DEAR STUDENT,

Are you looking for an interesting MSc project related to solar energy? The photovoltaic materials and devices (PVMD) group at TU Delft has the infrastructure and expertise to offer you a range of MSc projects in the following areas:

1. wafer-based c-Si solar cells
2. thin-film solar cells
3. Si/air batteries
4. photovoltatronics
5. x-integrated photovoltaic systems
6. photovoltaic multiscale modelling
7. projects with external partners

The following pages give you an overview of the projects currently available (updated June 2021) and provide you with the contact information of the project supervisors. When you are interested in a particular project, you can contact the (daily) supervisor for more information about the project of your choice.

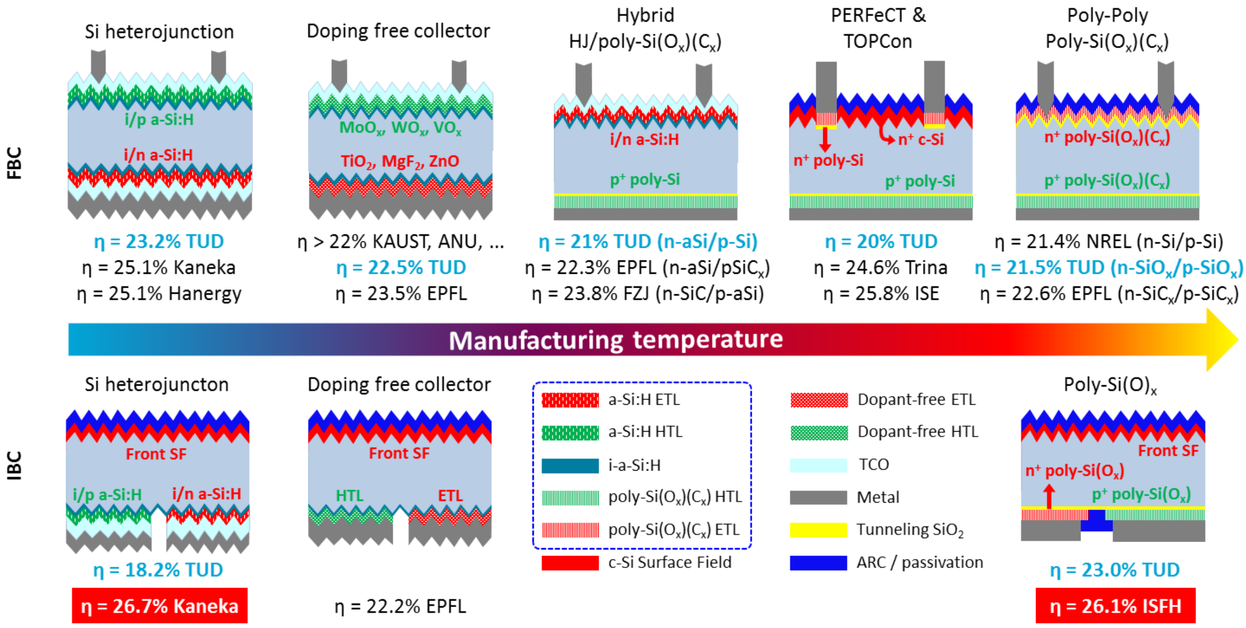
During the **matchmaking event on June 15th** (12:30 – 14:00) the (daily) supervisors will be available for an online chat. A list of Teams links and email addresses is provided at the end of this document. After the matchmaking event you can still contact the (daily) supervisors by email for further information.

Best regards,

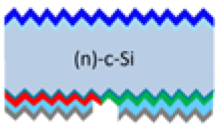
Olindo Isabella,

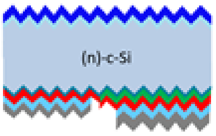
On behalf of the PVMD group

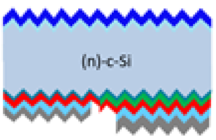
Area #1: Wafer-based c-Si solar cells



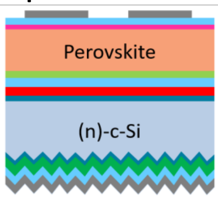
Heterojunction solar cells based on low-thermal budget or dopant-free carrier-selective passivating contacts

Title	**>24% interdigitated-back-contacted silicon heterojunction solar cell featuring novel nanocrystalline silicon-based passivating contact stacks and its application for 3-terminal tandem solar cells**
Daily Supervisor(s)	Ir. Yifeng Zhao, Dr. Guangtao Yang (Y.Zhao-4@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Silicon heterojunction (SHJ) solar cell is one of the most promising PV technologies thanks to its outstanding passivation quality from the a-Si:H that enables excellent V_{OC} of the cells. In the interdigitated-back-contacted (IBC) architecture, it enables the highest efficiency (26.7%) in single-junction c-Si solar cell. In this project, instead of using conventional doped a-Si:H as carrier selective contacts, the novel mixed phase materials, i.e. hydrogenated nanocrystalline silicon-based materials (e.g. nc-Si:H, nc-SiOx:H) simultaneously featuring higher transparency and higher conductivity compared to a-Si:H are applied. Those contacts have been successfully developed and implemented into front/back-contacted SHJ solar cells, which deliver an independently certified η = 22.5%. This efficiency is expected to be further boosted to be above 24% in an IBC configuration and above 27% in a tandem application. The research questions of this project are: (I) process flowchart optimizations of the IBC-SHJ solar cells; (II) optimize the doped layers for efficient charge-carrier selective transport in IBC solar cells; (III) compare doped a-Si and doped nc-Si:H-based contacts in cell performance; (IV) cooperate with partners for 3-terminal tandem solar cell fabrication and measurements. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapor deposition (PECVD), magnetron sputtering, metal evaporation. Besides, photolithography will be frequently used to pattern the doped layers, TCO and metal contacts. Fabricated thin films and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, reflection and transmission, J-V, EQE, $SunsV_{OC}$, lifetime). The student may be also involved in collaboration for tandem cells fabrication and characterization with external partners.
Available from	June 2021
Type	Experimental
Internal/External	Internal

Title	**Simplified process of high-efficiency interdigitated-back-contacted silicon heterojunction solar cell featuring tunneling recombination junctions and its application for 3-terminal tandem solar cells**
Daily Supervisor(s)	Ir. Yifeng Zhao, Dr. Guangtao Yang (Y.Zhao-4@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies thanks to its outstanding passivation quality from the a-Si:H that enables excellent VOC of the cells. Together with interdigitated-back-contacted (IBC) architecture, it enables the highest efficient, 26.7%, single-junction c-Si solar cell. Instead of using conventional doped a-Si:H as carrier selective contacts, in this project, the novel mixed phase materials, i.e. hydrogenated nanocrystalline silicon-based materials (e.g. nc-Si:H, nc-SiOx:H) that feature higher transparency and higher conductivity simultaneously as compared to a-Si:H are applied. While standard IBC flowchart is rather complex and generally requires multiple steps of photolithography for patterning the doped layers, TCO and metal contacts. In this project, aiming at demonstrating the simplified process for high-efficiency IBC solar cells, tunneling recombination junctions will be applied to enable the minimum or ultimately no use of expensive photolithography process. Various approaches can be used for patterning the back contacts, such as hard masks, wet-chemical, plasma, etc. The research questions of this project are: (I) process flowchart optimizations (simplified process) of the IBC-SHJ solar cells; (II) optimize the nc-Si:H-based doped layers for efficient charge-carrier selective transport and efficient tunneling recombination junctions; (III) cooperate with partners for 3-terminal tandem solar cell fabrication and measurements. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapor deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. Besides, photolithography flowcharts will be frequently utilized to pattern the doped layers, TCO and metal contacts. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, reflection and transmission, J-V, EQE, SunsV_{OC}, lifetime). The student may be also involved in collaboration for tandem cells fabrication and characterization with external institutes/universities.
Available from	June 2021
Type	Experimental
Internal/External	Internal

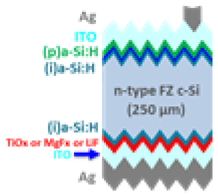
Title	**Towards industry-compatible high-efficiency silicon heterojunction solar cells**
Daily Supervisor(s)	Ir. Yifeng Zhao, Dr. Luana Mazzarella (Y.Zhao-4@tudelft.nl, L.Mazzarella@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Currently, silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies thanks to the outstanding passivation quality from the a-Si:H that enables excellent VOC of the cell. However, the use of conventional doped a-Si as carrier-selective-contacts (CSCs) at the illumination side induces high parasitic absorption, eventually the loss of JSC. In this project, the novel mixed phase material, hydrogenated nanocrystalline silicon-based materials (nc-Si:H, nc-SiOx:H), which feature high transparency and high conductivity simultaneously is implemented. Within the PVMD group, we have developed contact stacks based on nc-SiOx:H for front/back-contacted SHJ solar cells which enable ISFH-CalTec certified efficiency of 22.5% and fill factor (FF) well-above 80%. While further efficiency boosts are expected, especially, with improved passivation quality and optimized light management that brings gains in V_{OC} and J_{SC} of solar cells, respectively. Meanwhile, industry-compatible process flowcharts of solar cell fabrication are also of great interest. Therefore, in this project, silicon wafers with industrial standards will be used for fabricating high-efficiency SHJ solar cells. The research questions of this project are: (I) optimize the pre-treatments of industrial silicon wafers; (II) optimize intrinsic a-Si:H passivating layers for industrial silicon wafers; (III) optimize the doped layers for efficient charge-carrier selective transport that could deliver high VOC above 735 mV and high FF above 82%; (IV) improve

	the light management, thus the JSC of solar cells with the support of advanced optical simulations; (V) optimize the screen printing process.During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapor deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. Besides, photolithography might be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, reflection and transmission, J-V, EQE, SunsV_{OC}, lifetime). The student will also use advanced optical simulation software for analyzing solar cells. The student may be also involved in collaboration for tandem cells fabrication and characterization with external institutes/universities.
Available from	June 2021
Type	Experimental
Internal/External	Internal

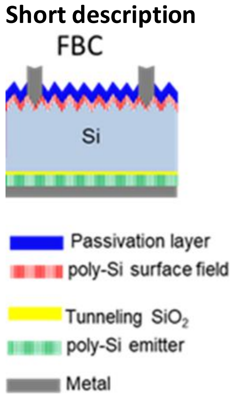
Title	**Understanding and optimizations of high-efficiency silicon heterojunction solar cell for tandem solar cells**
Daily Supervisor(s)	Ir. Yifeng Zhao, Dr. Luana Mazzarella (Y.Zhao-4@tudelft.nl, L.Mazzarella@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
 **Short description**	Silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies which achieves the record efficiency of 26.7% for single-junction c-Si. However, the spectral mismatch between the absorption characteristics of c-Si and the solar spectrum limits the conversion efficiency of the single-junction c-Si cell. To better utilize the solar spectrum, a high bandgap perovskite cell is stacked on top of the c-Si cell and demonstrates a record efficiency of 29.52%. Therefore, to eventually deliver highly efficient perovskite/c-Si tandem solar cells, the optimization of the bottom c-Si cell for the tandem application is critical. Currently, with our developed bottom cells, we have presented together with TU Eindhoven over 22%-efficient 2-terminal tandem solar cells. While there are still plenty of rooms for further improving this efficiency to above 27%. Therefore, tandem application-orientated optimizations of bottom cells are needed. The research questions of this project are: (I) cooperate with partners for tandem solar cell fabrication and measurements; (II) understand and evaluate key factors that contribute to the formation of efficient tunneling recombination junctions (TRJs) between the top and bottom cells; (III) optimize the optoelectrical properties of the doped layers to fulfil requirements for forming efficient TRJs; (IV) improve the infrared light utilization in the bottom cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapor deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, reflection and transmission, J-V, EQE, SunsV_{OC}, lifetime). Wafer dicing tool will be also used. The student will be also frequently involved in collaboration for tandem cells fabrication and characterization with external institutes/universities.
Available from	June 2021
Type	Experimental
Internal/External	Internal

Title	**Proof-of-concept of transparEnt PassIvated Contacts (EPIC)**
Daily Supervisor(s)	Paul Procel (p.a.procelmoya@tudelft.nl), Guangtao Yang , Luana Mazzarella
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl),
Short description	The application of carrier selective contacts (CSC) on crystalline silicon solar cells has markedly pushed the power conversion efficiency to almost theoretical limits. However, CSC commonly entails the use of highly doped layers at the cost of parasitic absorption. In this project, we will use state-of-art passivation layers combined with industry appealing processes to form the junction. Then, we will use a transparent conductive oxide layer as electrode and selective layers avoiding to deposit any highly doped layer (ITO, IFO or AZO). This will result in a proof-of-concept of highly transparent CSC. To do so, CSC for each

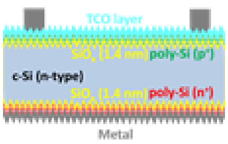
	polarity will be tested in terms of passivation at different process stages and also contact resistance. Finally, the CSC will be implemented and evaluated in solar cell devices.
Available from	September 2021
Type	Laboratory and characterization
Internal/External	Internal

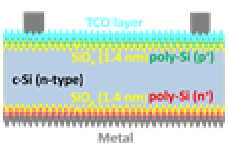
Title	**Novel doping free carrier selective contacts on tunnelling oxides for c-Si solar cells**
Daily Supervisor(s)	Ir. Liqi Cao, Dr. Luana Mazzarella (L.Cao-3@tudelft.nl L.Mazzarella@tudelft.nl),
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Recently, c-Si solar cells based on dopant-free carrier-selective contacts (CSC) have become an interesting alternative. Currently, several transition metal oxide (TMO) layers (e.g. titanium oxide (TiO_x), molybdenum oxide (MoO_x), nickel oxide (NiO_x), vanadium oxide (V_2Ox)) along alkali metal fluoride (AMF) layers (e.g. lithium fluoride (LiF) and magnesium fluoride (MgF_2)), have been investigated because of their good transparency in the wavelength range of interest and excellent electronic properties to extract and inject respective charge carriers in the device. Such CSCs are normally structured as (TCO) / HTL(hole transport layer) /i-a-Si:H / c-Si / i-a-Si:H / ETL(electron transport layer) / metal. Within the PVMD group, we have developed contact stacks based on light facing MoOx for dopant-free solar cells which have achieved efficiency over 22% and fill factor (FF) above 80%, and it shows great potential for further investigation. The main focus of this project is on the rear side. Normally, the ETL is directly contact with metal, but this may cause electrical loss. So a TCO layer will be added between the ETL and metal layer trying to minimize the issue. The research questions of this project are: (I) process optimizations of the thickness of electron selective contact layers; (II) optimize the TCO layer on the front and rear side; (III) compare the cell performance with/without TCO layer on the rear side for cell; (IV) cooperate with MOMENTUM project partners for dopant-free solar cell fabrication and measurements. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), thermal evaporation, silver screen printing. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, reflection and transmission, EQE, lifetime).
Available from	July 2021
Type	Simulation and experimental

Solar cells based high-thermal budget carrier-selective passivating contacts

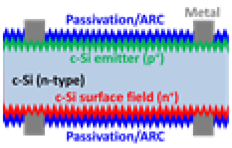
Title	**High aspect ratio copper grid for high-efficiency poly-Si solar cells with flat wafer surface**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	In recent years, poly-Si solar cell has received intense research interest in PV community, whose efficiency has been over 26%. Regarding its metallization aspect, the most common industrial process features screen-printed contacts. However, this process suffers from low aspect ratio, high metal finger resistivity and contact resistance, excessive shading and high price of silver. Copper-plating has proven to be an effective approach to tackle the abovementioned issues, in which PVMD group has cumulative experiences in past years. Nevertheless, it is still challenging to obtain a good adhesion of high aspect ratio metal fingers on flat wafer surface, which is normally needed for producing poly-Si cell precursors with good passivation quality. Therefore, the aim of this project is to develop high aspect ratio copper grid for high-efficiency poly-Si solar cells on flat wafer surface. Both direct and indirect strategies will be evaluated: (i) appropriate seed layer use, such as evaporated Ti; (ii) adjustment of copper electroplating process, such as multi-step metal deposition, choice of seed layer removal solution(s); (iii) building textured morphology on functional layer(s) that will be utilized in device level, such as transparent conductive oxide (TCO). Challenges may include passivation degradation upon seed layer growth, simultaneous control of

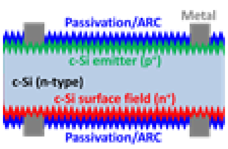
	copper-plating on both textured and flat surfaces (especially for bifacial plating metallization), uniformity and thickness control in TCO texturization, etc.) All the materials development and solar cell fabrication will be done in a cleanroom environment.
Available from	August 2021
Type	Experimental
Internal/External	Internal

Title	**TCO optimization for M2+ sized c-Si solar cells feature TOPCon passivation contacts**
Daily Supervisor(s)	Dr. Zhirong Yao, Dr. Guangtao Yang (Z.Yao@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	c-Si solar cells with tunnelling oxide passivating contact (TOPCon) is one of the most promising photovoltaic technologies thanks to the highest feasibility to the nowadays PERC cell production line among the passivating contact cell structures. TOPCon has outstanding passivation quality which enables excellent V_{OC} of the cell. However, applying the TOPCon materials at the illumination side of the cell induces high parasitic absorption, eventually the loss of J_{SC}. Therefore, to minimize this optical loss, the TOPCon materials need to be as thin as possible, which induces challenge to the solar cell FF, owing to the high series resistance of the thin TOPCon layer. In this project, the transparent conductive oxide (TCO) layer will be developed specifically for TOPCon solar cell application. The challenges are the TCO sputtering damage to the passivation quality of TOPCon and their band alignment, in other words, the work-function alignment. The research objectives of this project are: (I) Optimization of the optical and electrical properties for TCO materials deposited on industry size wafers; (II) TCO/TOPCon interface characterization; (III) TCO/TOPCon passivation quality optimization; (IV) Processes integration for high-efficiency c-Si solar cells with TCO/TOPCon passivating contacts. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. Besides, photolithography will be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, sheet/contact resistance measurement, reflection and transmission, J-V, EQE, SunsV_{OC}, carrier lifetime). The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	August 2021
Type	Experimental
Internal/External	Internal

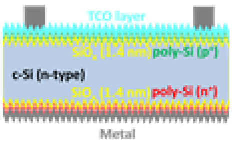
Title	**Metalization processes optimization for M2+ sized c-Si solar cells**
Daily Supervisor(s)	Dr. Guangtao Yang (G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Metalization processes for c-Si solar cells with tunnelling oxide passivating contact (TOPCon) are one of the most critical steps that have a huge influence on the final solar cell performances. TOPCon technology is a promising photovoltaic technology thanks to its highest feasibility to the nowadays PERC cell production line among the passivating contact cell structures. However, due to the nature of the TOPCon materials and the thickness limitation, the metallization steps for TOPCon contact structure are very different to those for the PERC solar cells. In this project, we aim at developing a low damage metallization approach for TOPCon passivating contact. The research objectives of this project are: (I) Study the critical process windows for metallization approach based on screen printing of low-temperature Ag and/or Ag/Al paste for TOPCon solar cells; (II) Engineering the Cu plating metallization processes, and study the influence of intersurface preparation, seed layer, plating parameters on the Cu-plated TOPCon solar cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as magnetron sputtering, metal evaporation, silver screen printing, and the electrical plating process. Besides, photolithography will be utilized. The fabricated metals and solar cells will be characterized by advanced characterization setups (SEM, sheet/contact resistance

	measurement, J-V, EQE, $SunsV_{OC}$). The student will also be involved in the national research project dedicated to high-η solar cell development.
Available from	June 2021
Type	Experimental
Internal/External	Internal

Title	**n^+ c-Si surface field optimization for n-PERT solar cells**
Daily Supervisor(s)	Dr. Zhirong Yao, Dr. Guangtao Yang (Z.Yao@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr Olindo Isabella (o.isabella@tudelft.nl)
Short description  	Currently, the passivated emitter rear contact solar cells, the PERx series, are still the dominating technology in the PV market. To keep the lifetime of the PV production line and enhance its competitiveness against the advanced/emerging PV technologies that squeezed in the PV market recently, for examples the TOPCon and SHJ technologies, the PERx solar cell was keeping on pushing the efficiency towards its limit, around 24%. The research of this project will contribute to the evolution by optimizing **the n^+ c-Si surface field** and apply the developed technology into high efficiency n-PERT solar cells with industry feasible tools. The research objectives of this project are: (I) Preparation of n^+ c-Si surface field by different industry feasible doping approaches: PSG/P-ion-implantation/$POCl_3$; (II) n^+ c-Si surface filed passivation with dielectric materials (SiOx, SiNx) prepared by PECVD tools; (III) Integration of the optimized processes into high-efficiency 6-inch n-PERT solar cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapor deposition (PECVD), magnetron sputtering, metal evaporation, and silver screen printing. Besides, photolithography will be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, sheet/contact resistance measurement, reflection and transmission, J-V, EQE, $SunsV_{OC}$, carrier lifetime). The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	September 2021
Type	Experimental
Internal/External	Internal

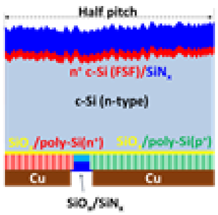
Title	**p^+ c-Si emitter optimization for n-PERT solar cells**
Daily Supervisor(s)	Dr. Zhirong Yao, Dr. Guangtao Yang (Z.Yao@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description  	Currently, the passivated emitter rear contact solar cells, the PERx series, are still the dominating technology in the PV market. To keep the lifetime of the PV production line and enhance its competitiveness against the advanced/emerging PV technologies that squeezed in the PV market recently, for examples the TOPCon and SHJ technologies, the PERx solar cell was keeping on pushing the efficiency towards its limit, around 24%. The research of this project will contribute to the evolution by optimizing **the p^+ c-Si emitter** and apply the developed technology into high efficiency n-PERT solar cells with industry feasible tools. The research questions of this project are: (I) Preparation of p^+ c-Si emitter by different industry feasible doping approaches: BSG/B-ion-implantation/BBr3; (II) p^+ c-Si emitter passivation with dielectric materials: ALD deposited Al2O3, PECVD deposited SiNx; (III) Integration of the optimized processes into high-efficiency 6-inch n-PERT solar cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as plasma-enhanced chemical vapour deposition (PECVD), magnetron sputtering, metal evaporation, silver screen printing. Besides, photolithography will be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, sheet/contact resistance measurement, reflection and transmission, J-V, EQE, $SunsV_{OC}$, carrier lifetime). The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	June 2021

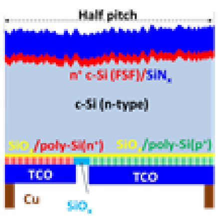
Type	Experimental (mainly) and simulation
Internal/External	Internal

Title	**p^+ LPCVD poly-Si on industry substrate (M2+) for high-efficiency solar cell**
Daily Supervisor(s)	Dr. Zhirong Yao, Dr. Guangtao Yang (Z.Yao@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	In recent years, industry tunnelling oxide passivating contact (iTOPCon) solar cells becomes one of the most promising photovoltaic technologies thanks to the highest feasibility to the nowadays PERC cell production line among the passivating contact cell structures. TOPCon has outstanding passivation quality which enables excellent V_{OC} of the cell. Therefore, this technology attracts incredible interests from the PV factory/new investors to upgrade their PERx production line for higher efficiency solar cells. Among the TOPCon preparation technologies, LPCVD is the most feasible one for high throughput solar cell production that can be used to upgrade the current PERx line with the least investment. However, the development of high-performance p^+ LPCVD poly-Si as p^+ TOPCon with industry-compatible processes is one of the challenges that limit its application in solar cells. In this project, we will take the challenge to developed high-performance p^+ LPCVD poly-Si on the textured c-Si surface as passivating contact for solar cells. The research objectives of this project are: (I) Study the process parameters of ultra-thin thermal-SiO_x on the SiOx properties and its influences on the carrier selectivity of the p^+ LPCVD poly-Si passivating contact; (II) Study the influence of intrinsic poly-Si layer preparation conditions on the carrier selectivity of the p^+ LPCVD poly-Si passivating contact; (III) Study the influence of BBR3 doping process conditions on the carrier selectivity of the p^+ LPCVD poly-Si passivating contact; (IV) Integration of the developed p^+ poly-Si passivating contacts into high-efficiency Cu-palted c-Si solar cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as low-pressure chemical vapour deposition (LPCVD), BBr3 diffusion, metal evaporation, Cu-plating. Besides, photolithography will be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, sheet/contact resistance measurement, reflection and transmission, J-V, EQE, SunsV_{OC}, carrier lifetime). The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	September 2021
Type	Experimental
Internal/External	Internal

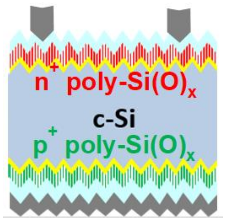
Title	**p^+ PECVD TOPCon on industry substrate (M2+) for high-efficiency solar cell**
Daily Supervisor(s)	Dr. Zhirong Yao, Dr. Guangtao Yang (Z.Yao@tudelft.nl, G.Yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	TOPCon as a passivating contact enables record high efficiency, >26%, c-Si solar cells. Besides the LPCVD deposition technology, PECVD is another candidate for the preparation of TOPCon passivating contact. PECVD has the advantages of in-situ doping and single-side deposition compared to the LPCVD approach. In this project, we will use PECVD approach to prepare the most challenging p+ TOPCon for high-efficiency solar cells. During this project, the novel in-situ plasma-SiOx will be developed as the tunnelling layer for the TOPCon structure. With the industry-compatible process, the developed p^+ TOPCon will be integrated into high-efficiency solar cells. The research questions of this project are: (I) Study the process parameters of the plasma-SiOx on the SiOx properties and its influences on the carrier selectivity of the PECVD p^+ TOPCon passivating contact; (II) Study the influence of the doping of the deposited p-type Si layer and interfacial intrinsic layer on the carrier selectivity of the PECVD p^+ TOPCon passivating contact; (III) Engineer the hydrogenation processes for the optimum carrier selectivity of the PECVD p^+ TOPCon passivating contact; (IV) Integration of the developed PECVD p^+ TOPCon passivating contacts into high-efficiency Cu-plated c-Si solar cells. During the project, the student will operate in a cleanroom environment with various deposition tools, such as low-pressure chemical vapour deposition (LPCVD), BBr3

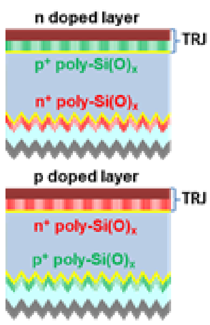
	diffusion, metal evaporation, Cu-plating. Besides, photolithography will be utilized. The fabricated thin-film and solar cells will be characterized by advanced characterization setups (spectral ellipsometry, Raman spectroscopy, sheet/contact resistance measurement, reflection and transmission, J-V, EQE, SunsV_{OC}, carrier lifetime). The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	June 2021
Type	Experimental
Internal/External	Internal

Title	**Identify and resolve the electrical losses in the high efficient IBC solar cells with ion-implanted poly-Si passivating contacts**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	c-Si solar cells with interdigitated back contacted (IBC) structure is steadily increasing their market share in recent years. Besides their higher aesthetics, their highest efficiency characteristic is one of the main reason behind this market share increase. Within the IBC solar cell architectures, those with carrier selective passivating contacts, namely the TOPCon/POLO-junction (poly-Si based passivating contacts) and the silicon-heterojunction (SHJ) technologies, show the highest potential to have their conversion efficiency close the practical efficiency limit of c-Si single-junction solar cells. In the PVMD group, we developed the IBC solar cells with poly-Si passivating contact with an efficiency of around 23%, with the potential to reach 25+% in conversion efficiency. In this project, we will identify and resolve the barriers for increasing the cell efficiencies, from the solar cell optical and electrical losses aspects. The research objectives of this project are: (I) Identify and resolve the cell Voc loss due to the processes and metallization; (II) Identify and resolve the cell FF loss due to the resistive loss. During the project, the student will operate in a cleanroom environment with various MEMS process tools, such as LPCVD, PECVD, metal evaporation, Cu-plating, photolithography. The fabricated thin-film and solar cells will be characterized by advanced characterization setups. The student will also be involved in the national research project dedicated to high-efficiency solar cell development.
Available from	January 2022
Type	Experimental
Internal/External	Internal

Title	**High energy yield Bifacial-IBC solar cells enabled by poly-Si carrier selective passivating contacts**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	c-Si solar cells based on the poly-Si Tunnel Oxide Passivating Contact (TOPCon) is becoming one of the most promising solar cell structures that enable both high efficiency and low cost. The record efficiency for the front-rear contacted cell with TOPCon structure is 26%. By moving both metal contacts to the backside, the so-called interdigitated back-contact (IBC) approach, the solar cell efficiency can be improved further due to the absence of optical shading from the front metal contact. Besides, the energy yield of the IBC can be further enhanced once they become bifacial solar cells. The objective of this project is to fabricate the bifacial-IBC solar cells with TOPCon contact structures. The research objectives of this project are: (I) Optimize the standard patterning processes for fabricating the rear emitter and BSF TOPCon finger patterns; (II) Optimize the Cu-plating processes of the fine metal grids for both emitter and BSF contacts. During the project, the student will operate in a cleanroom environment with various MEMS process tools, such as LPCVD, PECVD, metal evaporation, sputtering, Cu-plating, photolithography. The fabricated thin-film and solar cells will be characterized by advanced characterization setups. The student will also be

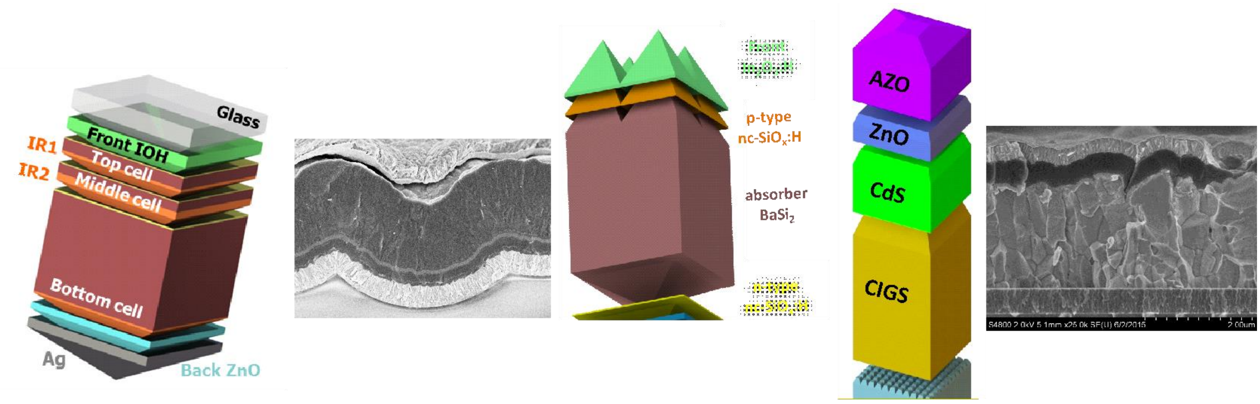
	involved in the national research project dedicated to high-efficiency solar cell development.
Available from	January 2022
Type	Experimental
Internal/External	Internal

Title	**Fabrication of high efficiency double side textured poly-SiOx passivated c-Si solar cells**
Daily Supervisor(s)	Manvika Singh (M.Singh-1@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description 	Poly-Si as a carrier-selective contact is now a hot research topic due to the fact that this novel carrier-selective passivating contact layer shows low recombination current, which enables high-efficiency solar cells. However, poly-Si is quite absorptive in the form of free carrier absorption. In this project, the poly-Si material will be alloyed with oxygen to from poly-SiOx material, which is more transparent than poly-Si material, therefore a higher short circuit current is expected. Currently, research on poly-SiOx passivating contacts has been limited to double side flat or single side textured wafers. The novelty of this project is that the student will be fabricating high efficiency solar cells with poly-SiOx passivating contact on double side textured wafers. The aim of this project is to: (I) Optimize the passivation quality, especially the p-type doped poly-SiOx passivating contacts on textured surfaces; (II) Study the effect of different tunnelling oxides such as thermal oxide, NAOS and plasma oxide on solar cells' performance; (III) Optimize screen printing for metallization.; (IV) Perform contact resistance study of the p type doped poly-SiOx layers; (V) Design and prepare high efficiency front back contacted (FBC) solar cells with poly-SiOx passivating contacts on double side textured wafers. All the materials development and solar cell fabrication will be done in the cleanroom.
Available from	July 2021
Type	Experimental
Internal/External	Internal

Title	**Recombination junction layers for 2T tandem solar cells with high temperature carrier selective passivating contacts.**
Daily Supervisor(s)	Manvika Singh (M.Singh-1@tudelft.nl), Dr. Luana Mazzarella (l.mazzarella@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl),
Short description 	Perovskite/c-Si tandem solar cells is a hot research topic in PV industry. Among the various tandem configurations, the 2-terminal (2T) has the highest potential to reach low levelized cost of electricity. While various such tandems have been fabricated using silicon heterojunction as bottom cell, area of c-Si bottom cells with high temperature carrier-selective passivating contacts still needs to be explored. One such tandem structure with high temperature carrier selective passivating contacts has been fabricated in Ref. [1]. In this project, single side textured poly-SiOx passivated c-Si solar cells will be fabricated to be used as bottom cell in 2T tandem configuration. The tunnel recombination junction (TRJ) is a crucial element of such tandem structures which helps combine carriers of one sub-cell with carriers of opposite charge from the other sub-cell. Conventionally ITO is used as the tunnel recombination junction layers. However, it has various drawbacks such as parasitic absorption at high wavelengths, poor refractive index matching with silicon and high lateral conductivity promoting shunt paths through the top cell [2]. One way to mitigate such losses is to implement p/n recombination junctions. In this project, we will study the use of different tunnel recombination layers such as nc-Si, poly-Si, poly-SiOx, IWO and IFO on poly-SiOx passivated c-Si solar cells. The following tasks will be performed in this project: (I) Study the optical properties of different recombination junction layers on glass to choose the layer with minimum parasitic absorption losses and appropriate refractive index for a TRJ; (II) Optimize the electrical properties of the recombination junction layers; (III) Optimize the passivation quality of doped layers; (IV) Fabricate single side textured front and rear junction poly-SiOx passivated c-Si solar cells with appropriate TRJ. Fabricated bottom c-Si solar cell

	structures will be used in addition to perovskite solar cells for 2T tandem applications. All the materials development and solar cell fabrication will be done in the cleanroom.
Available from	July 2021
Type	Experimental
Internal/External	Internal

Area #2: Thin-film solar cells



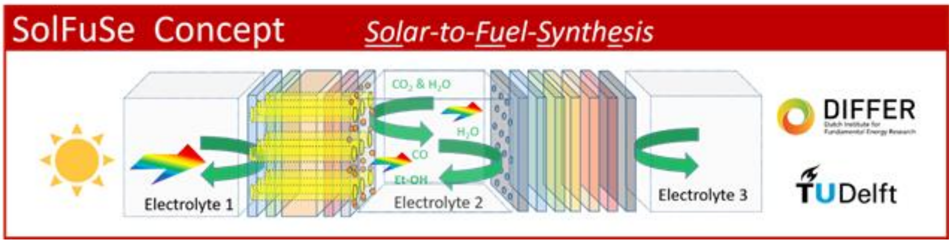
Title	**Optimizing the interconnection process for highly efficient and stable, flexible thin-film silicon photovoltaic modules**
Daily Supervisor(s)	Dr. Gianluca Limodio **(**g.limodio@tudelft.nl**)** **/**Dr. Davide Bartesaghi (davide.bartesaghi@hyetsolar.com) /
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	One of the key processes in the production of flexible, thin film silicon solar cells at HyET Solar Netherlands is the realization of interconnections. At the interconnection region, two adjacent cells are connected in series. An optimal interconnection is a combination of a 1) highly conductive pathway for the current to flow from the bottom contact of one cell to the top contact of the next cell; 2) highly resistive area preventing short circuits within one cell or between the two adjacent cell. In the current HyET Solar process, interconnections are realized with a combination of laser scribing and insulating ink dispensing. In order to optimize the process, an in-depth study should be carried out to elucidate which parameters have the largest influence on the resulting interconnection. In view of the possible future introduction of different active layers in the product, the aim of this project would not be limited to having a good control over the process parameters; the main goal would be instead achieving an understanding of how the process can be transferred and re-optimized on different materials. There are other projects available at HyET to be discussed, for more information, please contact Dr. Gianluca Limodio.
Available from	November 2020
Type	Experimental
Internal/External	External HyET Solar Flexible lightweight solar modules

Title	**Processing and characterization of novel low band gap GeSn alloys for PV and PV-EC applications**
Daily Supervisor(s)	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl), Thierry de Vrijer (t.devrijer@tudelft.nl) , Dr. Gianluca Limodio **(**g.limodio@tudelft.nl**) ,**
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	Be the first to process this new material! An innovative approach for PV research is that the solar spectrum (0.67-1.12 V) below the silicon band gap will be used as

	well. This will give an additional 0.2-0.4 V to achieve groundbreaking STF conversion efficiencies in photovoltaic-electrochemical (PV-EC) devices and high control of the product selectivity. In addition, in flexible and light weight thin film silicon technology, the low band gap material is a pathway to 18% module conversion efficiency. A low band gap thin-film PV junction based on a-GeSn:H using plasma enhanced chemical vapour deposition (PECVD) will be developed. A great advantage of such a bottom cell is that it will never be current limiting, in a device with 3-5 junctions, since a sufficient number of photons are present in the infrared spectral part (0.67-1.12 V) to generate an additional 20 $mAcm^{-2}$. The bottom junction will also not limit the FF of the total PV component due to this abundance of current density available in the bottom cell. This allows the a-GeSn:H material to have a higher defect density in reference to the other junctions. The research objective of this project is to be the first to develop the a-GeSn:H absorber material. Scientific concepts underlying the proposals here proposed are confidential until completion of the project. The project will consist of an investigation of deposition parameters and their influence on the material properties. Materials with best opto-electrical properties will be used as baseline for absorber layers in lab-scale solar (sub-) cells.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Processing and characterization of novel low band gap Ge-alloys solar cell junctions**
Daily Supervisor(s)	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl), Thierry de Vrijer (t.devrijer@tudelft.nl) , Dr. Gianluca Limodio **(**g.limodio@tudelft.nl**) ,**
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	Be the first to process this new type of solar cells! An innovative approach for PV research is that the solar spectrum (0.67-1.12 V) below the silicon band gap will be used as well. This will give an additional 0.2-0.4 V to achieve groundbreaking STF conversion efficiencies in photovoltaic-electrochemical (PV-EC) devices and high control of the product selectivity. In addition, in flexible and light weight thin-film silicon PV technology, the low band gap material is a pathway to 18% module conversion efficiency. A low band gap thin-film PV junction based on a-Ge:H or nc-Ge:H using plasma enhanced chemical vapour deposition (PECVD) will be developed. The material can be counter doped or alloyed with carbon, oxygen or tin. A great advantage of such a bottom cell is that it will never be current limiting, in a device with 3-5 junctions, since a sufficient number of photons are present in the infrared spectral part (0.67-1.12 V) to generate an additional 20 $mAcm^{-2}$. The bottom junction will also not limit the FF of the total PV component due to this abundance of current density available in the bottom cell. This allows the a-GeSn:H material to have a higher defect density in reference to the other junctions. The research objective of this project is to be the first to develop the Ge:H based solar cell juntion. Scientific concepts underlying the proposals here proposed are confidential until completion of the project. The project will consist

	of an investigation of deposition parameters and their influence on the solar cell properties.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**3D PV components for solar-to-fuel-synthesis**
Daily Supervisor(s)	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	 In this project, we will tackle the outstanding fundamental material challenges to realize direct artificial conversion of light, CO_2 and H_2O into the liquid fuel ethanol. As the responsible limiting electrochemical principles are poorly understood the consortium proposes fundamental scientific concepts to tackle this shortcoming. An inventive approach in which the direct reactions are spatially separated in a system into cascade reaction schemes is proposed. Such a pioneering concept could lead to autonomous solar-to-fuel synthesis systems (SolFuSe) that are based on a cascade reaction scheme in which both consecutive reactions are directly powered by the light incident on the SolFuSe system resulting in high yields in combination with low material utilization and high energy payback times. The fundamental scientific question of the SolFuSe concept is whether a 3D nano-structure of advanced mono-functional materials can act as a multi-functional component: ion-exchanger, photovoltaic current-voltage generator, electrical and chemical passivation, electrochemical catalysts or optical transmittance filter? This project requires innovative processing of 3D photovoltaic (PV) membrane-wrap-through (MWT) electrode assembly (EA) with spatially resolved functionalities on nano- and micro-scale. The 3D wireless PV-MWT-EA component is crucial in the SolFuSe concept (Figure 3.1) to cater the cascade reaction scheme as it includes multiple functionalities such as i) photovoltaic conversion (photon-to-electron); ii) electrochemical conversion (electron-to-chemical bond); iii) low resistive ion transport between electrodes through the MWT; iv) transmission of photons through the MWT to additionally power the consecutive photovoltaic-electrochemical component that facilitates the second reaction in the cascade scheme; and both electrical and chemical passivation of the multiple interfaces.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Lab-scale processing of flexible solar cell in an industrial setting**
Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl), Davide Bartesaghi (HyET)
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)

Short description	This project deals with thin-film, flexible solar cells. Within the framework of FLAMINGOPV project, the aim is to improve the lab-scale baseline processing at HyET Solar. Indeed, after silicon deposition, this consists of many steps; i) back contact sputtering, ii) laser interconnection, iii) lamination of the foil, iv) etching of the temporary Al foil. Unfortunately, some of these steps can introduce in some of the device some losses as shunt and high series resistance that hinder the solar cell performance. This project mainly focuses on optimizing the yield of the lab-scale processed samples. So the identification of the shunt, via introducing new processing methods, is one of the main objectives of this MSc thesis. Therefore, the task will be mainly to follow-up all the processing steps, analyse, identify and characterize all the possible issues emerging during this process. The final objective will be to increase significantly the yield of the lab-samples reducing the efficiency spread to less than 5% relative.
Available from	September 2021
Type	Experimental
Internal/External	External

Title	**Modelling, Analysis, fabrication and characterization of Fluorine Tin Oxide Layers for flexible solar cells application**
Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl), Davide Bartesaghi, Mohammed El Makkaoui (HyET)
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	This project deals with thin-film, flexible solar cells. Within the framework of FLAMINGOPV project, the aim is to improve the front TCO contact. This is a fundamental step to increase the solar cells efficiency. Indeed, the conductivity and transparency of TCO contact are key parameters to design an efficient front contact. This project will be carried out at HyET Solar Netherlands in Arnhem in close collaboration with TUDelft premises and it will regard mostly the understanding of the design rules for TCO contact, fabricate industrial roll-to-roll FTO layers on aluminium and characterize them.
Available from	September 2021
Type	Experimental
Internal/External	Internal/External

Title	**Analysis of outdoor field analysis of thin-film flexible solar cells**
Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl), Davide Bartesaghi (HyET)
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	This project deals with thin-film, flexible solar cells in collaboration with HyET Solar. Currently, to have a complete understanding on how the solar modules behave when they are not in standard test conditions. So the project mainly focuses on the monitoring, analysis, quantification and the investigation of the root cause of the performance degradation over time of the HyET Solar modules in the outdoor setup. The results then will be compared to the standard aging tests performed in parallel at HyET Solar by other researchers.
Available from	September 2021
Type	Experimental
Internal/External	External

Title	**Investigation of in-line measurements techniques for thin-film solar cells production**

Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl), Davide Bartesaghi (HyET), Furkan Sonmez (HyET)
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	This project deals with thin-film, flexible solar cells. Within the framework of FLAMINGOPV project, the aim is to improve the lab-scale baseline processing at HyET Solar. Indeed, after silicon deposition, this consists of many steps; i) back contact sputtering, ii) laser interconnection, iii) lamination of the foil, iv) etching of the temporary Al foil. Unfortunately, some of these steps can introduce in some of the device some losses as shunt and high series resistance that hinder the solar cell performance. This project mainly focuses on optimizing the yield of the lab-scale processed samples. So the identification of the shunt, via introducing new processing methods, is one of the main objectives of this MSc thesis. Therefore, the task will be mainly to follow-up all the processing steps, analyse, identify and characterize all the possible issues emerging during this process. The final objective will be to increase significantly the yield of the lab-samples reducing the efficiency spread to less than 5% relative.
Available from	September 2021
Type	Experimental
Internal/External	External

Title	**Nc-Si single junction solar cells fabrication and analysis on temporary Al foils for flexible solar cells application**
Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl),
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	This project deals with thin-film, flexible solar cells in collaboration with HyET Solar. It is very important to understand the properties of nc-Si solar cells in single junction configuration in view of tandem deployment. The project will be mostly divided in material properties investigation and solar cells fabrication.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Micromorph tandem solar cells fabrication, analysis and modelling on temporary Al foils for flexible solar cells application**
Daily Supervisor(s)	Dr. Gianluca Limodio (g.limodio@tudelft.nl), Dr. Carlos Ruiz
Supervisor	Prof. Dr. Arno Smets (A.H.M.Smets@tudelft.nl)
Short description	This project deals with thin-film, flexible solar cells in collaboration with HyET Solar. Within the framework of FLAMINGOPV project, the aim is to achieve 12% efficiency with a flexible tandem device. This is accomplished via optimization of different layers as doped layers or front window TCO layer and back contact/reflector. The task of this project will be to demonstrate fundamental effect of fabrication parameters via proof-of-concept lab-scale tandem solar cells on flexible devices. In parallel, also opto-electrical modelling is employed to understand the fundamental working principle of the solar cell under investigation.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Development of composition-controlled hybrid organic-inorganic perovskite absorber via thermal evaporation for photovoltaic applications**
Daily Supervisor(s)	Jin Yan (J.Yan-6@tudelft.nl), Dr. Luana Mazzarella (l.mazzarella@tudelft.nl)
Supervisor	Dr. Luana Mazzarella (l.mazzarella@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Recently metal halide perovskites materials demonstrated record efficiencies over 20% in solar cells devices. Semi-transparent perovskite cells are of great interest in the PV community to overcome the theoretical predicted limit for c-Si solar cells. In fact, perovskite top cells with appropriate bandgap can be combined in a tandem configuration with c-Si bottom cells demonstrating conversion efficiencies above 29%. Among the various deposition methods available, thermal evaporation of perovskite shows a great potential for the future industrialization of perovskite solar cells. This preparation method can avoid the unfavourable pinholes and non-uniformity, leading to high film quality and good photoelectrical properties also on large areas. In this project, organic-inorganic lead halide perovskite films, such as CsFAPb(I/Br)3, will be deposited via using co-evaporation of the different sources. The goals of this project are: • Optimize the evaporation rate and ratio of multiple precursor sources to form perovskite films with desired composition and bandgap. • Study and identify the effect of composition of material properties, stability and phase segregation. • Characterization of the structural, optical and electrical properties of the perovskite film with advanced characterization techniques (XRD, XPS, SEM, UV/Vis/NIR absorption spectrometers etc.) • Investigate the compositional, structural differences as function of the film area (up to 6 inches size) • Integration of perovskite absorbers in solar cell devices including characterization on the device level. • Gaining experience in working in a cleanroom environment, use of vacuum equipment for thin-film deposition and glow boxes. The activity will be in collaboration with the department of chemical engineering for advanced material characterizations (TNW).
Available from	November 202
Type	Experimental
Internal/External	Internal

Title	**Investigating the impact of substrate temperature on evaporated perovskite absorber**
Daily Supervisor(s)	Jin Yan (J.Yan-6@tudelft.nl), Dr. Luana Mazzarella (l.mazzarella@tudelft.nl)
Supervisor	Dr. Luana Mazzarella (l.mazzarella@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Metal halide perovskites materials demonstrated record efficiencies over 20% in solar cells devices in the last decades. Semi-transparent perovskite cells are of great interest in the PV community to overcome the theoretical predicted limit for c-Si solar cells. In fact, perovskite top cells with appropriate bandgap can be combined in a tandem configuration with c-Si bottom cells demonstrating conversion efficiencies above 29%. Among the various deposition methods available, thermal evaporation of perovskite shows a great potential for the future industrialization of perovskite solar cells. To ensure a reliable co-evaporation process, it is important to identify the impact of different parameters to develop a more detailed understanding of the film formation. In this project, organic-inorganic lead halide perovskite films will be deposited via co-evaporation from multiple sources to study the influence of the substrate temperature and perovskite precursors ratio on the perovskite optical, electrical and morphological properties. The goals of this project are:

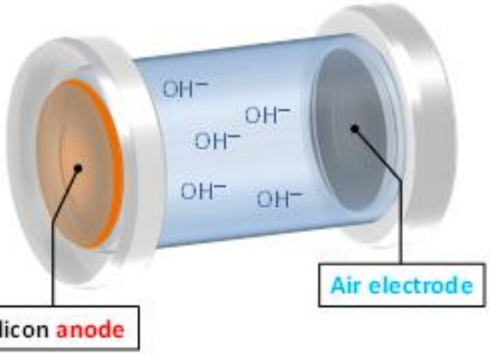
	• Analyse the evaporation of individual precursor and evaluate the adhesion of the organic and inorganic single layers as function of the substrate temperature. • Identify the optimal temperature window and its influence on the perovskite composition, properties, stability and phase segregation. • Characterization of the structural, optical and electrical properties of the perovskite film with advanced characterization techniques (XRD, XPS, SEM, UV/Vis/NIR absorption spectrometers etc.) • Steps for integration of perovskite absorbers in solar cell devices including characterization on the device level. • Gaining experience in working in a cleanroom environment, use of vacuum equipment for thin-film deposition and glow boxes. The activity will be in collaboration with the department of chemical engineering for advanced material characterizations (TNW).
Available from	November 2021
Type	Experimental
Internal/External	Internal

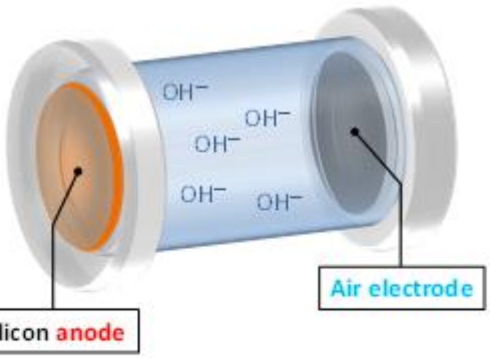
Title	**Development of organic and inorganic transport layers for semi-transparent perovskite solar cells**
Daily Supervisor(s)	Jin Yan (J.Yan-6@tudelft.nl), Dr. Luana Mazzarella (l.mazzarella@tudelft.nl)
Supervisor	Dr. Luana Mazzarella (l.mazzarella@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Recently metal halide perovskites (PVK) has emerged in the photovoltaic community for their outstanding optical and electrical properties. Thin-film perovskite solar cells demonstrated record conversion efficiency over 20% over the last decade. physical vapour deposition (PVD), bring some unique benefits: the exact control of the layer thickness, higher uniformity, conformal growth on various substrates and solvent-free. This project focuses on the development of hole and electron transport layers for their integration in thin-film perovskite solar cells. Selected materials, inorganic (MoOx, TiOx, LiFx) or organic (C60, BCP, NPB, Spiro-TTB) will be growth via thermal or e-beam evaporation and with deposition condition compatible with perovskite absorber. In particular, the activity involves: • Development and optimization of hole- and electron- transport layers via thermal evaporation optimizing deposition processes, material properties and post deposition treatments. • Particular attention will be paid to the optical and electrical properties of the deposited material and their integration on device level. • Control of the material properties and quality: conformal, uniform and large area films (up to 6 inches substrates) • First steps to integrate those layers at device level with perovskite or c-Si absorbers. • Gaining experience in working in a cleanroom environment, use of vacuum equipment for thin-film deposition and glow boxes. The activity will be in collaboration with the department of chemical engineering for advanced material characterizations (TNW).
Available from	November 2021
Type	Experimental
Internal/External	Internal

Title	**Optimization of low temperature tin-doped indium oxide layer for semi-transparent perovskite solar cells**
Daily Supervisor(s)	Dr. Luana Mazzarella (l.mazzarella@tudelft.nl), Jin Yan (J.Yan-6@tudelft.nl)
Supervisor	Dr. Luana Mazzarella (l.mazzarella@tudelft.nl), Dr. Olindo Isabella (o.isabella@tudelft.nl)

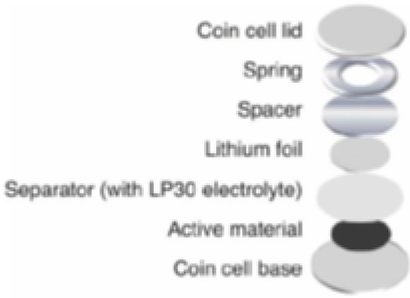
Short description	Transparent conductive oxides (TCOs) are widely used as the transparent contact material in most c-Si and thin-film solar cells. Among them, tin-doped indium oxide (ITO) layer has excellent optical properties and a low sheet resistance. In the recent developments of perovskite solar cells, TCO can be applied to both as front contact layer or tunnel recombination junction in single or tandem solar cells, respectively. In this project, design and optimization of TCO layers will be carried out to fulfil the specific requirements of perovskite and organic materials, such as low deposition temperature and soft deposition conditions. The optimized films will also be characterized by means of advanced technique by tuning the deposition conditions to find a trade-off between these properties. The goals of this project are: • Development of ITO layers via magnetron sputtering optimizing the interplay of deposition parameters and post deposition annealing. • Characterization of the optical and electrical properties of the deposited material via UVi/Vis/NIR spectrometers, Hall set up, sheet resistance etc. • Optimization of the growth condition for uniform, conformal and large area films onto different substrates • Integration of the optimized ITO layers on different types of solar cells including device fabrication and characterization. • Study the effect of various substrates (glass and transport layers) and surface morphology (flat and texture) and post-deposition treatments on ITO film quality.
Available from	November 2021
Type	Experimental
Internal/External	Internal

Area #3: Silicon/Air batteries

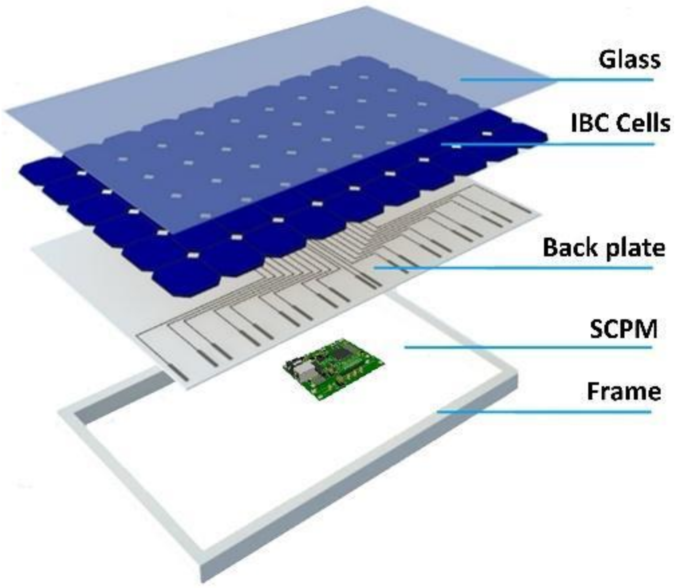
Title	**Mitigation of corrosion in a silicon-air battery**
Daily Supervisor(s)	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Short description	Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards batteries, primarily to Li-ion batteries. In this project, however, we investigate silicon-air batteries. Silicon is abundant and non-toxic, and can be processed relatively easy. Silicon-air batteries potentially have a higher energy density than some other technologies.  During operation of a silicon-air battery, a large fraction of the silicon is consumed in parasitic corrosion reaction. In this project we aim to investigate ways with which this corrosion can be mitigated. Two ways will be investigated: design of the silicon anode and change of the chemistry in the electrolyte. For this project you will need to: • Write a literature review on silicon-air batteries; • Learn to operate relevant processing equipment; • Carry out discharge experiments to test the batteries; • Work on a model correlating the texture to battery operation.
Available from	1 September 2021
Type	Experimental
Internal/External	Internal

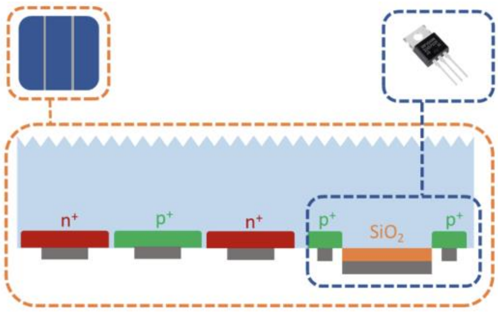
Title	**Using silicon alloys for silicon-air battery**
Daily Supervisor(s)	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Short description	Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards batteries, primarily to Li-ion batteries to Li-ion batteries. In this project, however, we investigate silicon-air batteries. Silicon is abundant and non-toxic, and can be processed relatively easy. Silicon-air batteries potentially have a higher energy density than some other technologies 

	In this project we investigate different silicon alloys for application as the anode in silicon-air batteries. These alloys will be deposited using CVD techniques, varying the composition and the structural properties of the materials. By variation of the composition and structural properties the battery performance may be influenced and optimized. For this project you will need to: • Write a literature review on silicon-air batteries; • Learn to operate relevant processing equipment; • Carry out discharge experiments to test the batteries; • Work out a model explaining the influence of the composition and structural properties on battery operation.
Available from	1 September 2021
Type	Experimental
Internal/External	Internal

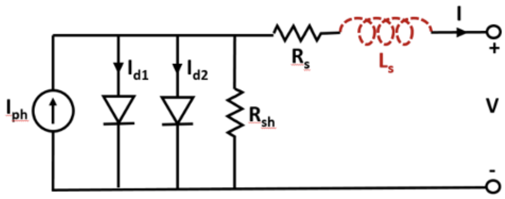
Title	**Using silicon alloys for Li-ion based batteries**
Daily Supervisor(s)	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor	Dr. René van Swaaij (R.A.C.M.M.vanSwaaij@tudelft.nl)
Short description	Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards Li-ion batteries. The anode material used in these cells is usually based on carbon, like graphite. In this project we investigate different silicon alloys for application as the anode in Li-ion batteries. This project is carried out in cooperation with another research group. These alloys will be deposited using CVD techniques, varying the composition and the structural properties of the materials. By variation of the composition and structural properties the battery performance may be influenced and optimized, at a range of charging and discharging conditions.  For this project you will need to: • Write a literature review on Li-ion batteries; • Learn to operate relevant processing equipment; • Carry out discharge experiments to test the batteries; • Work out a model explaining the influence of the composition and structural properties on battery operation.
Available from	1 October 2021
Type	Experimental
Internal/External	Internal

Area #4: Photovoltatronics



Title	**Integration of a power MOSFET into the body of an IBC solar cell**
Daily Supervisor(s)	David van Nijen (D.A.vanNijen@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	Power transistors play an important role in PV systems. For example, high-frequency switches are crucial for the operation of power converters. Alternatively, low on-resistance power transistors are necessary to realize innovative concepts, such as reconfigurable modules. It is worth to note that, even with module-level solutions such as power optimizers and reconfigurable PV modules, the power electronics is a module add-on: the converter or the reconfiguration matrix are physically realized on a printed circuit board (PCB). Wiring among the power transistors and the other electronic components is done on the PCB and the complete solution is then placed into a junction box that is finally added to the PV module. The same approach is used also for small PV-based devices, such as Internet of Things (IoT) nodes relying on PV harvesters: the power electronics needed to optimally control the operating point of the PV generator is realized on a PCB and then connected to the PV source. Interestingly enough, transistors are made of semiconductor material, just like solar cells. Therefore, it might be possible to actually save up a tiny part of the solar cell area for integration of one or more power transistors. Successful integration of power transistors into solar cells would reduce the burden of external power electronics and – even more exciting – pave the way towards cell-level power conversion. As submodule power conversion would reduce energy losses due to partial shading effects, this technology could substantially increase the energy yield of PV modules in urban areas. Furthermore, the integration of power transistors could completely change the design of PV harvesters for IoT applications. 

	In this thesis project, a power MOSFET is fabricated on a crystalline silicon PV wafer. The project can be broken down into the following sections: 1. Optimizing the MOSFET fabrication process (experimental) 2. Investigate the effect of illumination on the MOSFET performance (experimental) 3. Investigate the interaction between the MOSFET and solar cell performance (experimental)
Available from	June 2021
Type	Experimental
Internal/External	Internal

Title	**Integration of an inductor into an IBC solar cell**
Daily Supervisor(s)	David van Nijen (D.A.vanNijen@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	In both research and industry, we can observe a clear trend of increasing power electronics in PV systems. For example, numerous modern PV system architectures already make use of one power optimizer per module. This way, the performance of PV systems under non-uniform illumination conditions improves substantially. Furthermore, being able to independently set the operating point of small groups of cells rather than the one of a string of PV modules increases the overall PV system's flexibility and enable implementation and deployment of *ad-hoc* (sub-)module-level control, safety and diagnostic measures. Power optimizers for PV applications are basically DC-DC converters – usually *buck*, *boost* or *buck-boost converters* owing to their simplicity – in which the inductor is often the most bulky and expensive component. In this thesis project, the student will investigate the possibility of re-designing an IBC solar cell so that its self-inductance increases. A PV cell with increased self-inductance can be described by the following equivalent circuit:  One of the major benefits of this approach is evident when we consider a boost converter connected to the solar cell: the inductor can be left out of the converter. Thus, the size and costs of this external converter can be significantly reduced. Successful realization of solar cells with increased self-inductance would reduce the burden of external power electronics and – even more exciting – pave the way towards cell-level power conversion. As submodule power conversion would reduce energy losses due to partial shading effects, this technology could substantially increase the energy yield of PV modules in urban areas. Furthermore, it could enable distributed control and diagnosis within PV systems. In this thesis project, the self-inductance of IBC solar cells is increased by re-designing the cell. The project can be broken down into the following sections: 1. Characterizing the self-inductance of existing PV cells (experimental) 2. Optimizing an IBC cell design with a spiral-like metallization pattern (simulation) 3. Fabricating and characterizing IBC cells with increased self-inductance (experimental)
Available from	June 2021
Type	Experimental, Modelling/Simulation
Internal/External	Internal

Title	**Measuring thermal distribution over PV modules through integrated sensors**

Daily Supervisor(s)	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	PV modules performance and lifetime are very sensitive to the cell's operating temperature. One problem among all, long lasting exposure to high temperature, e.g. due to hot spots, can irreversibly damage a solar cell. Nowadays, thermal sensing (if any) is done by attaching few thermocouples to the back side of PV modules, or by shooting thermal pictures with drones. In the first case, the spatial resolution of the sensing is too limited (e.g. 2-3 sensors for a 60-cell module), whereas in the second case the temporal resolution is too little (drone flights are done e.g. once a week or when unexpectedly low performance are detected at system level). Ideally, thermal sensors should be embedded in the PV module laminate, as integral part of the generator. Your goal will be to build-up a demonstrator of PV module with integrated thermal sensors and validate its performance through indoor and outdoor measurements. This will happen in different steps: 1. Selection of proper sensor devices, with measurable temperature dependency and a form factor allowing their lamination within PV modules 2. Characterization of the selected devices 3. Design of the control circuit and fabrication of the control board 4. Fabrication of the PV demonstrator, where sensors are embedded within the PV module laminate 5. Validation.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Characterization and modelling of PV cells impedance**
Daily Supervisor(s)	Dr. Mirco Muttillo (M.Muttillo@tudelft.nl) and David van Nijen (D.A.vanNijen@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	Processing the power generated from a PV module is mandatory to ensure optimal operation of the module and maximize its energy production. Novel technologies based on wide bandgap semiconductors, such as GaN and SiC, promise a strong reduction of the converter size in terms of both active (switches) and passive (inductor, capacitor) components, thanks to their higher switching frequency. At the same time, with the rise of switching frequency, the parasitic capacitance and inductance of PV cells become more and more important, and can in theory (partly) replace the input filter of e.g. boost-type power optimizers. Your goal will be to evaluate the impedance of various types of solar cell under different illumination levels, and to model this distributed impedance for different metallization shapes and cell technologies. This goal will be achieved with the following steps: 1. Realization of a characterization setup for the measurement of PV cell impedance under different illumination and bias conditions 2. Preparation of samples, using market-available PV cells as well as in-house-fabricated devices 3. Development of PV impedance's models for different cell technologies 4. Validation of models with measured data
Available from	September 2021
Type	Experimental, Modelling
Internal/External	Internal

Title	**Photovoltaic cells for combined energy harvesting and Visible Light Communication**
Daily Supervisor(s)	Dr. Mirco Muttillo (M.Muttillo@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	The considerable increase in the number of devices needing connectivity, such as mobile phones and Internet of Things (IoT) devices, has led to an exponential rise in data volumes

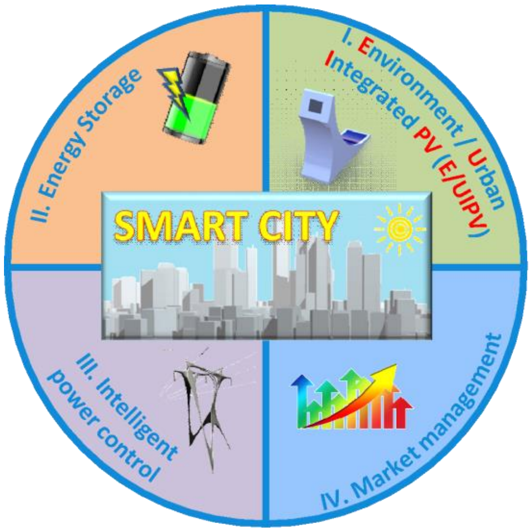
	during the last year, that will surely continue over the next decade. Therefore, it will be increasingly challenging to provide sufficient RF resources. A novel alternative to RF communications is the so-called Visible Light Communication (VLC). VLC is a communication technology that uses the visible light as information carrier. The use of VLC for indoor applications has been rapidly growing during the last years – Light Fidelity (LiFi) technology is an example of VLC application – with photodiodes being the most widely used receiving devices. However, to make VLC a realistic and widespread alternative to RF communication, the receiver should work optimally both indoor and outdoor. Photovoltaic cells represent a relevant alternative to photodiodes, with the additional advantage of being able to both produce energy and serve as receiving device. However, optimal performance as power generator do not necessarily mean optimal performance as receiver in VLC links. The goal of this project is to study and model different PV cell technologies, from c-Si up to CdTe, CIGS and multi-junction devices, to find out which one allows for the best trade-off between optimal energy harvesting and maximum bandwidth for communication. The project can be divided in the following sections: 1. Literature study on DC and AC models of PV cells (physics of operation; effect of bias voltage and light) 2. Implementation of models for the different technologies, in both DC and AC domains 3. Measuring the bandwidth of a variety of solar cells in different operating points 4. Validation of developed models
Available from	September 2021
Type	Experimental, Modelling
Internal/External	Internal

Title	**Analysis of different light sources for indoor and outdoor PV-based Visible Light Communication**
Daily Supervisor(s)	Dr. Mirco Muttillo (M.Muttillo@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	The considerable increase in the number of devices needing connectivity, such as mobile phones and Internet of Things (IoT) devices, has led to an exponential rise in data volumes during the last year, that will surely continue over the next decade. Therefore, it will be increasingly challenging to provide sufficient RF resources. A novel alternative to RF communications is the so-called Visible Light Communication (VLC). VLC is a communication technology that uses the visible light as information carrier. The use of VLC for indoor applications has been rapidly growing during the last years – Light Fidelity (LiFi) technology is an example of VLC application – with photodiodes being the most widely used receiving devices. However, looking at both indoor and outdoor communication, photovoltaic cells represent a relevant alternative for detecting the information. One of the advantages of using a PV cell as receiver is the huge sensitive area for detection of the information that simplifies alignment between transmitter and receiver. Different light sources can be used in VLC. Typically, either LEDs or LASERs are considered, depending on the characteristics of the link (such as distance, type of receiver, indoor/outdoor application). These light sources differ in terms of spectrum, directionality, optical power density and bandwidth. The performance of the whole VLC link strongly depends on the characteristics of the light source, since it affects the ability of the receiver – a PV device in this case – to detect the information when it *overlaps* with the ambient light, that can reach very high values, especially in outdoor application where the ambient light is the sunlight. Therefore, the modelling and analysis of the performance of different light source in a PV-based VLC link is as useful, since it will pave the way towards the realization of the PV-based communication system of the future, as non-trivial; and it is the focus of this thesis project. The project goals will be achieved with the following steps:

	1. Studying the characteristics of different light sources to understand their advantages and drawbacks in PV-based VLC 2. Development of models of the PV-based VLC link, with focus on the light source 3. Realization of a test setup, to characterize different light sources, both indoor and outdoor 4. Validation of developed models
Available from	September 2021
Type	Experimental, Modelling
Internal/External	Internal

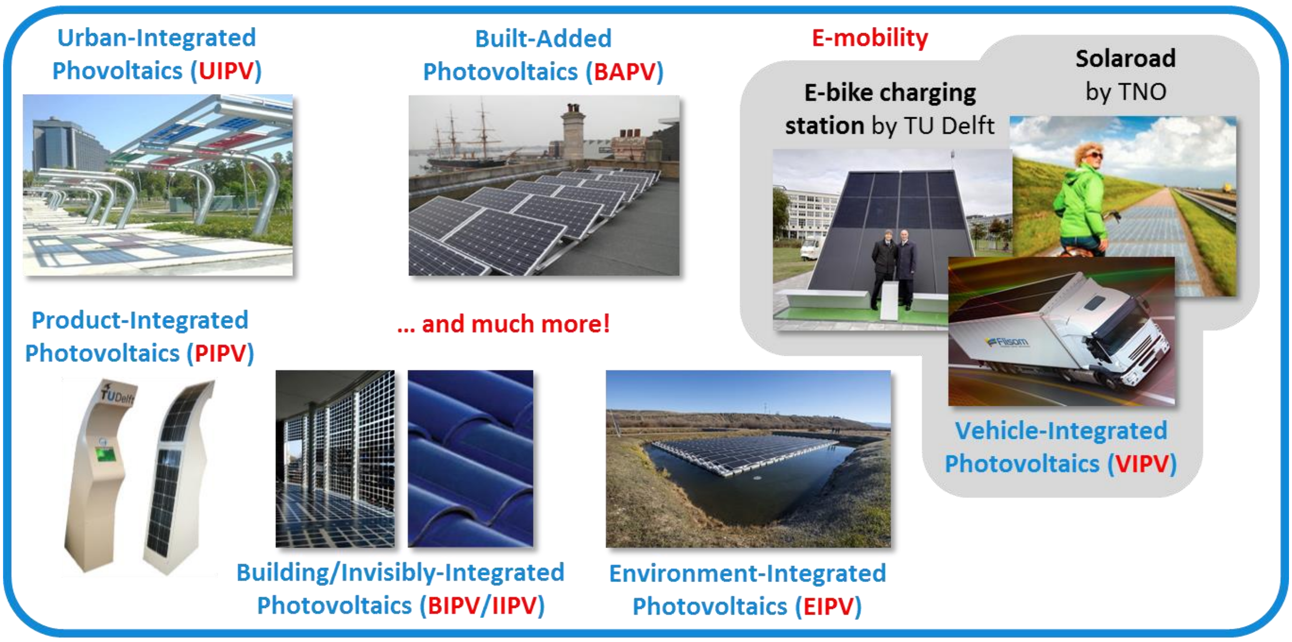
Title	**Development of an autonomous IoT device for VLC applications using a PV cell as receiver and power source**
Daily Supervisor(s)	Dr. Mirco Muttillo (M.Muttillo@tudelft.nl)
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	The considerable increase in the number of devices needing connectivity, such as mobile phones and Internet of Things (IoT) devices, has led to an exponential rise in data volumes during the last year, that will surely continue over the next decade. Therefore, it will be increasingly challenging to provide sufficient RF resources. A novel alternative to RF communications is the so-called Visible Light Communication (VLC). VLC is a communication technology that uses visible light as information carrier. The use of VLC for indoor applications has been rapidly growing during the last years – Light Fidelity (LiFi) technology is an example of VLC application – with photodiodes being the most widely used receiving devices. However, looking at both indoor and outdoor communication, photovoltaic cells represent a relevant alternative for detecting the information. The main advantage of using a PV cell is that it allows combination of energy harvesting and data transmission in one single device. In this research, you will design an autonomous IoT device that combines Maximum Power Point Tracking (MPPT) capabilities – to charge an integrated battery – and PV-based VLC. You will also build a first prototype. Such a demonstrator must integrate, together with the PV cell, the electronic circuits performing MPPT and data extraction/demodulation and analysis. The research activities can be further divided into the following step: 1. Market search and theoretical study, aiming at selection of the PV technology to be used with the demonstrator (best trade-off between efficiency and bandwidth). 2. Design and realization of the electronic circuits for MPPT and data elaboration 3. Study of the effect of sunlight on the overall performance of the device, especially on maximum reachable datarate 4. Experimental verification
Available from	September 2021
Type	Experimental, Modelling
Internal/External	Internal

Area #5: X-Integrated PV systems (XIPV)



As mankind population grows, providing with energy, water and food is among the ten top challenges for next 50 years[1]. The share of electricity in the total energy mix will increase in future and this trend is particularly valid for cities and urban areas. Today electricity networks are mostly mono-directional with power flux being transported and distributed from a central power station (gas, coal, nuclear) to the end users. However, a significant transition in energy mix from the fossil fuels to renewable energy sources is recently ongoing[2]. Such transition has a strong impact on electricity networks that must be re-designed to allow a high penetration of electricity generated from renewable sources, such as solar and wind energy. In these novel networks, often called *Smart Grids*, power flux flows in two directions, from and to the consumer, since the consumer can generate electricity and use it on site or feed it to the grid. This new electricity infrastructure will be implemented in present and future urban areas making them smart too. The main pillars of the future electricity infrastructure in cities will be (i) grid-connected environment / urban integrated photovoltaics (XIPV), (ii) energy storage, (iii) intelligent power control and (iv) market management.

The ESE department possesses such expertise and the PVMD group focusses especially on XIPV. The notion of EIPV systems includes not only classical low environmental-impact built-added PV (BAPV) and modern building integrated PV (BIPV) systems but also those PV systems that are incorporated both aesthetically and functionally in the place of installation. These can be flexibly-expandable modular systems, designed to exhibit both very high yearly energy autarky (self-consumption) and/or very yearly energy yield. The PVMD group is active in the R&D of a comprehensive energy yield modelling (i.e. from DC side to AC side) of customized PV systems as indicated in the flow chart below.



[1] Prof. R. E. Smalley (Rice University), the 27th Illinois Junior Science & Humanities Symposium (2005).

[2] Prof. E. J. Moniz (MIT) Lecture at Delft University of Technology (2010).

Title	Analysis of Solar PV Glare in the Urban Environment
Daily Supervisor(s)	Yilong Zhou (Y.Zhou-15@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	The expansion of urban PV systems brings up the concern that the reflection from PV modules will cause glare to neighbors. In a densely constructed city, glare can occur when you have PV systems installed on the rooftops of low rises where the solar reflections travel to the surrounding high rises. This issue is more detrimental at an airport, because glares from the PV system can blind the pilots or people working in the control tower which can lead to tragic accidents. This project aims to investigate the potential glare issues caused by solar systems in the urban environment. This is a hybrid project including modelling, algorithm development and implementation. The main research questions for this project include: How can we predict the glare of different PV modules and how big is its impact on the neighbors and aviation. For any urban PV system to be built, can we propose the mounting parameters to minimize the glare? For any urban PV system installed, what are the possible remedial measures to reduce the glare? To what extend can anti-reflective coating effectively reduce glare issue. To answer these research questions, first a computational model must be developed to realize the prediction of glare of any PV systems given the input of optical characteristics of the PV module. After that, experiments shall be conducted on various PV modules to determine their optical behavior. By feeding in the measured data, the model should generate a map for the selected neighborhood to visualize and analyze the glare. Optimal mounting parameters should also be delivered as one of the model outputs. Therefore, this project can be broken down into following: Research on optical models for urban glare issue analysis. Develop the algorithm to predict glare and visualize the dead angles/zones. Conduct experiment to determine the optical parameters of various PV modules. Implement the algorithm at one of the airports in the NL. Analyze, visualize and report the results. *(requirement for the project: student with background in Optics and proficiency in Matlab will accelerate the progress of this project)*
Available from	October 2021
Type	Modeling/Simulation
Internal/External	Internal

Title	Optical Filter Coated PV Cell for Noise-free Outdoor LiFi Application
Daily Supervisor(s)	Yilong Zhou (y.zhou-15@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	Light-fidelity (LiFi), also called visible light communication (VLC), has recently gained huge interest. In such a communication system, an optical sensor translates the received luminous modulation flux into an electrical signal which is further decoded. To consider LiFi as an alternative solution for wireless communication, the receiver must be operational in both indoor and outdoor conditions. Currently, the most widely used receiver is based on avalanche photodetector (APD), but its frequency response deteriorates drastically under outdoor conditions when it is exposed to the sunlight of more than 200 W/m^2. PV cells could appear as a solution to this issue because it was invented for outdoor application. It can convert the modulated light signal into electrical signal without any external power requirements, and meanwhile electricity can be generated from the DC component of the light. However, the sunlight spectrum is quite broad compared to that of artificial light sources. The wavelength that does not contribute to VLC can bring noise to the system and degrade its communication performance. In this

	project, you will be analyzing the effect of noises on PV cell performance in outdoor LiFi application, and design an optical filter to realize noise-free VLC for PV cells. The project can be broken down into following steps: 1. A deep theoretical research on effect of noise on outdoor LiFi receivers. 2. Design experiment to find the low Signal to Noise Ratio (SNR) wavelength range under AM1.5 background spectrum of different PV cells. 3. Design the optical filter and deposit it on commercial PV cells in the cleanroom. 4. Test and characterize the final optical filter coated PV cells in outdoor LiFi application. 5. Report. *(requirement for the project: students with background in physics or communication technology)*
Available from	December 2021
Type	Simulation/experiment
Internal/External	Internal

Title	**Study the Effect of Urban Development on Urban Albedo and Solar PV Potential based on LiDAR Data**
Daily Supervisor(s)	Yilong Zhou (y.zhou-15@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	In recent years, PV penetration in urban environment sees a large ramp-up due to its flexibility in integration with urban elements. Designing PV systems in the urban context requires additional considerations, because densely constructed cities limit the incoming sunlight and the rich urban morphology introduces complex shading patterns. To understand and analyze the urban environment, Light Detecting and Ranging (LiDAR) technology is widely investigated where laser light is used to densely sample the surface of the earth. From 1996 to 2002, the Dutch government created its first version of LiDAR data of the entire Netherlands (AHN1 (Actueel Hoogtebestand Nederland 1)). This Geo-data has been upgraded over the course of country development, and the latest version will be released in 2022 (AHN4). As this dataset provides the information of urban development, it can be used to study the effect of urban development on solar PV potential. By learning from this trend and considering few future scenarios for urban development as well as PV technology improvement, we can draw a more realistic prospective of the PV potential in the future. This can eventually make an impact on future energy predictions and electrical grid functionality. In this project, the municipality of Delft will be used as the study case and investigated in great detail. The main research questions for this project: How does the urban development affects the solar PV potential and local urban albedo, and what conclusions/suggestions can we draw based on the research for the future urban PV integration and energy prediction? The project can be broken down into following steps: 1. In-depth research on different versions of LiDAR data (AHN1 to AHN4) 2. Calculate the urban albedo for each AHN data set by investigating the roughness of urban fabric. 3. Reconstruct 3D building models (Level of Detail 2) for the municipality of Delft 4. Investigate the change in solar PV potential over the course of urban development (several coefficients can be proposed such as plot ratio, building volume ratio, etc.) 5. Report *(requirement for the project: proficiency in Matlab)*
Available from	September 2021
Type	Modeling/Simulation
Internal/External	Internal

Title	**Control Strategy for PV-powered Electrolyzer**
Daily Supervisor(s)	Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl>)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	Water electrolyzers are well suited for using under variable power conditions. However, electrolyzers must be stopped when there is not enough input power for safety reasons. Frequent stop-start cycles lead to the reduction of the lifetime of the electrolyzer and these cycles depend on the solar variability of the site. To prevent frequent stop-start cycles, a small storage unit can be used to smooth the power to the electrolyzer. This project will result in a control strategy for such unit. A validation of the control strategy will be performed using a hardware emulator. A background in electrical engineering can accelerate the project.
Available from	December 2021
Type	Modeling/Simulation
Internal/External	Internal

Title	**Albedometer v3.0**
Daily Supervisor(s)	Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl>)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	A spectrally-resolved albedometer is being developed by the PVMD group. So far two version of the instruments has been made, with several innovative aspects. This instrument measures the irradiance over several spectral bands. A newer version of this instrument will be made in this project, which has two main aspects: (1) Testing the previous version (albedometer v2.0) for ingress protection, climate chamber, and also long-term monitoring for self-reading corrections (2) further increase the spectral resolution of this instrument. The first part will be done by sending out the current version of the instrument for external test and measure its performance afterwards. Second part is divided into hardware and software improvements. At hardware level, sensing devices should be further tunned and on the software level a logic to reconstruction of the irradiance spectrum will be implemented. This reconstruction will be based on the measured quantities and inputs from the user. The Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) software will be used as a starting point for spectral irradiance reconstruction. At the end of the project the new version of the instrument will be tested and calibrated under field conditions.
Available from	October 2021
Type	Modeling/Simulation
Internal/External	Internal

Title	**Cloud resolving models v2.0**
Daily Supervisor(s)	Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl>)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	Short-term prediction of irradiance (minute-scale) is important for the control of industrial processes powered by solar energy and power systems. All-Sky imagers (sky-cameras) along with deep learning algorithms can help in the prediction of the short-term irradiance. However, these algorithms fail under cloudy (and very variable) conditions. One option to improve the accuracy of the models is to use hybrid models, combining classification with deep learning. The objective of this project is to improve the recently developed model in PVMD group for irradiance prediction. This second version of the model will incorporate hybridization and comparison against cloud-vector prediction.
Available from	September 2021
Type	Modeling/Simulation
Internal/External	Internal

Title	**Bifacial Tracking Algorithm**
Daily Supervisor(s)	Arturo Martinez Lopez (V.A.MartinezLopez@tudelft.nl>)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	This project will produce a universal algorithm for bifacial tracking targeting the reduction of intra-hour variability while maximizing the power output. Nevertheless, its viability vs fixed systems must be explored. This includes the determination of the total power output considering the power needed to control the tracker. To develop the algorithm, measurements will be taken at the monitoring station of the PVMD to identify the involved variables of the algorithm. Once it has been developed, a validation will be carried out in the same installation with commercially available bifacial modules.
Available from	April 2022
Type	Modeling/experimental
Internal/External	Internal

Title	**Design and fabrication of heatsink for photovoltaic modules**
Daily Supervisor(s)	Juan Camilo Ortiz Lizcano (J.C.OrtizLizcano@tudelft.nl), Hesan Ziar (h.ziar@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl) Olindo Isabella (o.isabella@tudelft.nl)
Short description	Currently, Silicon based single junction PV modules are reaching their theoretical limit when tested under Standard test conditions (STC). However, under outdoor working conditions, the energy yield from a PV module can be significantly reduced due to high operational temperatures. Efficient thermal management of PV modules can not only improve its efficiency but be beneficial to its reliability. One thermal management approach for PV modules is to reduce their operational temperature by using heat sinks. The aim of this project to design, fabricate and use a heatsink(s) for PV modules and compare how its performance compares with standard PV modules. In this research, we are aiming at designing and fabricating heatsinks for several 60 × 60 cm2 PV modules, including the use of different type of cells, encapsulation materials, interconnecting sheet, frames, etc. After the fabrication phase, performance comparisons will be carried for modules with and without heatsink. Extensive internal tests, such as STC test, electroluminescence test, temperature profile test, etc. will be run in a laboratory environment to study and further improve the design of the heatsink (material, size, thickness, and geometry). At each case, cost for bill of material will also be considered. Then, selected modules will be installed outdoor, and their performance will be monitored. Finally, an optimum heatsink design will be suggested. A good knowledge of photovoltaic and solar energy is required. Background of mechanical engineering is preferred.
Available from	September 2021
Type	Experimental
Internal/External	Internal

Title	**Floating PV yield simulation and validation considering wave effect**
Daily Supervisor(s)	Alba Alcañiz Moya (A.AlcanizMoya@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	PV plants tend to occupy a considerable amount of area. With the expanse of PV systems, agriculture and energy sectors might compete or already are competing over land. One of the solutions to this problem would be to place PV systems on another vastly available surface area: the water. These installations are referred as floating PV. Placing the PV systems on top of water bodies has effects on its power production. Even though the PVMD toolbox has already considered some of these effects, there is one consideration not taken into account: the movement of water. Waves can modify the tilt and azimuth

	of the PV modules, having strong consequences on the PV power production and also operation of inverter. This project peruses two key aspects: 1. The goal of this project is to simulate the effect of wave movement on floating PV systems, implement it into the PVMD toolbox and validate it with system data. 2. Quantify the effect of perpetual movement of PV modules in floating PV array on inverter efficiency through in-lab measurements. This project is a part of European Trust PV project (https://trust-pv.eu/). Good programming skills in MATLAB are required.
Available from	September 2021
Type	Modeling/experimental
Internal/External	Internal-collaboration with Trust PV partners

Title	**Irradiance sensor optimizer for PV plants**
Daily Supervisor(s)	Alba Alcañiz Moya (A.AlcanizMoya@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	With the increasing share of electricity generated by PV systems, it is important to know as accurately as possible the amount of photovoltaic power that will be generated in order to prevent grid stability issues. When predicting the photovoltaic power produced, an accurate irradiance measurement is essential, which often implies placing irradiance sensors along the terrain. However, the location and number of these sensors need to be properly determined in order to be as representative as possible of all the photovoltaic modules within the area. This is an issue often encountered by photovoltaic plants planners and specialists in the measurement of solar radiation. The goal of this project is to determine the suitable number of irradiance sensors and its location within a certain area. Height data will be used to analyse the topology of the terrain and the surrounding obstacles. These will affect the incident irradiance differently across the terrain so that a map with the irradiance in each point will be built. With that information, the most suitable number of sensors and its location can be determined. By integrating this algorithm into an interactive software, photovoltaic plants planners and similar specialists can find the most suitable location for their sensors. This project is related to European Trust PV project (https://trust-pv.eu/). Good programming skills in MATLAB are required, *as well as being open to learning other programming languages.*
Available from	July 2021
Type	Modeling/Simulation
Internal/External	Internal

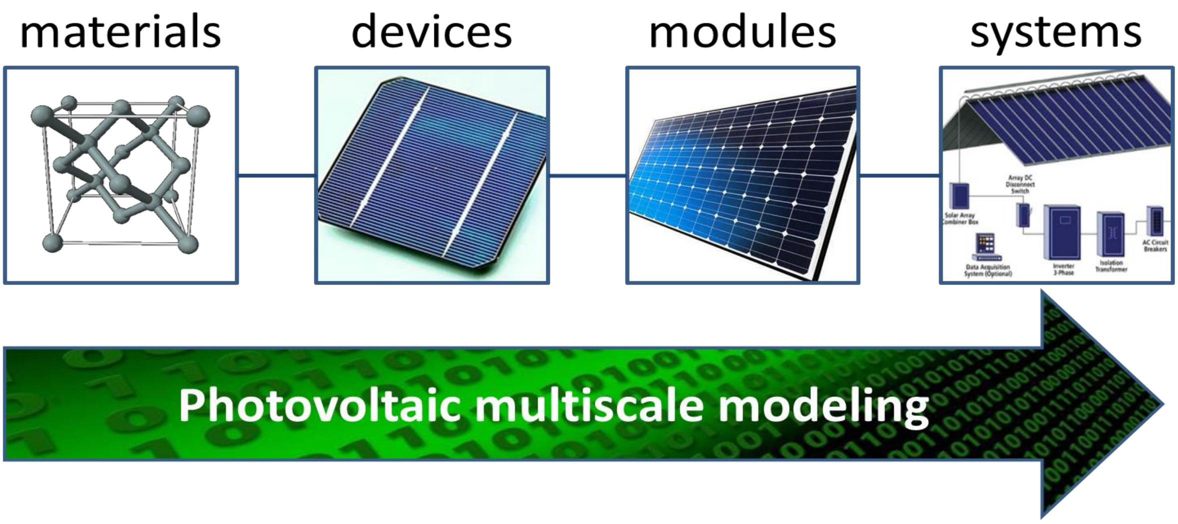
Title	**Calculation tool for PV modules shading tolerability**
Daily Supervisor(s)	Alba Alcañiz Moya (A.AlcanizMoya@tudelft.nl), Hesan Ziar (h.ziar@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)

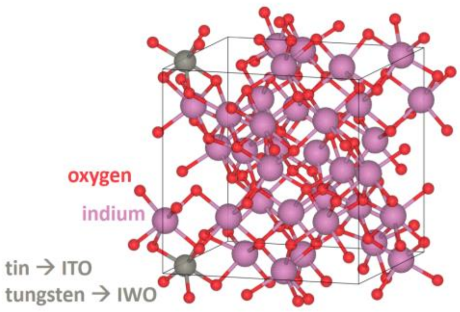
Short description	PV module are being installed everywhere. In urban areas shading is more frequent. It is thus of great importance to distinguish and rate PV modules in terms of their shading tolerability. However, from a PV module point of view that is now being produced on a factory line, shading has a random nature as the module itself does not know where it is going to be placed and what shading profile is going to experience. Therefore, a probabilistic approach is needed to calculate shading tolerability of PV modules. This was already done in 2017 by PVMD group (reference paper 1). Now, within a European consortium, PVMD group is trying to establish shading tolerability as a ranking parameter on PV modules datasheets and establish design rules for shade tolerant PV modules. To achieve this, a simulation tool will be developed in this project. The aim of the tool is to quickly calculate shading tolerability of a PV module given specific inputs (cell technology, interconnections, bypasses, size and shape of the cells, etc.). MATLAB will be used as the coding environment. Then, the tool will be used to make a database of shading tolerability for PV modules available in the market. Alongside this activity, for several modules shading tolerability will be measured in-lab and also the measured data from other Trust PV partners will be collected. Ultimately these measured data will also be added to the database. This project is a part of European Trust PV project (https://trust-pv.eu/). A good MATLAB programming skill is required for this project. Before applying, please read the following two papers about the shading tolerability: 1. H. Ziar, et. al. "Quantification of shading tolerability for photovoltaic modules." IEEE JPV 7, no. 5 (2017): 1390-1399. 2. S. Mishra, et. al. "Selection map for PV module installation based on shading tolerability and temperature coefficient." IEEE JPV 9, no. 3 (2019): 872-880.
Available from	September 2021
Type	Modeling/Simulation
Internal/External	Internal-collaboration with Trust PV partners

Title	**Photovoltaic potential on Mars**
Daily Supervisor(s)	Hesan Ziar (h.ziar@tudelft.nl)
Supervisor	Hesan Ziar (h.ziar@tudelft.nl)
Short description	Either for further exploring the universe, or to have industries in a lower-gravity planet, or even as an escape plan, Mars looks like an interesting planet. At the PVMD group of TU Delft, we have experience in PV potential modelling ranging from mono-facial rooftops in urban areas to floating bifacials on waterways, but all are on Earth. However, in this project we aim to focus on a neighbor planet, Mars. It will bring several interesting challenges; we might even need to tweak a few definitions. The key questions are however about three main features on Mars (i) irradiance, (ii) temperature, (iii) geometry. Studying PV potential on Mars might raise a lot of questions already in our heads but the ultimate goal of this project is: *Calculating Martian year energy yield of an optimally designed imaginary PV system installed on the planet Mars*. Background in physics would accelerate the project progress.
Available from	November 2021
Type	Modeling/Simulation
Internal/External	Internal

Area #6: Photovoltaic Multiscale Modelling

For MSc students interested in this area, we recommend the course Photovoltaic Modeling (EE4680), starting in Q5.



Title	**Density functional theory (DFT) calculations of photovoltaic materials**
Daily Supervisor(s)	Paul Procel Moya (P.A.ProcelMoya@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	Within the PVMD group we use device simulation software to analyse new solar cell designs. Input for these simulations are the opto-electrical properties, such as refractive index or density of states, of each solar cell material. These material properties are usually derived from measurements but could also be derived from first principles using density functional theory (DFT). In this project you will be using commercially available DFT software, running on a powerful server, to calculate the material properties of novel photovoltaic materials. You will be validating your results against material properties measured in our lab. Finally, you will be using the opto-electrical material properties, obtained from DFT, as input for device simulations to identify promising new solar cell designs. 
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Opto-electrical simulations of perovskite / silicon tandem solar cells**
Daily Supervisor(s)	Paul Procel Moya (P.A.ProcelMoya@tudelft.nl), Carlos Ruiz Tobon (C.M.RuizTobon@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	To achieve conversion efficiencies of solar cells above 30% a better utilization of the solar spectrum is required. This can be done by a tandem solar cell approach in which a crystalline silicon (c-Si) solar cell is used as the bottom cell and perovskite solar cell as the top cell.

	However, it is still a challenge to achieve >30% efficiency tandem cells due to their inherent complexity. Most of them are related to: i) understanding of optical-electrical coupling/interconnect between the component cells depending on the bandgap of a perovskite absorber, ii) design of a tandem device that maximizes power conversion efficiency, and iii) module integration of tandem solar cells depending on their architecture. This project will tackle the above-mentioned issues by modelling of perovskite/c-Si solar cells. Therefore, the student will perform optical simulations using GenPro4 and electrical simulations of perovskite/c-Si tandem solar cells using the commercial software package TCAD Sentaurus and ASA7 software developed in house.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Improvement of the algorithms of ASA software**
Daily Supervisor(s)	Carlos Ruiz Tobon (C.M.RuizTobon@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	The ASA (Advanced Semiconductor Analysis) program is developed in the PVMD group for the opto-electrical simulation photovoltaic devices such as solar cells. The software solves the basic semiconductor equations in one dimension (Poisson equation and continuity equations for electrons and holes). This set of coupled partial differential equations must be solved numerically. For this, the main solver implementation is the Newton root finding algorithm. However, for this algorithm to converge, an initial approximation close to the sought root is required. To find this approximation, the so-called Gummel method is used first. The switch from Gummel to Newton's method is currently not optimized and left to the user. The user must select the number of iterations prior to the switching and use trial-and-error to achieve convergence. Therefore, the goal of this project is to implement new algorithms and numerical methods that improve this procedure using modern numerical calculation tools. Also, the possibility of extending the solver from 1 dimension to 2 dimensions, which is relevant to interdigitated back contact (IBC) solar cells, can be explored. For this project we are looking for a student with a strong background in mathematics or computer science.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Photorealistic rendering of goniochromatism in colored PV modules**
Daily Supervisor(s)	Ricardo Marroquim (R.Marroquim@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl),
Short description	Goniochromatic materials change color depending on the viewing angle or illumination direction. This effect is also known as iridescence and can be perceived in soap bubbles and oil puddles, for example. Color coatings, also used to improve the appearance of photovoltaic cells, also exhibit goniochromatism. You can note this effect on the windows of the Applied Science building at TU Delft. By tuning the thickness and texture morphology of the coating it is also possible to maximize the energetic efficiency while taking into consideration aesthetic integration. To achieve a balance between these two aspects, it is important to reproduce this effect in a virtual scenario to help architects and urban designers in previewing what their installation in a specific environment will look like.

	 The goal for this project is to develop photorealistic rendering methods that consider such phenomena using precise captured data and optical models developed by the Photovoltaic Materials and Devices group at TU Delft. The results will then be compared to photographs and test samples for validation. This project requires programming skills in C++. In addition, having prior experience with raytracing or rendering methods would be an advantage.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Energy loss analysis of tandem PV modules under realistic operating conditions**
Daily Supervisor(s)	Malte Vogt (M.R.Vogt@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	Perovskite/silicon tandem modules have the potential to reach an energy conversion efficiency of over 40%, overcoming the Shockley-Queisser limit of single junction solar cells of around 33%. However, no perovskite/silicon tandem cell has exceeded 30% in energy conversion efficiency so far. Energy loss analysis helps indicating the most promising areas for future improvements. In this project you will implement loss analysis formalism into the PVMD toolbox and evaluate the performance of several types of PV modules including tandems in different climatic conditions. The planned steps of the thesis project are as follows: 1. Literature review of energy loss analysis for PV modules. 2. Implementation into the PVMD Toolbox. 3. Analyze the energy loss of different PV modules for standard testing conditions in the lab. 4. Analyze the energy loss of (c-Si) single junction modules under realistic operating conditions and validate your results with data from PV systems. 5. Analyze the energy loss of perovskite/silicon tandem modules outdoors. 6. Simulating optimizations to reduce energy losses for the analyzed modules.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Modeling degradation processes in PV modules**
Daily Supervisor(s)	Malte Vogt (M.R.Vogt@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	PV modules degrade in power output during their operational lifetime due to different effects, such as backsheet cracking, finger corrosion, snail trails, potential induced degradation (PID) or light and temperature elevated induced degradation (LeTID). PV

	module manufacturers and insurance agencies typically guarantee >80% performance for 20-30 years. In the meantime, new more efficient PV modules will be developed likely containing new technologies or materials whose aging and degradation mechanisms are unknown. Thus, there is a big need to predict the aging and degradation behavior of PV modules based on simulations. In this project you will use the Finite-Element-Method (FEM) software COMSOL to develop detailed models degradation processes in PV modules and investigate their impact on energy yield and lifetime in the field using the PVMD Toolbox. The planned steps of the thesis project are as follows: 1. Literature review of simulation models for aging and degradation mechanisms. 2. Learning COMSOL or alternative simulation packages. 3. Development of models for degradation processes in PV modules. 4. Validation with measurement data. 5. Simulating the impact on PV module lifetime energy yield.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Reconfigurable 2-terminal tandem modules**
Daily Supervisor(s)	Malte Vogt (M.R.Vogt@tudelft.nl)
Supervisor	Rudi Santbergen (R.Santbergen@tudelft.nl), Patrizio Manganiello (P.Manganiello@tudelft.nl)
Short description	In the urban environment chimneys and other objects can cast shadows on PV modules. A shadow cast on even a single cell can dissipate the power output of the entire module. Reconfigurable PV modules use switches to continuously adapt the cell interconnection scheme to the actual shading pattern. Such partial shading scenarios can put the shaded cells into reverse bias and create hot spots. For perovskite cells this leads to rapid degradation. In this project you will develop concepts for reconfigurable 2 Terminal Tandem modules and determine the best number of cells for series and parallel connection through optimization. The planned steps of the thesis project are as follows: 1. Literature review of reconfigurable modules and interconnection of tandem modules. 2. The PVMD Toolbox contains models for reconfigurable modules and for tandem modules at the moment they cannot be combined, you will change this. 3. Develop a control strategy, which prevents the tandem cells from going into reverse bias. 4. Calculate the energy yield gain compared to regular modules. 5. Optimize the number of cells per reconfiguration block.
Available from	July 2021
Type	Modelling
Internal/External	Internal

Title	**Optimization of perovskite/silicon tandems for maximum annual energy yield under real-world conditions.**
Daily Supervisor(s)	Manvika Singh (M.Singh-1@tudelft.nl)
Supervisor	Dr. Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	Within the PVMD group we are developing the PVMD toolbox software for accurately predicting the energy yield of PV systems. A very promising new type of PV cell technology is the perovskite / silicon tandem. The student will improve the existing models in PVMD toolbox to make them suitable to be used for perovskite/c-Si tandem applications. The student will work on improving the current irradiance model i.e. Preetham model which is

	used in energy yield calculation. Also, the student will work on integrating Preetham model and parameter extraction into the toolbox. Unique to this project is that the bottom cell will be a new type of c-Si solar cell with high thermal budget carrier-selective passivating contacts poly-Si, poly-SiO_x and poly-SiC_x carrier-selective passivating contacts. Usually, the design of a new solar cell is optimized for maximum efficiency under standard test conditions. However, in the real world, the cell temperature, the irradiance level and the spectral distribution vary and are often far from this standard. Therefore, a better approach would be to optimize the solar cell design for maximum real-world energy yield. To achieve this, energy yield calculations for this type of perovskite/silicon tandem solar cells will be performed and data will be analysed for different locations in the world using PV device, module, and system models. Also, levelized cost of energy calculations will be performed for such tandem architectures.
Available from	August 2021
Type	Modelling
Internal/External	Internal

Area #7: Projects with external partners

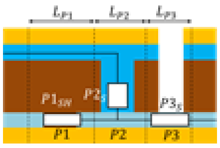
Title	Angular mismatch correction for PV modules with light trapping ribbons.
Daily Supervisor(s)	Koen van Domburg kvandomburg@eternalsun.com, Stefan Roest sroest@eternalsun.com
Supervisor	Dr. Patrizio Manganiello (P.Manganiello@tudelft.nl), Dr. Rudi Santbergen (R.Santbergen@tudelft.nl)
Short description	New innovations in the solar PV market keep increasing solar module power and energy outputs. One of these innovations are so called light trapping ribbons or light redirecting film. By applying this method onto non-active areas (e.g. busbar) of the solar cells, light can be redirected to the active area of the solar cells. Outdoor testing with these materials resulted in power gains of 1.5 – 1.8%. Since outdoor conditions are not always the same, solar simulators are required to compare the power output of PV modules at standard test conditions in laboratories. A solar simulator produces artificial sunlight that is as close as possible to natural sunlight and is mainly compared to outdoor sunlight on spectral match, irradiance non-uniformity and stability over time. However, since the introduction of these light trapping ribbons, PV power output measurements can differ significantly between different types of solar simulators. The hypothesis is that these differences are caused by so called angular mismatch: differences in angular response of the optical materials vs the angular distribution of light from the solar simulator.

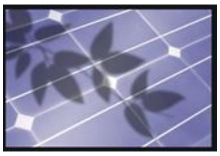
	The goal of this project is to investigate these differences and to develop an angular mismatch correction with the use of raytracing (optical simulation) and experimental testing on PV cells and modules. The developed angular mismatch correction can then be applied on PV measurements done with different types of solar simulators and varying angle of incidences. The ultimate goal is to standardize the correction into an IEC norm, similar to spectral mismatch correction.
Available from	February 2021
Type	Modelling and Experimental
Internal/External	External

Title	**Dopant free passivating contacts for industrial crystalline silicon solar cells.**
Daily Supervisor(s)	Mike Ah Sen (mike.ahsen@tno.nl), Dr. Agnes Mewe (agnes.mewe@tno.nl) or Dr. Jimmy Melskens (jimmy.melskens@tno.nl)
Supervisor	Prof. Dr. Arthur Weeber (a.w.weeber@tudelft.nl)
Short description	Commercial crystalline silicon solar cells that are currently manufactured in high volumes reach efficiencies beyond 22%. This efficiency is mainly limited by losses in functional layers and at interfaces. Developing advanced technologies to reduce these losses are important to increase the efficiency and, moreover, to enhance the annual energy output. Currently, novel coatings are explored to maximize the surface passivating quality and simultaneously maximize the carrier selectivity: so-called passivating carrier selective contacts. An example of a passivating carrier selective contact is MoOx, that can be deposited at TNO with a unique Pulsed Laser Deposition (PLD) tool. Because these contacts are highly transparent, parasitic absorption losses are low. Optimization of this kind of layers enable efficiencies beyond 25%, using a simple cell process. Your contribution to this research topic will consist of • optimization of the PLD (and other) processes; • characterization of the functionality of the layers; • integration in the solar cell process; • analysis and discussion of the results. The work consists of hands-on experiments, characterization, data analysis, and validation. See Internships and graduation assignments | TNO as well (on the website called: advanced crystalline silicon solar cell technology). Be aware, TNO only uses the word internship, although in many cases thesis project is meant.
Available from	June 2021
Type	Experimental
Internal/External	External - TNO location Petten (North Holland)

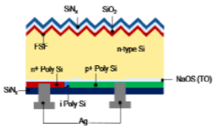
Title	**Reliability and energy yield of tandem solar cells, modules and PV systems.**
Daily Supervisor(s)	Prof. Dr. Gianluca Coletti (gianluca.coletti@tno.nl)
Supervisor	Prof. Dr. Arthur Weeber (a.w.weeber@tudelft.nl)
Short description	We want to accelerate the market introduction of the Tandem Solar Energy technology. Tandem technology overcomes the current limit of photovoltaic modules namely the single-junction efficiency-limit by better using the light spectrum. Tandem enable efficiency potential up to 40% and beyond. The project deals with three main pillars: • Developing advanced tandem devices, bifacial and with different electrical configurations (4T, 2T) and their interconnections and encapsulation into modules. • Reliability of modules including accelerated aging test, outdoor test and fabrication of minimodules • Improved light management and energy yield calculation including prototyping and testing The work consists in hands-on experience and data collection and analysis as well as modelling (optical) and validation. See Internships and graduation assignments | TNO as well. Be aware, TNO only uses the word internship, although in many cases thesis project is meant.

Available from	September 2021
Type	Experimental and/or modelling
Internal/External	External - TNO location Petten (North Holland)

Title	**Toward customized high-efficient perovskite based modules**
Daily Supervisor(s)	Jacopo Sala (jacopo.sala@imec.be), Aranzazu Aguirre (aranzazu.aguirre@imec.be)
Supervisor	Prof. Dr. Ivan Gordon (ivan.gordon@imec.be)
Short description  P1P2P3 interconnection	The development of new materials such as perovskites promises even lower prices for solar PV modules. With efficiencies that already equal mature technologies such as Silicon, CIGS and CdTe, perovskite-based cells unlock the development of cheap multijunction solar cells with efficiencies higher than 30%. Moreover, perovskites deposition methods allow increased flexibility to shape the ending module to create alternative designs or shapes. More than for traditional technologies, module interconnections optimization becomes crucial to maximise efficiencies and lower potential failures. Therefore, we propose this project on perovskite-based modules to optimize and evaluate modules' interconnection parameters. At imec, we already demonstrated elevated module efficiencies and fill factors for rectangular shapes. In this framework, this project will initially focus on laser parameters optimization to study their effect on the total module resistances. Laser scribing after deposition of all layers, also called back-end processing will also be explored. In a second phase, modules with customizable shapes will be tested and characterized to evaluate the interconnection impact on electrical performances. Moreover, these experiments will be used to validate a software-based model under various illumination and temperature conditions. The work will be conducted in the newly built laboratories at imec in EnergyVille, Genk, working in one of the world's premier research centres in nanotechnology. Skill required: A basic knowledge of Python is a plus.
Available from	September 2021
Type	Experimental
Internal/External	External – imec Energy Ville (Genk, Belgium)

Title	**Shade effects in thin film perovskite PV modules**
Daily Supervisor(s)	Aranzazu Aguirre (aranzazu.aguirre@imec.be)
Supervisor	Prof. Dr. Ivan Gordon (ivan.gordon@imec.be)
Short description  Example of a tree branch sharing a Si-PV module	Photovoltaics is becoming a leading energy generation source and broadening its field of applications further than traditional PV plants. Now PV modules become part of facades, car tops or even flexible substrates such as fabrics or plastic foils. Photovoltaic module performance can be altered by the shading of part of the module. The shade of trees, passing clouds or neighbour buildings can hamper the total module performance or even permanently damage it. In Si PV modules, part of the potential damage by shading can be avoided using bypass diodes. A thorough knowledge of the possible shading effects and how they can affect the current, voltage or overall performance of the module will help us avoid potential module breakdown. Shading does not have the same effect in the different PV technology modules. While in traditional widely used Si technology shading can lead to complete module breakdown, the effect of cell shading in new generation of PV modules, or assemblies of them, is still unknown and little studied. Moreover, in thin film PV, in particular in perovskite technology, a monolithic interconnection approach is used to fabricate modules. With this methodology series connection between cells can be done in hundreds of microns. Perovskite solar cell modules typically deliver high voltages and low currents. To obtain larger current values, modules can be treated as submodules and connected to form a module as an assembly made of submodules. We propose to build up and test an experimental setup to characterize and understand the effects of shading in perovskite PV modules or assemblies of them. A comparison to c-Si modules will be the starting point. The results will aid validation of our module model software. The experimental and modelled data can support new designs of (large area) modules or assemblies of them. The characterization work will be done at our Energyville laboratory in Thor Park, Genk, Belgium.
Available from	September 2021
Type	Experimental

Internal/External	External – imec Energy Ville (Genk, Belgium)

Title	**Development of industrially viable passivating contacts IBC solar cells**
Daily Supervisor(s)	Mr. Vaibhav Kuruganti (vaibhav.kuruganti@isc.konstanz.de)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl) Dr. Valentin Mihailetchi (valentin.mihailetchi@isc-konstanz.de)
Short description  	High efficiency solar cells are realized on IBC structure because (I) the trade-off between electrical and optical losses on the front side of the solar cell is eliminated, (II) module integration is easy; and (III) low series resistance can be achieved due to higher metal fraction. With best quality substrate and state-of-the-art surface passivation, the efficiency of the cells is limited by recombination losses at the metal contacts. One of the approaches to reduce the contact recombination losses is the use of passivating contacts. Though passivating contacts IBC (Poly-IBC) solar cells sounds very promising, making them cost effective is quite challenging due to multiple high thermal budgets processes and complex process flow for patterning the rear side. The goal of this project is to realize an industrially viable interdigitated p+ & n+ poly-Si for an IBC solar cells with iVoc > 720mV using of APCVD glass ex-situ doping, co-annealing, laser doping and laser ablation. We are looking for a master's student who can support us with helping in process development and optimization of Poly-IBC solar cells. The tasks of the potential master student include familiarization with different PV characterization techniques, understanding the process fabrication of IBC solar cells, perform statistical DoE analysis to optimize various process parameters.
Available from	July 2021
Type	Experimental
Internal/External	External – International Solar Energy Research Center Konstanz (Konstanz, Germany)

The **matchmaking event will be held on June 15th (12:30 – 14:00)**. It will start with a plenary introduction by the head of the photovoltaic materials and devices (PVMD) group, Olindo Isabella. You can join this online event by clicking the link indicated below:

CLICK HERE TO JOIN THE MATCHMAKING EVENT (June 15th 12:30 – 14:00)

After this introduction you can chat with the supervisor of your choice. Personal Teams links are provided in the table below.

(Daily) supervisor contact information		
Name	**E-mail**	**Personal Teams link** (June 15th, 12:30 - 14:00)
Rudi Santbergen	r.santbergen@tudelft.nl	Click here to join the meeting
Gianluca Limodio	g.limodio@tudelft.nl	Click here to join the meeting
Malte Vogt	M.R.Vogt@tudelft.nl	Click here to join the meeting
Ivan Gordon	I.M.F.Gordon@tudelft.nl	Click here to join the meeting
Olindo Isabella	O.Isabella@tudelft.nl	Click here to join the meeting
Alba Alcañiz	A.AlcanizMoya@tudelft.nl	Click here to join the meeting
Yilong Zhou	Y.Zhou-15@tudelft.nl	Click here to join the meeting
Hesan Ziar	H.Ziar@tudelft.nl	Click here to join the meeting
Manvika Singh	M.Singh-1@tudelft.nl	Click here to join the meeting
David van Nijen	D.A.vanNijen@tudelft.nl	Click here to join the meeting
Guangtao Yang Zhirong Yao	G.Yang@tudelft.nl Z.Yao@tudelft.nl	Click here to join the meeting
Liqi Cao	l.cao-3@tudelft.nl	Click here to join the meeting
Mirco Muttillo	M.Muttillo@tudelft.nl	Click here to join the meeting
Luana Mazzarella Jin Yan	L.Mazzarella@tudelft.nl J.Yan-6@tudelft.nl	Click here to join the meeting
Arno Smets	a.h.m.smets@tudelft.nl	Click here to join the meeting
Patrizio Manganiello	P.Manganiello@tudelft.nl	Click here to join the meeting
Juan Camilo Ortiz Lizcano	j.c.ortizlizcano@tudelft.nl	Click here to join the meeting
Yifeng Zhao	Y.Zhao-4@tudelft.nl	Click here to join the meeting
Arturo Martinez	V.A.MartinezLopez@tudelft.nl	Click here to join the meeting
Rene van Swaaij	R.A.C.M.M.vanSwaaij@tudelft.nl	Click here to join the meeting
Arthur Weeber	A.W.Weeber@tudelft.nl	Click here to join the meeting
Vaibhav Kuruganti	vaibhav.kuruganti@isc-konstanz.de	Click here to join the meeting

Supervisor not on this list? An updated list can be found here.