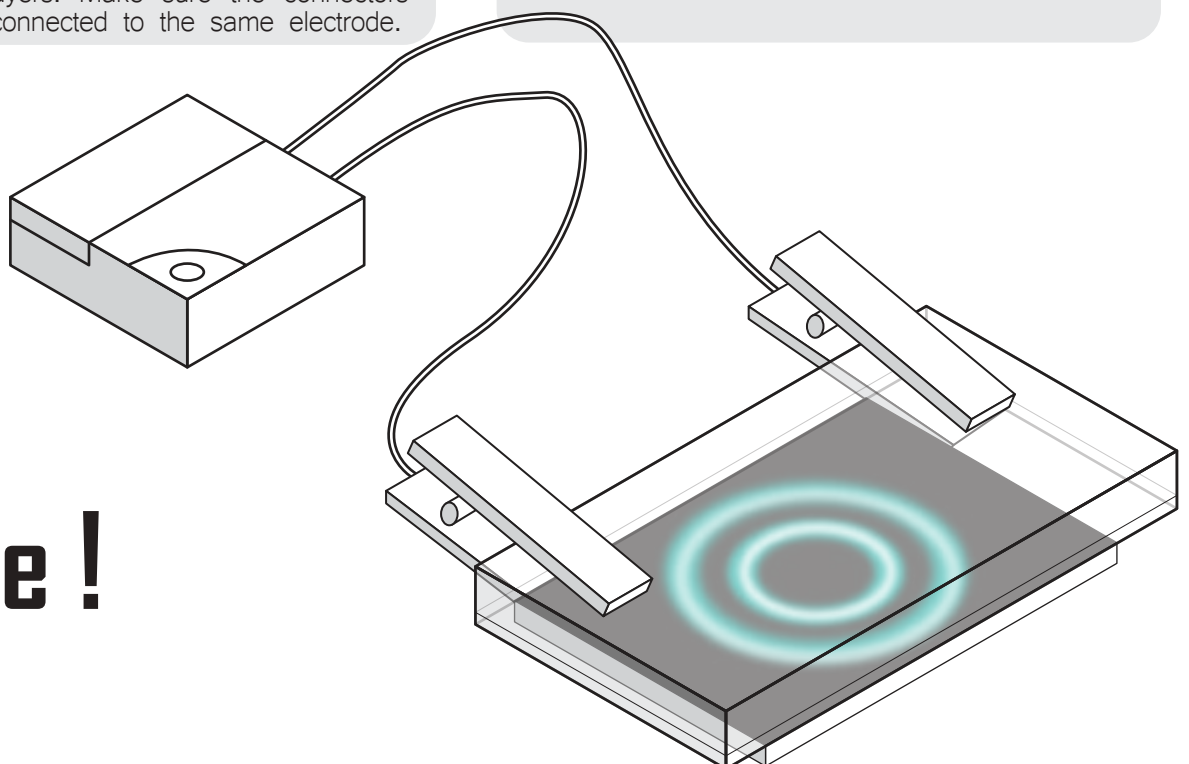
Remove the EL device from your working area and attach the clamps with the conductive side touching the two different conductive layers. Make sure the connectors are not connected to the same electrode.



16

Flip the device and turn on the inverter.

**Done !**



Appendix 11

# User test 3

The time for each step is noted in the tables in Fig172 and Fig173. Time is noted in minutes.

**Screen printing**

From start to finish the screen printing method took 115 minutes. The application of the second layer took the most time. This is mainly caused by troubles during the alignment of the design that was placed on the screen printing mesh and the sample. During later steps this was done with less difficulty, with exception of the final layer. This means that if all steps are as done as fast as possible without hiccups it could be done in

100 minutes.

**UV method**

Like the previous user tests this method took less than 20 minutes. No real trouble where encountered, which means there is no room for significant time improvement.

If you compare the fastest screen printing method (100 minutes) with the fastest UV method (12), the latter method is 8 times faster. This is when both methods make a single sided EL device.

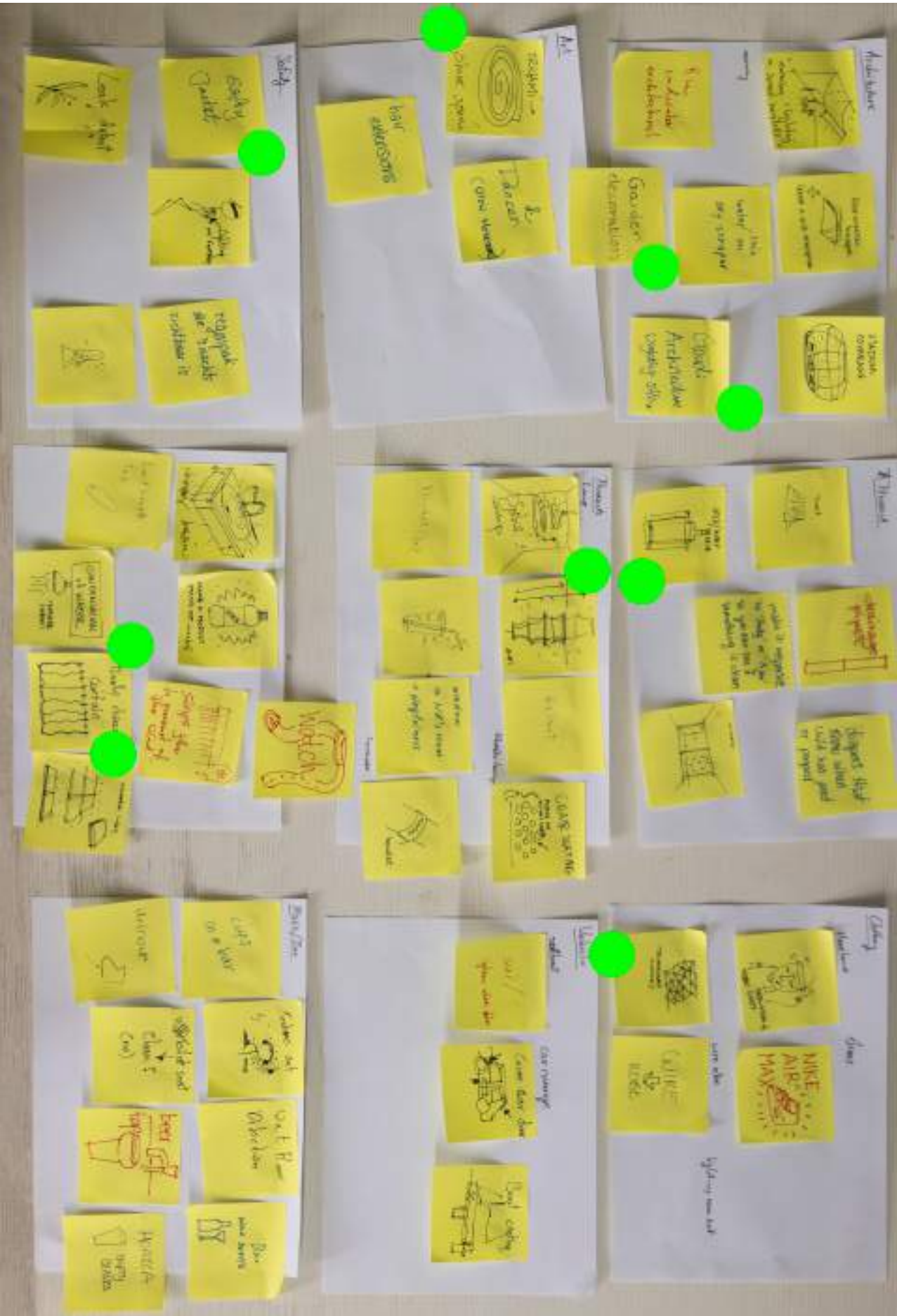
Fig172Application time screen printing

20	00:00	Apply vinyl
	00:03	Apply phosphor layer
	00:05	Enter oven
	00:20	Exit oven
28	00:21	Align vinyl layer
	00:30	Apply dielectric layer 1
	00:32	Enter oven
	00:48	Exit oven
22	00:49	Align vinyl layer
	00:52	Apply dielectric layer 2
	00:54	Enter oven
	01:10	Exit oven
19	01:12	Align vinyl layer
	01:13	Apply dielectric layer 3
	01:15	Enter oven
	01:29	Exit oven
26	01:30	Align vinyl layer
	01:36	Apply rear electrode
	01:40	Enter oven
	01:55	Exit oven
	01:56	Finished

Fig173Application time UV method

5	00:00	Apply vinyl
	00:02	Apply UV/phosphor
	00:05	Cure
7	00:07	Remove vinyl
	00:09	Apply UV adhesive
	00:12	Cure
5	00:14	Apply rear electrode
	00:16	Cure
	00:19	Finished

Appendix 12  
Workshop ideation





Demonstrator render

