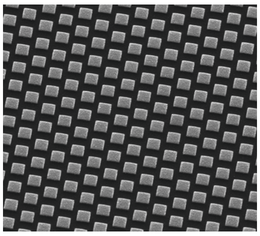
Diamonds are an engineer's best friend

Diamond is not just a natural mineral famous for its beauty and cost; it is also a highly useful crystalline form of carbon that can be grown in a synthetic fashion. The list of properties that make diamond an attractive engineering material seems endless: extreme mechanical hardness, high wear resistance, high thermal conductivity, excellent optical transparency, very good electrical insulating properties, high resistance to chemical corrosion, and biocompatibility. Dr. Ivan Buijnsters, assistant professor at the Micro and Nano Engineering research section of TU Delft's Department Precision and Microsystems Engineering (PME), is an expert in the production and use of synthetic diamond layers. He emphatically confirms: "Diamonds really are an engineer's best friend."



Electron microscope image of a microstructured diamond surface as grown in the lab of Buijnsters at TU Delft. Here, synthetic diamond layers can be produced with a structure already defined during growth, such that expensive lithographic and etching techniques are not necessary.

Real and exciting

In concert with his colleagues at PME who work on other carbon allotropes, in the form of thin sheets (graphene) and elongated cylinders (carbon nanotubes), Buijnsters works to develop and apply new diamond-based materials. "We're looking at applications ranging from biochemical sensors to wastewater treatment." There are many, many potential application areas but Buijnsters remains realistic. "In the 1990s, when the possibilities of diamond-based materials first came to light, people's expectations exploded. But diamond will not replace all current electronic and mechanical materials. Still, in many application areas the opportunities are real and exciting."

Chemical vapour deposition

To synthesize the diamond materials in the form of thin layers, Buijnsters utilizes a technique called chemical vapour deposition (CVD). Inside a well-controlled vacuum environment, hydrogen gas is brought into contact with a filament at 2000°C, which breaks up the H_2 into highly reactive H radicals. These hydrogen radicals then interact with methane gas (CH_4), which is also present in the vacuum chamber, enabling the crystallization of the carbon atoms into diamond. The synthetic diamond Buijnsters grows in this way takes the form of polycrystalline thin films. By creating three-dimensional structures in these films, Buijnsters aims to add functionality.

'Point of care' analysis

One area of application is that of biosensors. Imagine a tiny chip onto which a single droplet of blood or saliva is applied. Through electronic means, the chip quickly determines the glucose level and checks for specific substances such as dopamine, signalling stress levels. The results can be read out immediately. The simplicity of this biosensor system implies that its use isn't limited to expensive medical labs. Instead, it can be used at the time and place of patient care, hence the name 'point of care analysis'. While this concept is currently being implemented with various other materials, diamond holds much promise as sensing material for next-generation biosensors: "Diamond in itself is electrically insulating. If we

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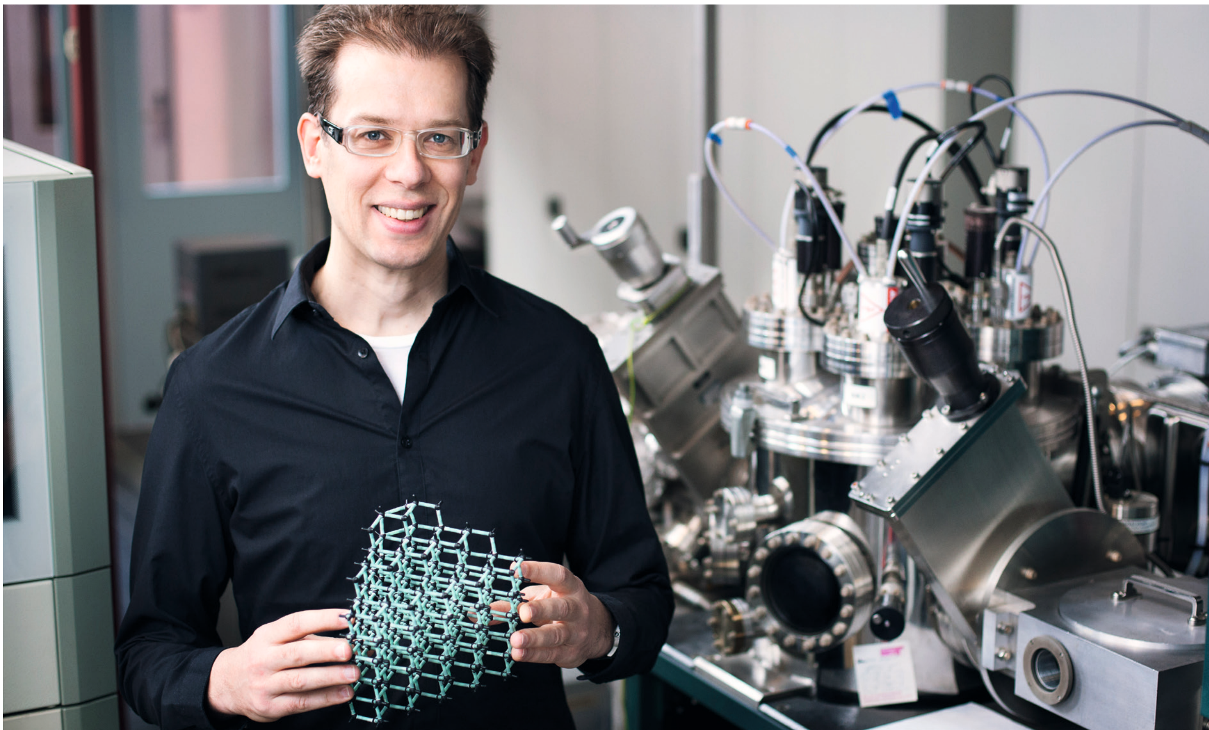

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introduce boron impurities, so-called dopants, the material becomes conducting. In this doped form, diamond has a much larger electrochemical operation window to substances in aqueous solutions than traditional electrode materials such as gold or platinum. This results in a more versatile (multi-purpose) biosensor with improved detection limits."

Selectivity and sensitivity

The CVD production technique makes diamond biosensors more expensive than current disposable solutions, yet their robustness and even self-cleaning properties allow the sensor to be used multiple times. "We are working to exploit the specific advantages offered by diamond to design biosensors that very selectively look at the presence of one or more substances, and that are able to detect extremely low concentrations of these substances, down to the millimolar or even micromolar level, without suffering from contamination." "At the same time, we're looking for simpler and cheaper ways to produce diamond-based biosensors." Within a few years, it should be possible to produce diamond-based biosensors on the scale of the micrometre (a millionth of a meter) at a competitive price. And beyond that? Buijnsters envisions inkjet-printing a structured starting material from which the diamond layers can be grown.

Wastewater treatment

Another –unexpected– application area in which diamond is already gaining traction is that of (waste) water treatment. Here, the synthetic diamond is applied as electrochemical electrodes where water contaminants, such as medicine residues, are oxidized and hence broken into harmless parts. In this treatment scheme, there is no need for aggressive chemicals. "This application combines many advantages of the diamond material: its electrochemical sensitivity (to measure the contamination levels of the water), its metal-like electrical conductivity in doped form (to achieve the high electrical current levels needed to drive the oxidization process), and its high mechanical robustness and chemical inertness (to withstand the harsh wet environment). The cleaning process even works as a self-cleaning strategy, allowing the system to be used over and over without loss of effectiveness.

Buijnsters: "While the diamond-based wastewater treatment concept is already widely used in the form of bulky systems, we're developing similar technology on a much smaller scale for bench-top use, such as in a medical lab."

Single molecules

Buijnsters' dream for the future features diamond devices capable of detecting single molecules. This ultimate detection sensitivity, many orders of magnitude better than the millimolar level currently achieved, should be possible through the clever use of optical techniques, in which a laser illuminates the diamond surface.

The surface is structured on the level of the nanometre (a millionth of a millimetre) in such a way that it amplifies the response of the molecule to the laser beam to a level where it can be detected optically. "Exploiting the latest findings in the research area of the nanosciences to nanostructured diamond is the next frontier we're aiming for."

A Dutch topic

The diamond revolution, which was anticipated 30 years ago but didn't materialize, has given way to a more gradual evolution. It is a long-term development process. "In a world where it is increasingly difficult to obtain long-term funding, PME's Nano Engineering Research Initiative (NERI) will prove very important in solving major challenges through joint multidisciplinary and most importantly long-term collaboration."

Buijnsters stresses another important aspect of NERI: that of education. "NERI is a platform to intensify contacts between academia and the future work fields of the (PhD) students being trained there." No matter the challenges taken on under the NERI umbrella, Buijnsters is sure diamond will offer exciting opportunities. "The Netherlands isn't just internationally renowned for its high-tech industry, it also has a historically important diamond industry. Diamond technologies are a very Dutch topic, indeed."