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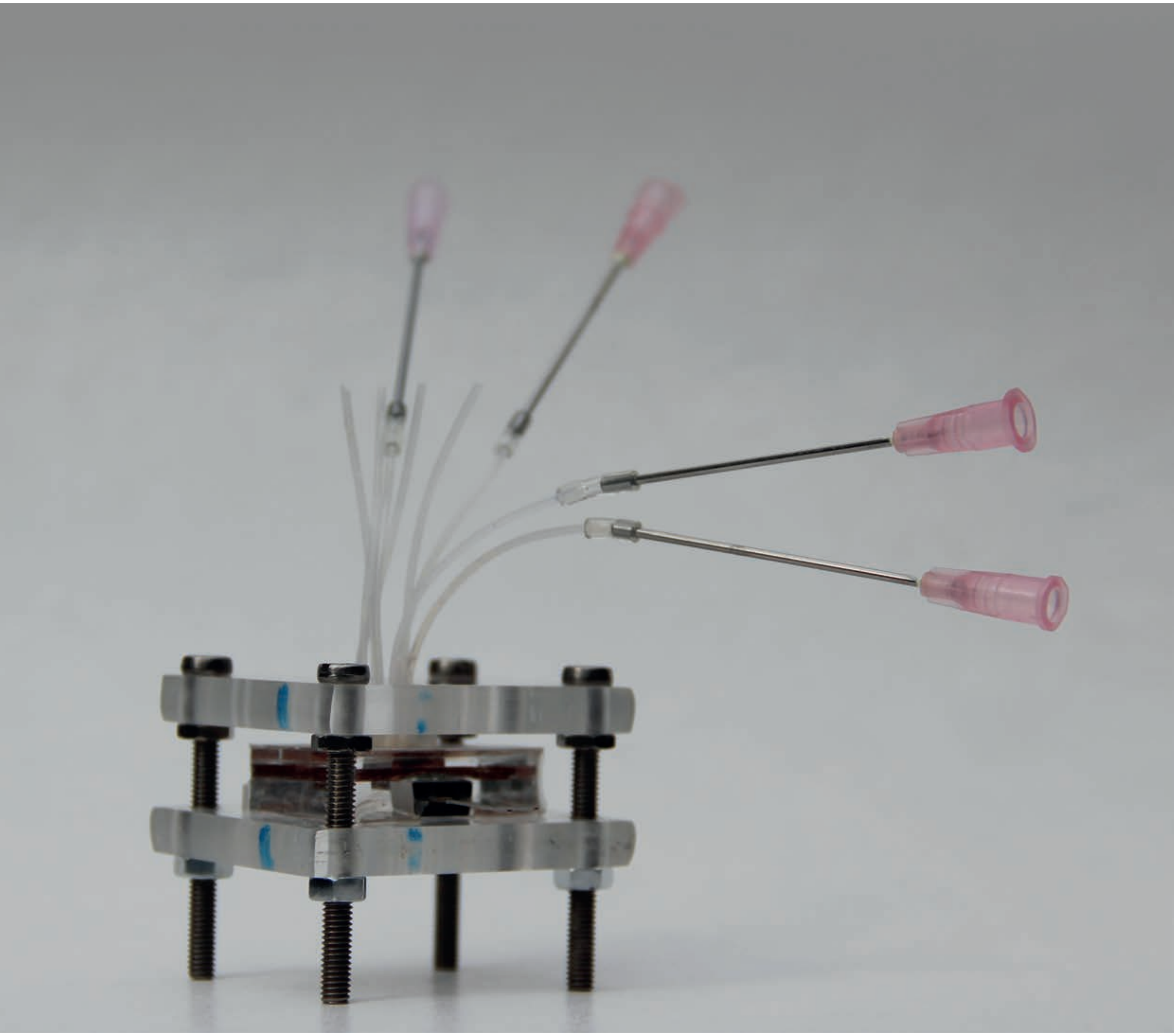

Materials Science

Thematic papers

The goal of the thematic papers is to present Flemish scientific research internationally. They focus on fundamental and applied research.

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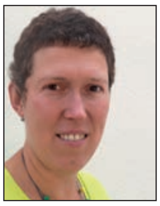
For this thematic paper we talked to:

Sara Bals, researcher at EMAT, Physics Department, University of Antwerp

Wim Van Paepegem, head of the Composite Materials Research group, Mechanics of Materials and Structures, Department of Materials Science and Engineering, Ghent University

Jean Manca, head of the Organic and Nanostructural Electronics research group at the IMO-IMOMEC Institute for Materials Research, UHasselt

Staf Van Tendeloo, head of the EMAT research group, Physics Department, University of Antwerp



Heidi Ottevaere, researcher at B-Phot Brussels Photonics Team, Vrije Universiteit Brussel

Patrick Wagner, head of the Biosensors research group at the IMO-IMOMEC Institute for Materials Research, UHasselt

Karel Van Acker, co-ordinator at the KU Leuven's Materials Research Center, KU Leuven

Martine Wevers, co-ordinator of the Materials Performance and Non-destructive Testing research group, Department of Materials Engineering, KU Leuven

Materials Science
working on the future unnoticed

From small atomic-scale structures to constructions of 200 metre high. From the solar panel on your roof to the OLED TV in your home. Everything around you is made up of specific materials that haven't just found themselves there at random. Enthusiastic and committed researchers have used advanced techniques to get to know the internal structure and characteristics of these materials, to make sure the right material is put in the right place.

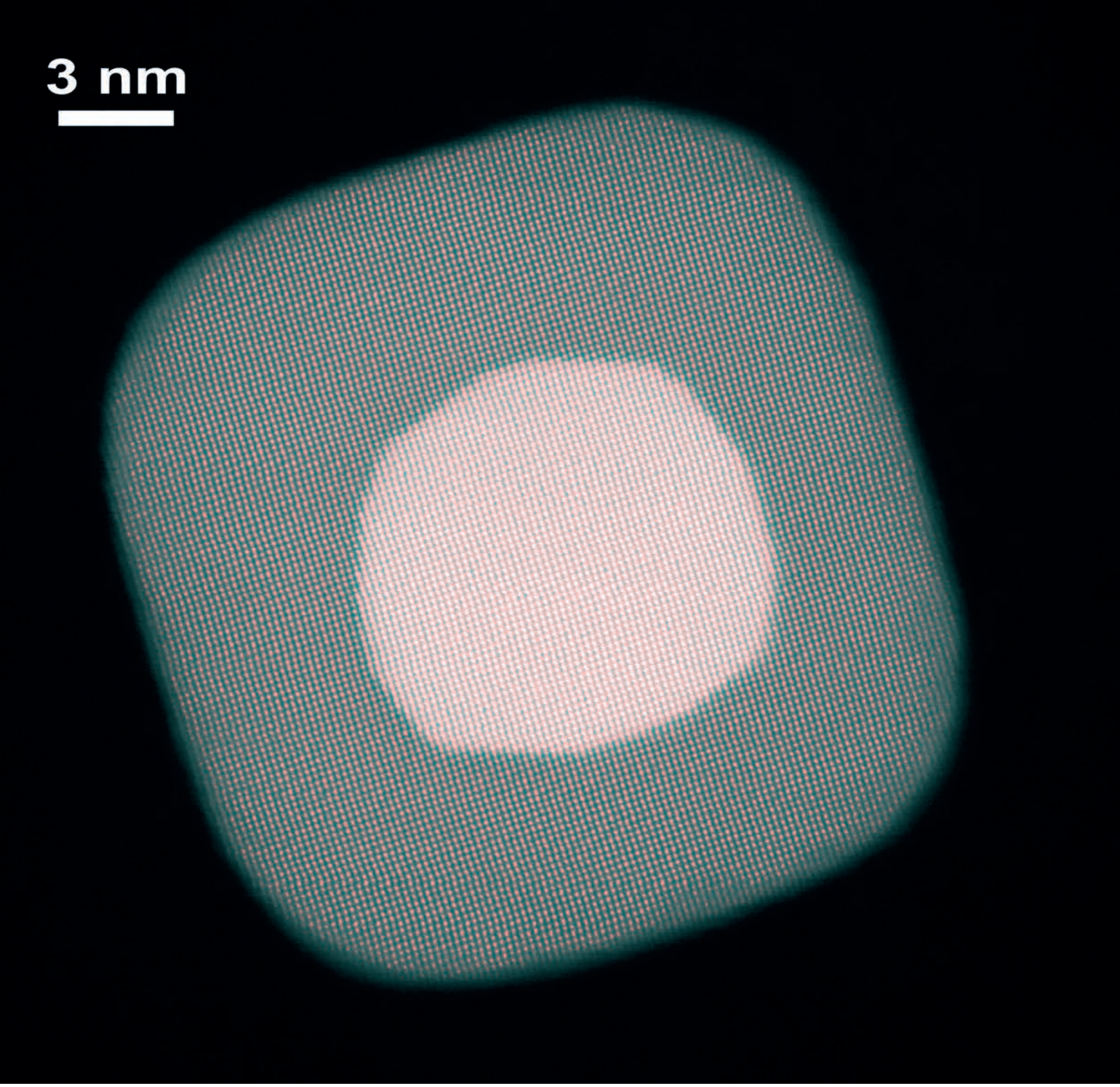
They conducted extensive tests focusing on every possible detail, fired birds into aeroplane engines, incorporated photovoltaic cells into double glazing, listened to materials cracking, were fascinated by light and its applications or wanted to detect diseases with small sensors.

During their research they worked on new theories, materials, applications and constructions that will contribute to our environment today, tomorrow or in the distant future. These new, researched materials will sneak into our lives unnoticed and when at some point in the future you'll look around, all the research that has gone into it will still not be obvious to you. And that is how researchers of materials science keep working on the future unnoticed.

Materials science in Flanders
Flemish materials science is definitely strong in five different domains, says Karel Van Acker, co-ordinator of the KU Leuven's Materials Research Centre.

1. **Sustainability.** 'For example, we research material recycling, scarcity and lightweight materials', explains Van Acker. 'We are ahead of many other countries when it comes to recycling, because we've always kept up our knowledge about metallurgy. Many universities in Europe discontinued such research, but now it's gaining more importance again, because we are recycling more and more rare materials from used products'.
2. **Energy.** Research into and development of new materials for photovoltaic cells or wind turbines, for instance.
3. **Health.** 'In this area we work around materials for prostheses, for example, and materials living cells can grow on', says Van Acker. 3D printing is becoming ever more important for this, because the technique is able to make materials with a certain kind of porosity that will be able to mimic bone structure, for example.
4. **Functional materials.** For ICT or microelectronics. Examples of this are semiconductors, self-healing materials or new types of batteries.
5. **Structural materials science.** 'Ordinary' materials like steel and concrete are still researched very thoroughly in Flanders.

It may be said: it is impossible to paint a complete picture of all the materials research that goes on in Flanders, but we'll still lift a few topics from the myriad of possibilities to discuss them in this paper. We'll start with the very smallest of details.



Atom

'When it comes to resolution we have the most powerful microscope in the world'

Staf Van Tendeloo is head of the EMAT lab (Electron Microscopy for MATerials Science) of the University of Antwerp and was already working with electron microscopes when the technique was still in its cradle. Sara Bals, who also works at EMAT, is specialised in electron microscope 3D imaging.

The University of Antwerp's EMAT research group has six electron microscopes in total, each with its own applications. Do they also have, as has been said, the most powerful electron microscope in the world? 'That's difficult to say', Staf Van Tendeloo explains. 'What would you say if I asked you what the most powerful car is? Is it a Formula 1 car or a 4x4? It all depends what you focus on. But when it comes to resolution, in other words being able to see the smallest detail, then we do have the most powerful microscope in the world'.

Coloratom

Sara Bals uses these powerful devices to make 3D images of atoms. 'Images from an electron microscope are 2D projections of 3D objects', she explains. 'And that's misleading sometimes. For example, if I show you the back of a pencil, you'll see a circle and you'd never have a clue if the pencil is a cylinder, a sphere or a cone. So it's very interesting to be able to 'walk' around the object and see it in its 3D shape. By capturing images in the microscope while turning the object, we can make a 3D reconstruction'.

Coloratom, that's the name of the project Sara Bals is working on. It aims to characterise nanomaterials atom by atom. 'With the project, we want to be able to know the position of each and every atom in a material and say which type of atom it is. Is it iron, cobalt, silver or gold, for instance? That's interesting, because certain crystallographic planes have other catalytic properties', Bals clarifies. A sphere behaves differently in a chemical process compared to a cube, so to say.

'Because the industry and other research groups want to optimise their applications, they want to know very specifically what the shape and structure of their nanoparticles are. Electron microscopy is ideal for that. We don't only do this because we get nice pictures', she smiles. So electron microscopy complements other analysing techniques that show the information in a less detailed way. Van Tendeloo: 'It's essential we can provide other research groups of information down to an atomic scale. We get requests from all over the world, more than we can accept even'.

Print a sheet of electronics

The Organic and Nanostructural Electronics research group of Jean Manca appreciates such careful analysis. Manca is professor in experimental physics associated with the IMO-IMOMEC Institute for Materials Research at UHasselt and the associated lab of not-for-profit organisation IMEC. Amongst other things, the research group develops printable electronics and thin film solar cells. Manca: 'We're doing research into new materials and look at how we can use them in new applications. From flexible photovoltaic cells to new lighting. We're working with materials on a nanometre scale, so it's very important we know exactly what our substance consists of'.

Simply put, the layers in a thin film solar cell are made of a mix of semi-conductive polymers with so-called *bucky balls*. 'You have to think of it as spaghetti with meatballs', explains Manca. 'It's important to know the mix is well made, because if all the 'meatballs' conglomerate on one side, our photovoltaic cell will perform badly. The mix and the order are very important'.

Apart from photovoltaic cells, IMO-IMOMEC also researches more generally the possibility of printing electronics on paper, textile or glass, for example. Production costs for

printable electronics based on semiconductive polymers are lower than those for current electronics technologies based on silicon.
'When the technique has been perfected, a classic printing machine will be able to use its equipment to print electronics', says Manca. 'The only problem at the moment is the stability and make-up of functional nano-inks. All over the world researchers are still working on the right mix'.

In addition to cost, printable electronics also means new applications you can't achieve with existing technology.

Manca: 'Existing silicon photovoltaic cells are relatively expensive, they only come in one colour and they're not flexible. Cells made of organic components, as we are developing now, are flexible and you can give them a particular colour or even make them see-through'. Transparent, pliable photovoltaic cells can then be incorporated as a foil in double glazing, for example. 'That way you can integrate photovoltaic cells into architecture', elaborates Manca. 'That is called *Building integrated photovoltaics or BIPV* and we can see lots of future in that - also in economic terms'.

'Printable electronics means new applications you can't achieve with existing technology'

More information

EMAT, University of Antwerp: www.uantwerp.be/en/rg/emat

IMO-IMOMEC, UHasselt: www.uhasselt.be/IMO

Composite

‘We must look to the future and shouldn’t allow ourselves to be limited by something that seems unfeasible now’

Wim Van Paepegem, head of the Composite Materials research group at Ghent University, works with composites: plastics with added reinforcement fibres. One more well-known composite can be found in high-end racing bicycles and tennis racquets under the popular name *carbon*.

But Van Paepegem researches materials to use them in applications very different from tennis racquets. 'In the research group we look at composites' mechanical behaviour under load', he explains. 'Wind load on a wind turbine blade, for example, but also the load in car parts and bikes or on wave energy convertors'. To assess this the research group uses experimental tests and computer simulations.

Popular computer simulations

Computer simulations are becoming increasingly popular in labs like Van Paepegem's. That's not surprising. Van Paepegem: 'One of the goals of Europe's future energy policy is putting even bigger wind turbines in the sea. They would have blades of 100 metre long which would mean the total diameter of the construction will be more than 200 metre'.

Van Paepegem continues: 'You don't just start building such a construction to do some experimental tests on it to see when it bends and under what circumstances the glue seams will be affected. You obviously start with computer simulations you know work for existing 70-metre-long turbine blades and with these you conduct a feasibility study before you start experimental testing'.

So in the research group experimental testing is often done on smaller pieces of material, then simulation programmes are used to predict the larger picture. Important construction or material characteristics researchers want to map out in this way include: stiffness, flexibility under pressure, natural frequency, the firmness of glue seams and lifespan.

Composites make you use less

Why work with composites at all? Why not just stay with materials we know, like concrete and steel to build constructions? Van Paepegem explains: 'The fibres incorporated into plastics have a much greater tensile strength than metal. Because the fibres and the plastics weigh little, their high stiffness and tensile strength can be combined with lightness. This means the part itself will need less energy to get moving. And that's an advantage in almost all applications where you're using energy to make something move or slow down. Think of cars, trains, ships or aeroplanes, but also of anything that turns very fast. Also think of the sports industry where bikes, skis or sailing boats all have to be as light as possible'.

'We're getting lots of questions from the car industry at the moment', says Van Paepegem. 'They're mainly after re-designing existing components like bumpers or car panels from a solution out of metal to one out of composite material. That makes cars lighter and more efficient in terms of fuel. Not straightforward, because the component has to be lighter and stiffer, but at the same time offer the same performance and flexibility as a metal component when a car crashes or collides with another vehicle'.

Fundamental calculating times of 2 to 3 weeks

The research group also does more fundamental work: 'It's absolutely our task to think ahead and develop computer simulations now that will only be possible in 5 to 10 years', explains Van Paepegem. 'So we're now doing fundamental simulations where calculation times

on the calculation cluster of Ghent University are taking two to three weeks'.

Like calculations on the constructions generating energy from waves. Van Paepegem: 'A wave energy convertor will stay at sea for twenty years and the construction also has to survive the heavy winter storms. The impact of a fifteen-metre-high wave battering a construction is enormous. If you generate a wave numerically on a true scale and have it numerically strike the construction, you're saddled with a few weeks' calculation time on our, shall we say, pretty powerful, calculation cluster'.

Van Paepegem continues: 'That looks like a long time and it's not really helpful in practice, but if you see how quickly computer science advances, those same calculations will maybe only take two hours in 10 years' time. We must look to the future and shouldn't allow ourselves to be limited by something that seems unfeasible now'.

'We always stay a bit like small children in that respect,' admits Van Paepegem. 'Every time our machines become more powerful, we want to move the boundaries of what we can simulate. That way we can study composites in ever more extreme circumstances'.

Testing aeroplanes

The research group of Van Paepegem also conducts bird strike tests. Bird strikes are still one of the most critical impact loads for jet engines and the issue is still experimentally tested by speeding up a duck to 250 to 300 km/h and firing it at the aeroplane part.

It may sound daft – or shocking – but it *is* an important topic in aeroplane applications: 10,000 bird strikes are reported every year in the United States alone. It shows the importance of proper research in this quarter. A bird strike is seldom a reason for disaster, exactly because jet engines are designed to be able to withstand it.

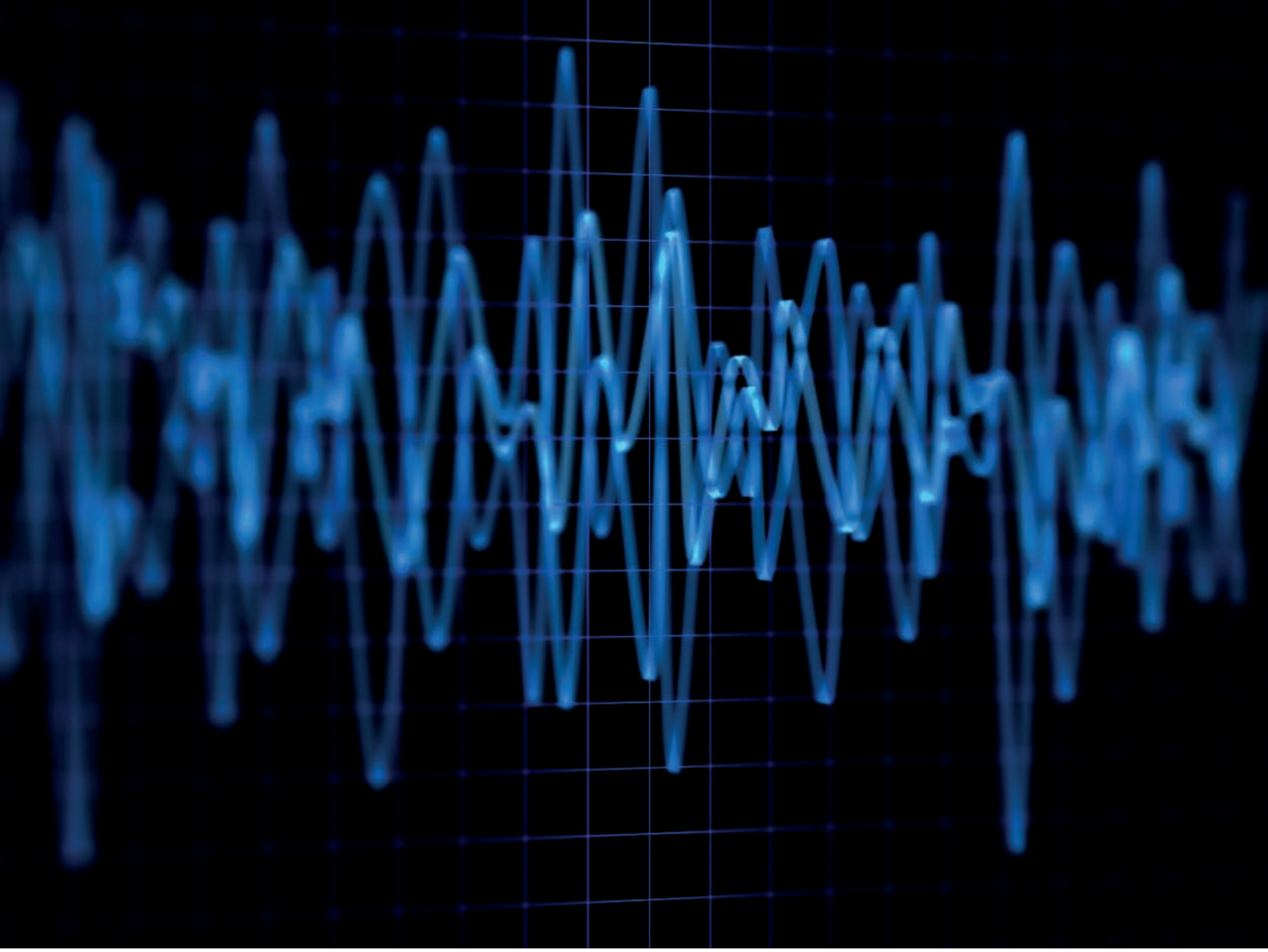
Turn the picture 90°

Composites are the future, but there's still a long way to go to education and training. Van Paepegem: 'A fibre - and therefore the composite as well - is lengthways immensely rigid and strong. The forces needed to break it are phenomenal. But if you just turn the picture 90° and pull the fibre sideways, you'll have hardly anything left. The only thing that will still keep the composite together is its plastic casing'.

So the material has different characteristics in different directions when it comes to tensile strength, expansion or shrinking. Van Paepegem: 'We call such a material *anisotropic*. We've noticed this behaviour is a problem, because lots of engineers and designers are not used to working with this kind of thing. After all, ordinary metals and plastics behave the same way in all directions'.

More information
Mechanics of composite materials, Ghent University: www.composites.ugent.be

'One well-known composite can be found in high-end racing bicycles and tennis racquets under the popular name *carbon*'



Sound

‘We listen to growing defects and cracks, like metal rusting or chocolate crystallising’

Once the material is incorporated in a construction, you can't put it under a drawbench or slice it up to put under an electron microscope. It's at this point that Martine Wevers' technique will come in handy. She is co-ordinator of the Materials Performance and Non-destructive Testing research group at the Department of Materials Engineering at KU Leuven. Wevers: 'Non-destructive testing allows you to look for possible faults in a material or construction and predict if intervention is necessary or not'.

One of the techniques the group specialises in is listening to growing defects and cracks. 'If you break a branch, you'll hear it snap', clarifies Wevers. 'Exactly the same happens when a material starts showing internal cracks. Only, you'll hear that high-frequency sound exclusively with special equipment. That way we can detect small cracks, but also listen to chemical processes like metal rusting or chocolate crystallising'.

During a materials test, the construction - like a wind turbine or pressure vessel in a chemical company - is subjected to a load slightly higher than normal and then listened to with sound sensors. And the one material isn't the other, explains Wevers: 'Not all materials are acoustic. There are metals that produce a clear sound, but there are also those that only make a sound if they are in the final process of breaking. And in ceramic materials, small defects can be instantly critical with the slightest load, contrary to metals'.
Wevers' research group uses several non-destructive techniques in their materials research, but the research group mainly focuses on sound as an analysing technique, because it works well in complex materials like composites. 'For example, an impact on metal most often causes a visual dent or perforation', says Wevers, 'but in a composite material, there may be nothing to see on the outside, although it could be totally broken internally. The best way to detect that internal damage is listening to the material'.

Structural health monitoring

In order to help finding defects, the research group developed the so-called *percolation sensor*. This sensor doesn't work with sound, but gives a signal when it gets wet. The sensor attracted interest from the aviation and chemical industries.

'Think of the kilometres of pipes in chemical factories', says Wevers. 'Such piping has insulation around it and the pipe and its insulation together sit in a protective casing. This casing can start cracking or

Contactless techniques

The sound techniques Martine Wevers's research group uses assume the materials can be touched or allow sensors to be installed on them, but that's not always possible. Air-coupled ultrasound techniques allow materials to be studied without making contact. Certainly for the textile industry - where contact with materials is not desirable - this is an interesting technique.

Another contactless, non-destructive technique is the recently developed MatchID technique (www.matchid.org) from the research group Mechanics of Materials, Products and Processes (MeM2P) of Odisee University College. This technique makes it possible to measure the distortion of a material based on digital images and associated custom-written software.

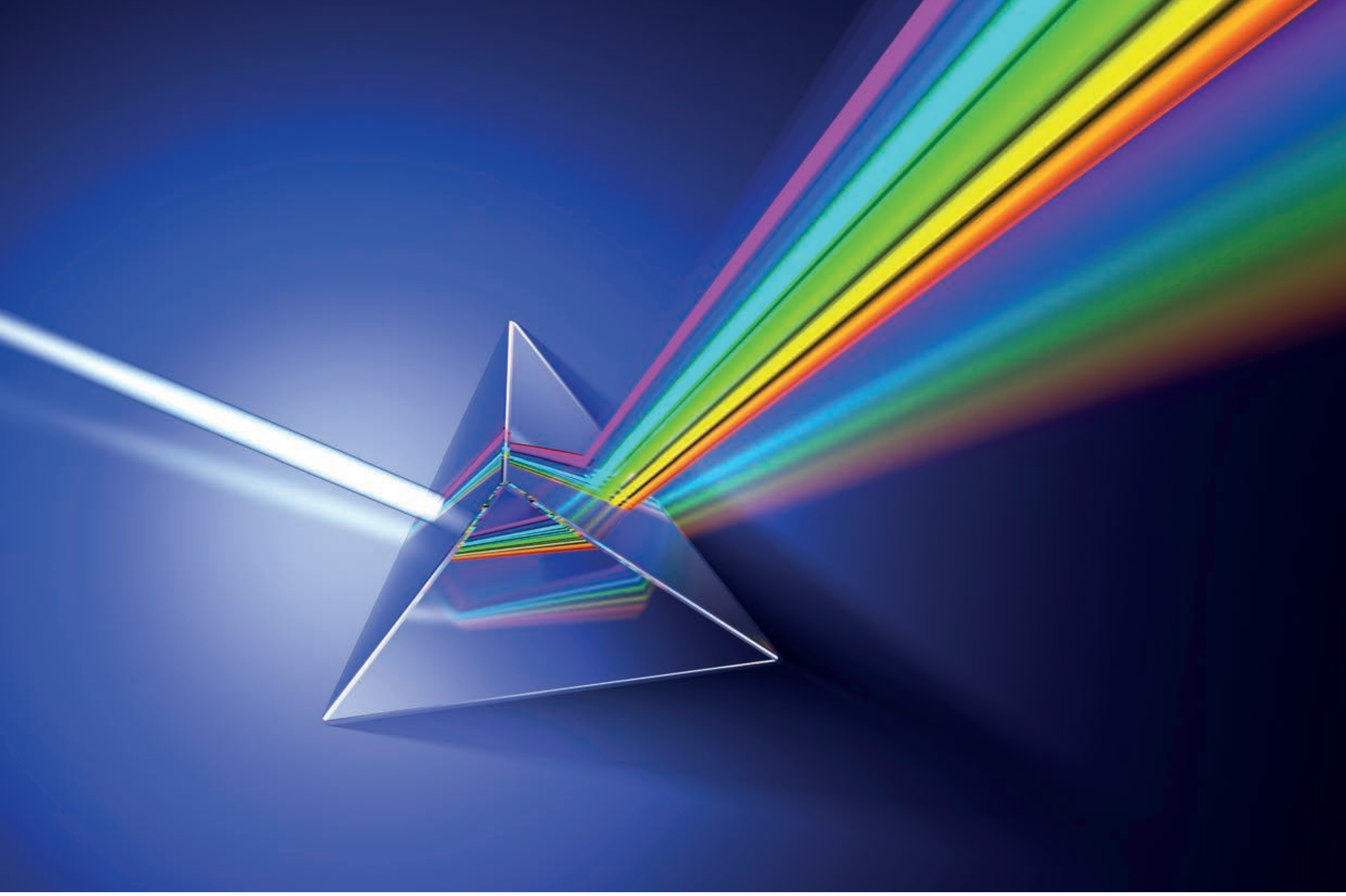
denting, so water can seep through. Then the pipe inside transporting the chemicals may start corroding and fail in the end'.

'You can imagine how difficult it is to check kilometres of pipes for corrosion, certainly if it's all going on beneath encasing and insulation. The sensor works in a preventative way and can warn you if water is seeping in somewhere, so maintenance can be done in time'.

More information

Materials Research Centre, KU Leuven: http://set.kuleuven.be/mrc

Industrial Valorisation of Research on Non-Destructive Testing and related Materials Characterisation within the KU Leuven Association: http://www.kul-a-ndt.be



Light

‘Liquids can be analysed in different ways with the aid of light’

Together with her research group, Heidi Ottevaere, associated with B-Phot and professor at the Department of Applied Physics and Photonics at Vrije Universiteit Brussel, develops methods for characterising materials with the aid of light. Amongst other things it enables her to examine liquids. ‘This way we'll be able to do blood analyses with photonics and detect cancer cells more easily’, says Ottevaere. But the analysis of olive oil is an example of this too.

Ottevaere: ‘There's lots of fraud. Olive oil being sold as so-called *extra virgin* oil is in reality often mixed with cheaper kinds of olive oil. During the research we characterised geographical olive oil clusters with photonics and we saw that some *extra virgin* oils had been mixed with Hungarian, Greek or Chinese oils, but were still being sold under the guise of a real Italian product’.

Characterising motor oil

Liquids can be analysed in different ways with the aid of light. It only depends on what you want to look at exactly. Concentrations can be determined with absorption and fluorescence, but with Raman spectroscopy and chromatography you can also separate substances and determine how many molecules there are in a given substance.

For example, degradation in motor oil can be detected very easily with spectroscopic analysis. Ottevaere: ‘At the moment we're working very closely with companies to see whether these analyses can be implemented on an industrial scale’. Currently car drivers and mechanics replace motor oil at fixed intervals. ‘There's already a sensor in expensive cars telling the driver when the oil has to be replaced, but the aim is to move towards a cheap sensor that can be used in all cars’, says Ottevaere. ‘Then people won't replace their oil too quickly or too slowly and that'll have a great impact on the environment and will reduce unnecessary expenditure’.

A lab on a chip

Another light-liquid analysing application the research group is working on is the *lab on a chip*. Ottevaere: ‘A lot of what's being examined in an elaborate chemical lab at the moment can actually in principle be done on a small, easy to transport chip. We're talking analysing water for bacteria, for example. The detection of these bacteria is normally a slow process of pre-treatments and growing bacteria cultures. We want to integrate this all onto a quick, small and low cost chip. That way people getting water from a well will be able to see very fast whether the water is polluted or not’.

For this project, the research group is working together with researchers from Rwanda. They've already shown the concept works, but now want to make the chip more robust, smaller and cheaper.

Measuring stress

Light can characterise more than liquids alone. *Stress* (tension) in materials can be measured too, for instance. Think of a CD box that's bent a little: all colours of the rainbow will appear. They are a measure for the tension the box experiences. Ottevaere: ‘Polarimeters allow us to monitor *stress* in materials. Of course this tension doesn't matter to a little CD box, but if light needs to get through the lenses in a pair of glasses, for example, it's very important there's no tension in the glass. Otherwise the light will refract in different ways on the surface, depending on the way it reaches it, and you'll see lots of strange effects through your glasses’.

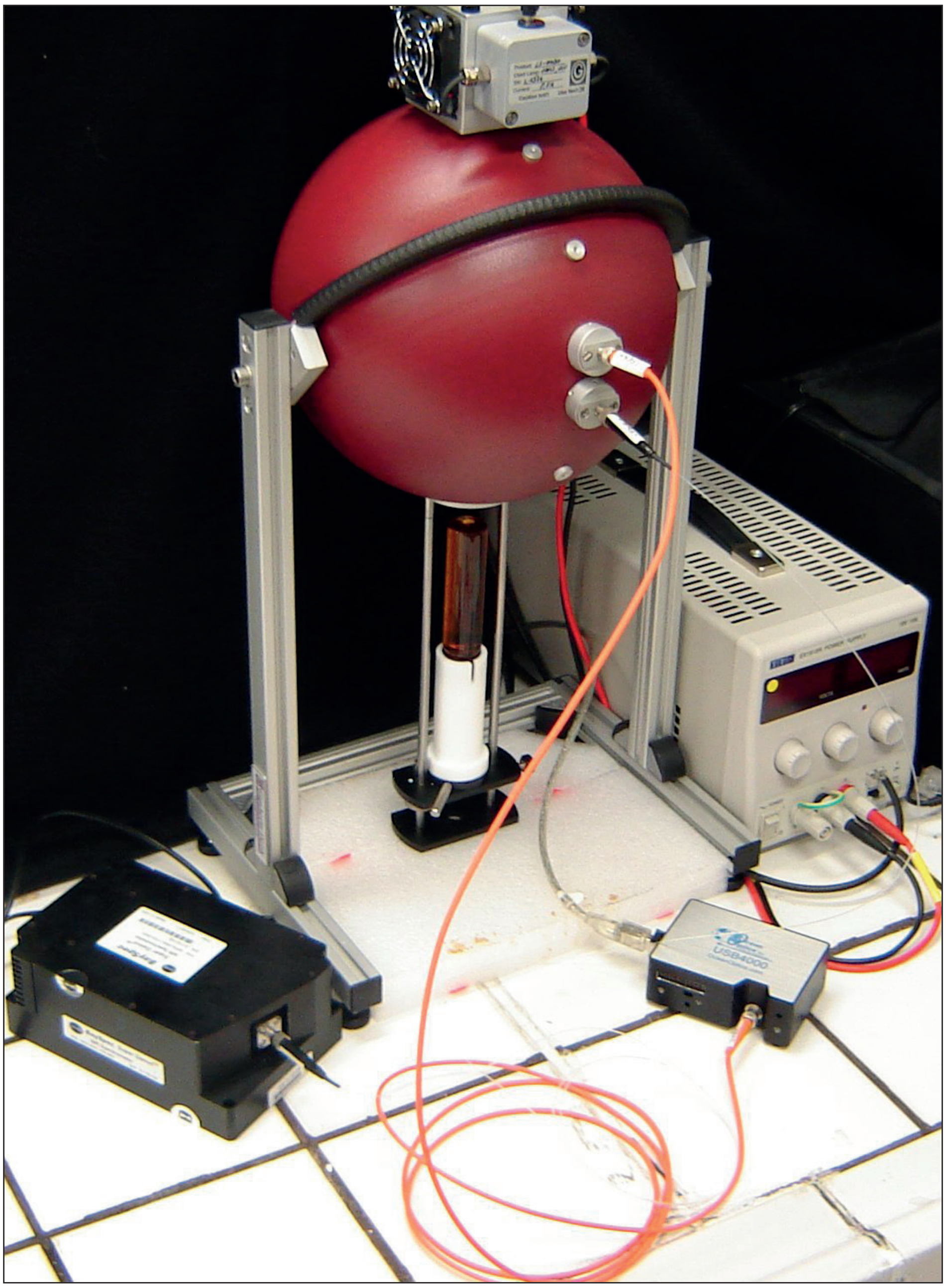
More information

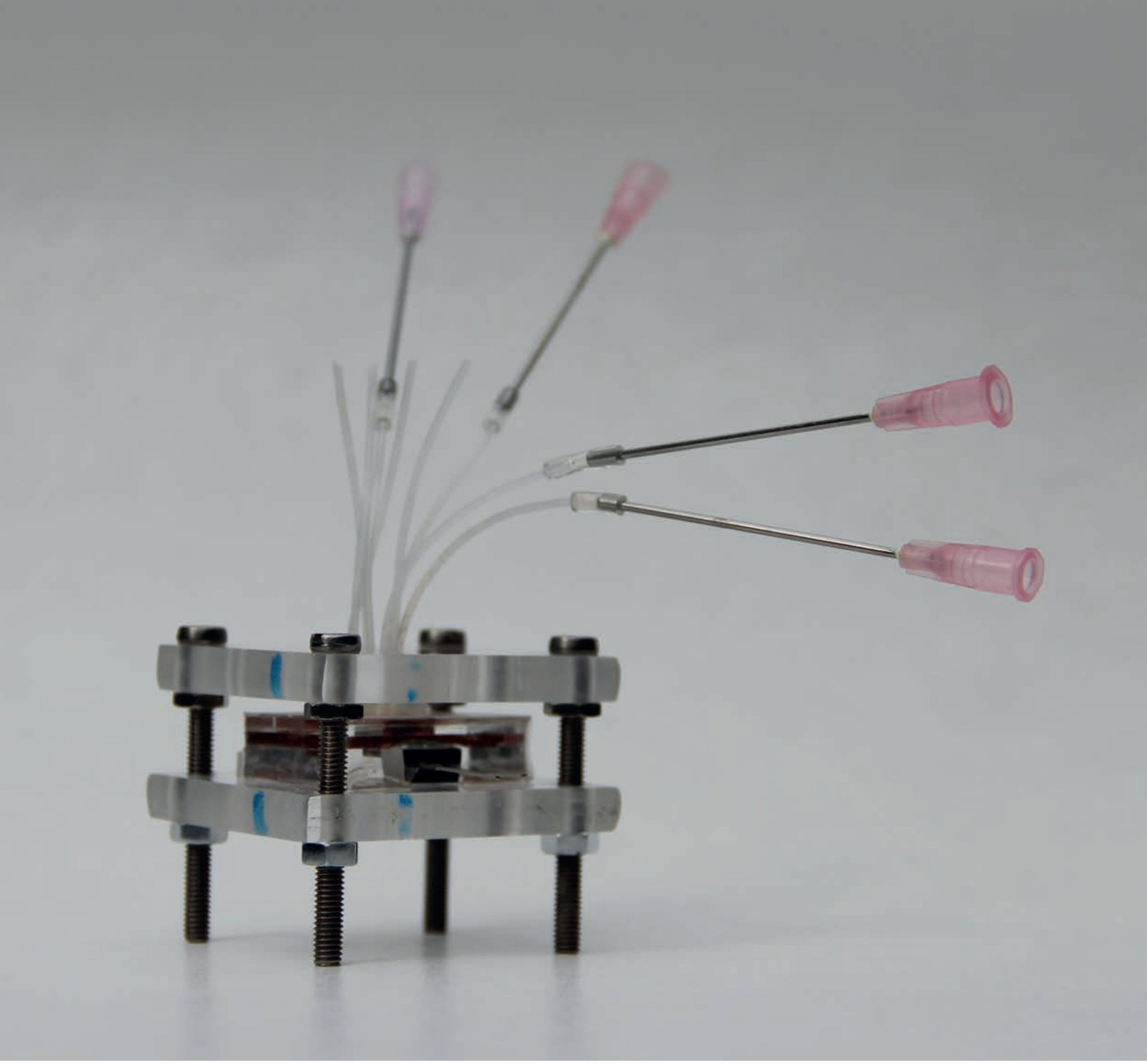
B-Phot, Vrije Universiteit

Brussel: www.b-phot.org

Festival screens

B-Phot is also doing considerable research into micro-optic components. Heidi Ottevaere: ‘Thanks to this kind of research we can achieve a uniform image on festival screens, for instance, or on your smartphone. It’s important for these screens that you can see the image well, independent of weather conditions and the angle you’re looking at the screen from. After all you want to see your favourite band playing right there, whether the sun is shining on the screen or not’.





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Biosensor

‘We want to use our sensors to make analysis more accessible for everyone’

Patrick Wagner is head of the Biosensor research group within the IMO-IMOMEC Institute for Materials Research at UHasselt. The research group develops sensors able to characterise various living materials and molecules. From identifying point mutations in DNA to analysing blood, saliva and food.

One of their goals is complementing existing medical diagnostics, to enable GPs to do certain analyses themselves. ‘Hopefully it will no longer be necessary in the future to send samples to a medical lab’, says Wagner. ‘It costs time and money, and all kinds of things can go wrong during transport. We should be able to conduct these tests quickly and cheaply with biosensors’.

Well-known examples of biosensors are glucose sensors for diabetics measuring sugars in the blood or a pregnancy test telling you in a few minutes whether your urine has a pregnancy hormone in it. These are two examples that have been available for a long time. Wagner and his team are now looking at other interesting substances and applications.

Detecting illnesses via point mutations in DNA

Wagner’s research group is working on systems identifying point mutations in DNA. These mutations are related to a great many conditions: from breast cancer to Alzheimer’s. Detecting a mutation on a certain gene can indicate if someone is likely to get a given illness. ‘We can do that now already’, says Wagner, ‘but often with *microarrays*, a pretty complex and time-consuming technique’.

For the technique being researched, DNA with known characteristics is tied to DNA with unknown characteristics. This produces a double helix. However, the constructed DNA helix will be less stable if a point mutation occurs somewhere in the unknown DNA. ‘Just like a zip that’s missing a tooth in one of its two sides’, clarifies Wagner. ‘By sending a current through the helix or increasing the heat, the helix will break into pieces. If the helix breaks up fast, you know there was a point mutation somewhere. If on the contrary the string holds out longer, you know the DNA is mutation free’.

The measuring principle based on heat was invented by Wagner’s research group. ‘We’re proud of that. It was a surprising result, because we’d never expected the effect of a breaking DNA helix to be measurable at all in the change of heat conductivity. We can use the technique for DNA now, but also for detecting other molecules in bodily fluids and living cells’.

Detecting molecules in bodily fluids

Wagner and his team are currently working on a sensor that can measure levels of serotonin in blood. Interesting, because serotonin influences peristaltic movements of the gastrointestinal tract and can cause depression or hyperactivity. ‘It’s already possible to conduct these analyses in a medical lab, but our sensor chip has to be quicker and cheaper. That way it’s possible to learn what the patient’s serotonin level is in a few minutes’.

‘We’re also developing a sensor to detect histamine’, says Wagner. ‘This is a substance that influences asthma, allergy and IBS (Irritable Bowel Syndrome). This is why the university hospital of Maastricht in the Netherlands has joined us in looking for a sensor that can measure histamine levels directly in the small intestine. That way doctors can follow up histamine levels very fast and test what happens if a patient eats something particular, if they are subjected to stress or when they’re sleeping’.

‘We want to use our sensors to make analysis more accessible for everyone’, says Wagner. ‘So analysis can be done at low cost in a nonspecialised lab by - preferably - anyone'. Wagner remarks though that the goal is not to develop sensors people can buy in their local drug store. There are always people who would test themselves too much and that way become too worried or try to cure themselves unnecessarily.

Recognising living cells

A last type of sensor the research group is working on is a sensor able to detect living cells. In the future this sensor must be able to determine how many cancer cells are left in patients' blood. Indeed the number of circulating tumour cells is an important factor to assess a patient's chance of survival.

'But developing a sensor that can find a few cancer cells is not easy', admits Wagner. 'There are ten million cells in every millilitre of blood and in and amongst those ten million there are maybe only ten cancer cells. We're not able to find these specific cells amongst the ten other million yet, but we're working on it'.

Personal motivation

'It makes me happy that our research really serves a purpose and may improve people's lives in the future. That's a strong motivation to work with', Patrick Wagner concludes. 'I've got asthma myself. That's maybe why I'm interested in developing diagnostic means that can be used to detect certain illnesses. Investing in means to improve people's health really pays and it satisfies me a lot'.

When I ask Patrick Wagner to see a few photos of biosensors, he answers: 'Our equipment doesn't look very impressive. There are no wall-to-wall cupboards with plenty of wiring and lots of buttons. Our aim is rather to develop small, simple things. The sensors are no bigger than a matchbox and they look rather ordinary, but they do extraordinary things'.

More information

IMO-IMOMEC, UHasselt: www.uhasselt.be/IMO

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Flanders
State of the Art

Author: Toon Verlinden

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