Fraunhofer IZM

Special Edition

*Real*IZM Online-Magazine

Science Blog about Microelectronics

»Making Ideas Happen«
5 Years *Real*IZM

Dear readers,

*Real*IZM, the Fraunhofer Society's first science blog dedicated to microelectronics, was first launched on September 5, 2019. In the five years since then, the original vision of Yulia Fedorovich and Marieke Lienert, two former colleagues from our Marketing & PR team, has grown into a bustling platform for electronics enthusiasts.

*Real*IZM offers exclusive insights into the exciting research and development work on electronic packaging happening at Fraunhofer IZM. From the revival of Moore's Law through chiplets to the challenges and opportunities of co-packaged optics, our 100+ published articles, created with the support of more than 80 experts, are a testament to our collective effort.

Our blog is a space for sparking a dialogue between researchers and specialists and our wider interested readership. Its success is reflected not least in the award in the »International Research Marketing Ideas Competition« of the German Research Foundation (DFG) in 2022.

On behalf of the editorial team, I would like to thank you, our readers. A science blog thrives on high-quality content, but especially on the conversation it creates between researchers and experts worldwide.

In this special edition, we have curated the most popular articles from the last five years for your enjoyment in a new format. Seize this opportunity to continue networking and share ideas with scientists, innovators, and visionaries in the field of microelectronics.

Enjoy the read!

Kind regards
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How E-Textiles Will Affect Protection, Health-Tech, Fashion, and Communication

Author: Marieke Lienert

There are smartphones, smart homes – and now even our textiles are getting smart. Their practical potential is already being tested by the emergency services, but smart textiles are also set to conquer the world from medicine to fashion and, maybe soon, our everyday lives.

Malte von Krshiwoblozki speaks to *Real*IZM about his projects and future vision.

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*Real*IZM: What is your history with Fraunhofer IZM?

Malte von Krshiwoblozki: I studied microsystems technology at the FHTW and then joined the Fraunhofer IZM in 2007 during my practice semester. I graduated in 2009 and stayed on as part of the »System on Flex« group. This brought me into contact with the whole topic of smart textiles right from the start. And now, I am in charge of the »System on Flex« group and all textile-related activities.

Did you have a particular vision you wanted to pursue after your studies?

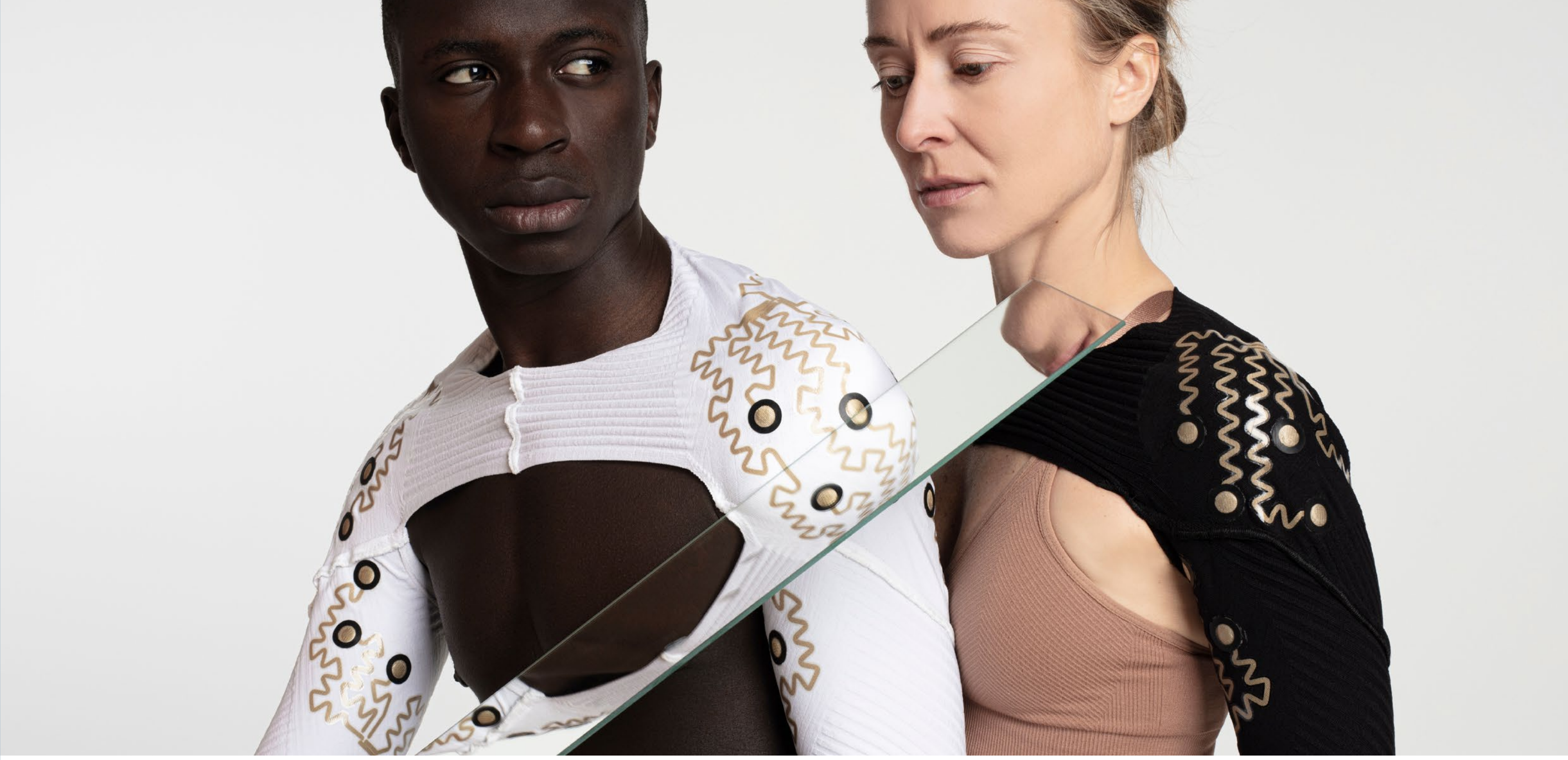
Well, not really, to be honest. I studied microsystems technology, which means that you have little to do with smart textiles at first. The first time I came into contact with smart textiles was when it came to conductive cleanroom suits.

Other than that, this topic was – and, frankly, still is – very exotic. I always thought that I was going to end up in a classic field of microsystems technology. That is why everything here was quite a surprise to me too. It just happened like that.

And yet here you are: Could you walk me through the topic »smart textiles«?

I prefer the term »electronic textiles« or »e-textiles« now, since »smart textiles« also refer to textiles made from smart materials like shape changing polymers that have no electronic functionality. E-textiles can be used in a wide variety of areas. The first you might think of, of course, is a dress that lights up, or the fashion industry more generally. But these are markets where e-textiles will probably only end up later on.

In the short or medium term, the medical technology markets and others are much more interesting. You can get really close to the human body, you can build comfortable, breathable systems to scan vital signs. Protective clothing for professional use is another big topic. Just think of firefighters or soldiers, who could have a kind of energy and data network in their clothing that would allow them to plug in any wearable device they need in an emergency. The sports sector also has a lot of potential. Motion analysis allows you to record the movements of an athlete's body with textile sensors and to draw certain conclusions from this information.



Connextyle - Fraunhofer researchers and designers combine style with functionality: in this case with clothing that measures muscle activity and thus optimizes rehabilitation processes. © Jessica Smarsch

Muscle activities can be measured with electromyogram (EMG), or you could actually stimulate muscles with electric pulses. Besides, regular ECG measurements are also possible. Everything to make training more efficient and avoid overtraining is of interest in the wearables area.

What we often forget is that textiles are actually a much bigger field: You come home and step on a carpet, sit on a couch. In your car, everything is upholstered with textile products. There is great potential for us to introduce new functionalities in these products. This can be considered a worthwhile opportunity to create new business models.

For example, think of electric mobility: In an electric car, the waste heat from the engine is negligible. An electric engine does not produce as much waste heat as the internal combustion engine. So you have to think about how to heat the passenger compartment during cold weather. This could be achieved using textile heating surfaces integrated into the cladding.

With this many different markets for smart textiles, you cannot really be focused on any one specific field, but rather have to spread yourself out. If you specialize, you do so more in one of the underlying technologies that can then be adopted in different fields.

Do you have a key field of expertise for e-textiles at Fraunhofer IZM?

Of course, we stay with the core topics of our institute: packaging and interconnection technologies. We think about how we can connect electronic modules and components with textiles as efficiently and as appropriately as possible for the material.

For example, standard soldering processes would not work with many textiles on an industrial level. This is because textiles cannot withstand the temperature, and solder joints usually do not cope that well with getting bent or put in the washer. We are developing new alternatives, such as adhesive technologies where the modules are mechanically and electrically connected.

We have also developed stretchable printed circuit boards. We are currently spinning this further, so that we now have stretchable printed circuit boards in which the conductors are no longer based on copper foil or printed silver paste. We are utilizing fully conductive fabrics that are already very robust by nature. We then structure these with a laser and subsequently embed them into an elastic polymer. The polymer insulates the conductive fabric where necessary, makes it more robust, and allows easy integration into textile products.

#e-textiles

By integrating electronic components, textiles can be enhanced with many different functions such as sensors and lighting and therefore become e-textiles. This enables completely new application areas for e-textiles.

E-textiles are an indispensablepart of our everyday life. They are not limited to clothing made of fabric, knits and fleece, but also include technical textiles and composite materials.

They withstand extreme stresses during washing and have many different functions while being light and highly flexible.

What else is in progress at the moment?

We are expanding our contacting technology capabilities and converting everything to a larger dimension. Adhesive bonding involves bonding electrical modules to textiles with integrated conductors. This creates a mechanical and electrical connection in one process step. It allows many contacts to be contacted at once, and it even supports insulated conductors if the insulation is designed to match the process.

We are currently developing this further on textile tapes, which we could use as an add-on webbing system for protective workwear or as highly robust belts e.g. for medical applications. Introducing completely new products to the market is difficult. If an existing product portfolio can still be used and you bring in add-on upgrades, that hurdle might be lower.

And since such add-ons can be easily removed, this has no effect on standard logistics, such as cleaning. Keep in mind that most customers are still not aware of e-textiles at all and might be wary about this new technology.

Is there an application that we can already see in everyday life?

We have a medically focused FMD project with a start-up and the Fraunhofer Heinrich Hertz Institute to help patients who have lost their sense of touch in their hands. If they do not see their hand, they cannot tell whether they are holding something. They are also not able to feel how hard they are squeezing.

The HHI institute is working on a sensor glove, and we at Fraunhofer IZM are developing a vest with 16 textile-integrated vibration motors. This allows the patient’s body to receive signals through an additional communication channel without using the visual or auditory track.

By vibrating at sixteen spots on your back, an algorithm and a specific language can transmit specific information from the sensor glove. The haptic language is developed by the start-up. The goal for the glove is to measure information and pass it on through vibration.

Is there any technology you developed that you are particularly proud of?

I mentioned the contacting technique earlier. We call this »adhesive bonding«. This is adapted from raw microsystems technology. We know from microelectronics that chips are applied with the flip-chip method, where the contacts are oriented directly downwards. We have now adapted this process to textiles. Adhesive bonding was also the topic of my diploma thesis. I have continued to develop the technology ever since then. I am enthusiastic about transferring this into the industry soon.

Where would you like to be in a year?

E-textiles have been a topic for a long time now. At the institute, the first projects were executed in 1999, and I have been working in this field for more than 12 years. But if you look around in a department store or out and about, these products are still very rare indeed. There are a few niche products that already use e-textile technology, but everything is going very slowly. It would be great if we made the leap to industrialize all of this and really bring it to the market in the near future.

What does the market look like? Have any competitors emerged?

There is definitely competition. Above all, there are many different approaches being pursued in this area, all of which are viable and promising. What I have noticed lately is that more and more major companies like Google or Microsoft have projects in this field and actively invest money to promote it.

There are many start-ups as well; there is a lot of capital invested in these companies. You can see that there is a huge push going on, so I am convinced that, sooner or later, there will be a good market for it. The challenge is to position yourself so intelligently that you will still be in demand in five years’ time.

Does the Fraunhofer IZM have a unique selling point to get such a position in the industry?

Absolutely. We are very well positioned in terms of contacting technology, highly robust e-textiles, and testing and analytics as well. There are many institutes that deal with the topic of e-textiles in general: from electronics or the textile side.

They usually tend to be better in a specific sub-area. But when it comes to bringing these things together, we have a unique selling point. The equipment and our years of research alone have given us a lot of experience, and I believe we are in a very good position.

Are there any current projects you can tell us about?

Among lot of other things, we are currently running »Refream«, an EU project in which we are part of the Berlin hub. Artists are presenting their ideas and applying for technology funding. Within a certain budget, they have the opportunity to use the technologies we provide to build next gen e-textile prototypes.

But that is not all there is: We are working with our colleagues from the environmental engineering department to look into the environmental impact of these approaches and the potential for the circular economy

Another project is the **»Textile Prototyping Lab«** funded by the Ministry of Education and Research. The aim is to establish a central and a local laboratory with other partners from Germany, where fast smart textile prototyping can be done.

The difficulty for many companies (especially SMEs) is to guarantee the necessary textile and electronic know-how and the necessary financial and time investment in advance. Besides this, getting machine time for trying new things is often problematic. This is where the Textile Protyping Lab can help. The aim of our project is to provide input for textiles, design, and electronics and the equipment, so that prototypes can be produced quickly.

Is it sometimes difficult to manage the balancing act between being a serious researcher and fooling around, inventing color-changing shoes for example?

There are certainly some colleagues who like to have a laugh in this sense. And of course, we have technologies and very cool means and equipment here in the house. Sometimes, you come up with ideas that you would like to implement right away, which is great and also important for research, but unfortunately you do not always have the time.

However, I am satisfied at the moment with the path my career is taking. I like to look at everything from a bird's eye perspective and

EU project Re-Fream - Second Skins designed by Malou Beemer

The garment consists of three layers. Undergarment: With integrated LED modules that generate light. Diffuse layer: This changes the light with the help of Profactor. Upper layer: This gives the garment its final shape. The wearer can upload their own LED color patterns and adjust them using a tap sensor. The ability to customize colors, patterns and textures extends the life of the garment.

© Fraunhofer IZM I Patrik Klein Meuleman

Read more about the Textile Prototyping Lab!

control it in such a way that I get where I wanted to get in the end. That is also important if you want to avoid developing tunnel vision and developing things that shoot past what people actually need.

Alexa and Siri are part of our lives already – will we be talking to our clothes soon? Is that even an issue?

When I talk about e-textiles, I usually mean the technologies behind them. It is a big challenge to get all this ready for the market. A computer has a hard and solid case and is electromagnetically shielded. Textiles, on the other hand, are moved and bent every day. Besides, **the user** is actually inside the electronic system. The textiles are washed hot and cold; they generally get wet and come into contact with sweat and dirt. These are extremely tough conditions.

Think about how fast normal T-shirts wear out after a few washes. If you now add electronics with conductor paths to these textiles, whose resistance must be guaranteed over the entire service life, this represents an extreme challenge.

Voice control itself does not have to be reinvented for clothes. All you have to do is supply a new add-on and connect it – theoretically, that is just business as usual. But the actual challenge is somewhere else for now.

When the time comes, will it be just a luxury product or will it be affordable for the average consumer?

In the fashion sector, it will probably be high priced at the beginning, or the products won't last long. The really good things will only come when all these manufacturing technologies have been established in the professional sector, such as protective clothing, medical technology, professional sports, etc. Once the technologies have matured enough so that you can upscale production – produce at low prices – then you can also expect reasonable, affordable fashion products, I would think.

Since this is now often mentioned when fashion is discussed: What about sustainability in the field of e-textiles?

Right after the extractive industry, the textile industry is the industry with the worst environmental impact. This means that the textile industry, without even including »smart« or »e-textiles«, is under lots of pressure to make its processes more environmentally friendly.

If, however, textiles in combination with electronics are offered at a very high level of

Textile with electronic numbers as a temperature-resistant display for vital signs in firefighter jackets © Fraunhofer IZM integration, this becomes more difficult, which is why sensible solutions have to be worked out from the very beginning.

One solution are technologies where you know that the electronic modules can be separated from the pure textile parts in order to recycle them. Metal in clothing has actually been around for much longer than one might think: socks with silver to fight body odor, cleanroom suits.

In care homes, silver fibers are often woven into fabric curtains for example because they have an antibacterial effect. It will be difficult to separate metal from non-metal. Sustainability and the circular economy will definitely be a big challenge to come in this area.

In the area of e-textiles, you are combining different branches of industry that normally do not necessarily work together. Is this a problem?

Well, it took me a while to understand textile professionals. If you come from the field of electrical engineering or microsystems technology and then get face to face with a textile professional, you first have to make sure that you use the same words for the same things.

This means that there is a phase of communication in which you need to find common ground, and only then can you start working. By now, however, the topic has been on the table for a long time, and many companies are approaching each other and building up know-how in complementary fields.

There are many textile companies that are setting up multidisciplinary teams. There, electronic engineers, chemists, material scientists, and possibly medical people are put together in a team to develop e-textile products.

Also, looking at the manufacturing technologies, microsystems technology consists of soldering, laboratories, clean rooms – everything is highly accurate and sterile. When I come into a weaver’s mill, there are fibers flying around in the air, depending on the material, and everything is only »accurate« to the millimeter. So it will take a few years until you reach common ground on the industrial side.

Speaking of laboratories: What does a typical day look like for you?

Unfortunately, I am rarely in the laboratory. I spend a lot of time on my computer, in meetings, and on the phone, or I travel around to meet customers and project partners. Writing project proposals, reading project reports, making sure projects run etc.

… because you delegate others who are in the lab for you?

As a group manager, you do not longer have the time to be really hands-on involved, which is why the scientific staff, technicians, and also many of our students do this. You rather move into a planning, »controlling« role. That might sound boring, but you can still learn a lot as you access much more information.

Are you looking for cooperation partners?

Yes, we are always on the lookout for industry partners who want to manufacture e-textiles and use our knowhow to bring new production technologies to the market. We can help them with our comprehensive technology portfolio to realize their innovative ideas.

A final prognosis: In 2017, it was said that 238 million smart clothes will be on the market in 2021. Is this realistic?

Of course it always depends on what you count as an intelligent piece of clothing. But, to put it in a nutshell, if you include everything that contains conductive material, I could imagine that number.

First published on 06/02/2020

Infinite Potential of Wire Bonding: New Research Findings

Authors: Yulia Fedorovich and Marieke Lienert

With more than half a century of history behind the technology, progress in wire bonding shows no signs of slowing down. For proof of the technology's unbroken potential, look no further than the AlCuBo project. Run by Fraunhofer IZM and its partners, the project is developing processes for scaling up the production of AlCu composite wires for power electronics to mass production readiness by extrusion and wire drawing.

*Real*IZM chats to Prof. Martin Schneider-Ramelow about the project.

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He is also a professor at the TU Berlin and a senior member of the IEEE, a fellow of IMAPS USA and 1st chairman of IMAPS Germany as well as chairman of the DVS bonding working group.

***Real*IZM: How did you come up with the idea for this project?**

Prof. Dr. Martin Schneider-Ramelow: I come from a background of materials science, especially wire bonding technology, here at Fraunhofer IZM. From my work with the Extrusion Research and Development Center of TU Berlin (our partner for this research project), I discovered that the smallest metallic wires they are able to produce by extrusion are only 500 micrometres small. This corresponds exactly to the largest size that we use for heavy wire bonding for power electronics. This process is used in over 90% of power electronics modules.

The idea is now to develop new material compositions for heavy wire interconnections, so that we can build more reliable power modules that last longer. There are relatively few companies in the world that manufacture these wires. With that in mind, we tested bimetal wires from this company, and they are suitable for wire bonding, in principle. However, because of the relatively thin Al sheath, many semiconductor chips failed during the bonding process.

So, now we want to optimize the thickness of that Al sheath with the help of our colleagues at the Extrusion R&D Center. These composites will be tested and systematically analysed here at the Institute. Our hope is that we can use them to build new types of highly reliable power modules.

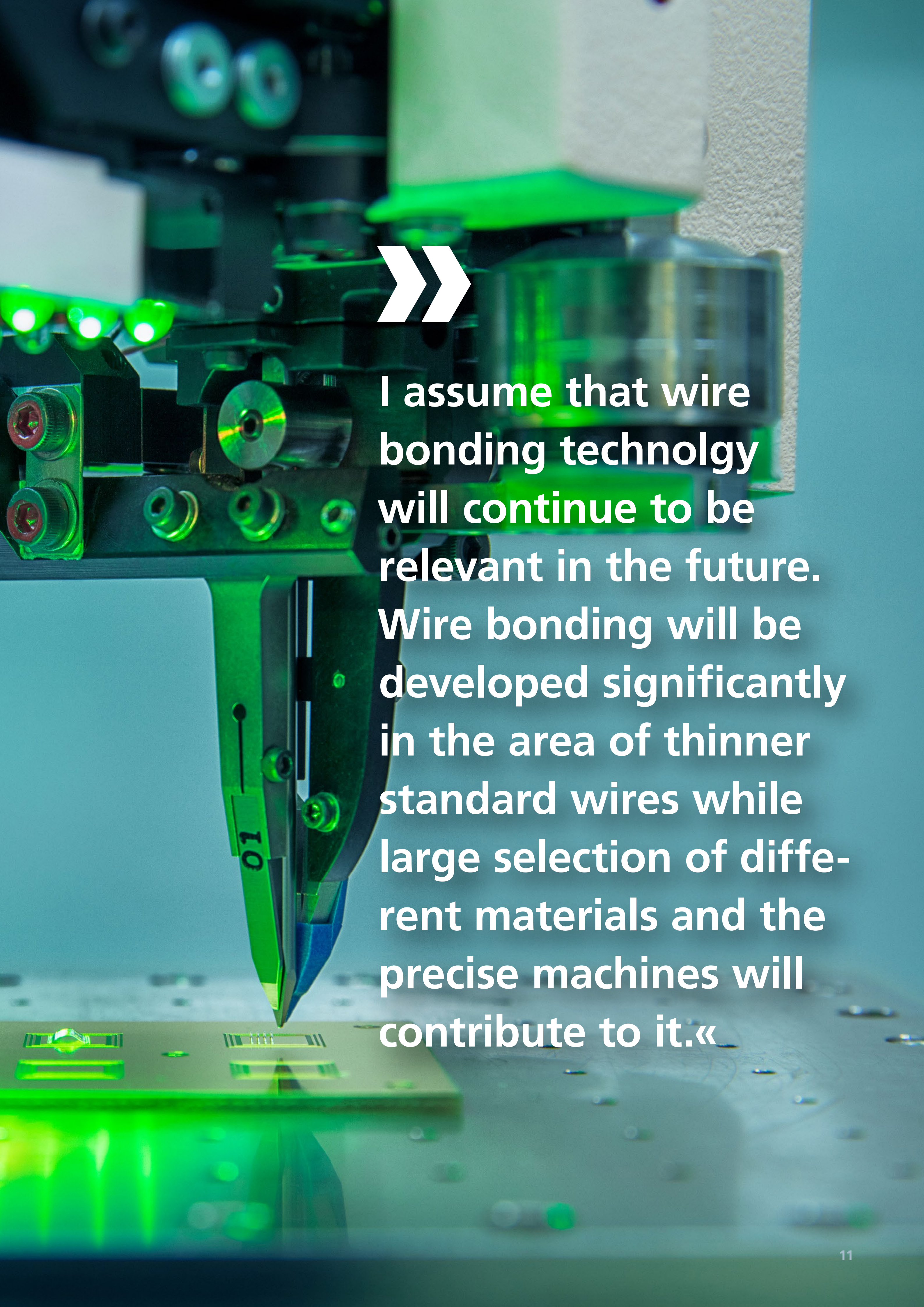
The technology itself has been around for quite a long time. Why is it still relevant for us?

Wire bonding technology was invented back in the late 1950s and refined in the 1960s. As a technology, wire bonding is very versatile. Fully automatic wire bonders can be programmed so that almost any geometry on the surface can be accurately contacted.

By comparison, if you look at our embedding technology, you have to use a laser in order to get to the contact points. This becomes particularly difficult when working on large areas, but this difficulty does not exist with wire bonding. That is what makes the technology so flexible and so cost-efficient. Not to forget, it is also very fast, as you can get 2 or 3 heavy wire loops every second.

Why are you looking to new materials for the technology's future?

The back sides of semiconductors are no longer soldered, but made with high-quality sintered bonds. In the past, this was their weak spot, as the soldering points tended to break. Once we started sintering (which we



> »I assume that wire bonding technolgy will continue to be relevant in the future. Wire bonding will be developed significantly in the area of thinner standard wires while large selection of different materials and the precise machines will contribute to it.«

Last page: Bonding head of a fully automatic thick wire bonder during bonding on a power module substrate © Fraunhofer IZM I Volker Mai

also do here at Fraunhofer IZM), the thick wire bonds at the top became the weak spot. With the usual 99.99% high-purity aluminum wires, symptoms of fatigue set in relatively quickly. Specifically, fatigue cracks can occur when thermal and mechanical stresses alternate. Ultimately, you get lift-off and an electrical failure of the whole module.

What can you do to avoid that?

The idea is to achieve higher strengths with new aluminum-copper wires. With the previous alternatives made of copper, however, we only achieved very low yields so far (i.e. a small yield of functioning chips).

The forces strengths were simply too great, and many chips already broken (because of cratering) during production. That is why no alternative materials have yet been used in industrial production. In our project, we now want to adjust the thickness of the aluminum to that sweet spot, at which chips will not fail by cratering and we get closer to the best case scenario of a 100% yield. On the other hand, the copper cross-section should, of course, remain as large as possible, because copper has better electrical and thermal conductivity and also higher strength. In short, the aim of the project is: Optimizing such a material composition for power modules.

So you could say that copper is the top dog in this material mix?

Copper is more important in the sense that it has better electrical and thermal conductivity and higher strength. However, with pure copper – i.e. if the wire were a full copper wire – there would be the risk that the semiconductors under the very thin aluminum layer (3-5 microns) could be damaged during the bonding process (cratering).

We would be back to power modules failing. Aluminum is important, because it is relatively soft and can serve as a weld or a contact partner. To be more precise, the aluminum layer around the wire is connected to the aluminum layer that can be found on the surface of nearly every power semiconductor. In sum, one can say: Aluminum is important for welding, and copper for its electrical, thermal, and mechanical properties.

Are there any other materials that could be used for these purposes, e.g. gold or silver?

Gold and silver are also used in wire bonding, but not for thick wires because of costs. The distinction between standard and heavy wire is very important. Power semiconductors are bonded exclusively with heavy wires in wedge-to-wedge technology because of the high currents needed for these chips.

Thick wires have a diameter between 100 and 500 micrometers. Standard wires are typically thinner than 50 micrometers, and they are typically bonded with so-called ball-wedge bonding. The smallest diameters are less than 15 micrometers in thickness. 20 years ago, these were made almost exclusively from gold, but we switched to copper and silver in the past decade – again, simply for cost reasons.

Could you tell us more about the project's goals and how the responsibilities are shared?

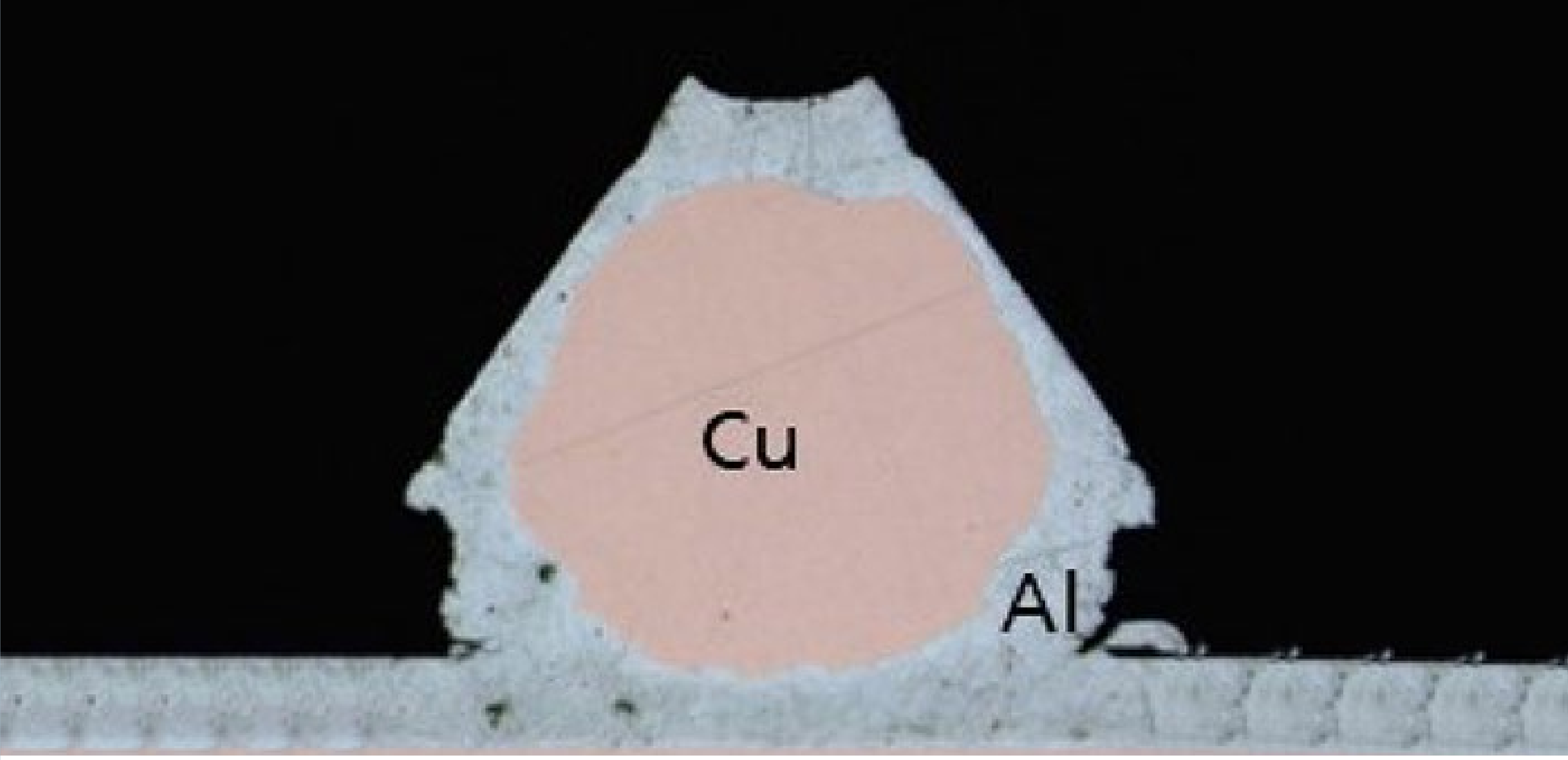
At the Extrusion R&D Center of TU Berlin, composite wires are produced first by extrusion and, afterwards, by drawing. The bonding wires have a diameter of approx. 0.5 mm and consist of an Al sheath around a Cu core. The suitable forming conditions are determined by numerical process simulation. The results are validated by comparing them to observations from real-life forming tests.

At Fraunhofer IZM, the mechanical properties of the bonding wires are characterized by tensile tests and hardness tests (micro/nanointended). We can also determine their current carrying capacity can and compare them to other commercially available materials. The optimum thickness of the aluminium cladding is determined, focusing on the bond yield on semiconductor material without cratering (with a goal of 100% yield due to thicker Al cladding) and on a high current carrying capacity achieved with the largest possible Cu core.

#wirebonding

Wire bonding is a standard process for electrical contacting in packaging and interconnection technology. It is widely used in semiconductor assembly. Applications are, for example, in chip-on-board technology or power module technology.

In wire bonding, the electrical connection is usually made using wires made of aluminium, gold, copper or silver. These are connected to each other in a solid state using various techniques through the temporary action of pressure, temperature and/or ultrasound.



Heavy Wire Al-Cu-Bi-Metal Bond Wedge © Fraunhofer IZM

We are using a demonstrator setup for industrial wire bonding equipment with our industry partners Hesse GmbH and Vitesco Technologies GmbH to carry out bond tests and introduce the necessary adjustments to the equipment or tool geometries.

Finally, temperature cycling and mechanical stress tests are conducted as part of our reliability and lifetime evaluations.

What will come of the results of this project?

From a scientific point of view, the analyses of the extrusion and wire drawing process chain could initiate a further process chain and improve material properties.

With our mechanical and thermo-mechanical investigations, we can see new bimetallic combinations coming for bonding wires, which could keep up with the new requirements of the power modules of the future, e.g. working at higher temperatures. The insights gained from this project will be an important basis for the production and processing of Al/Cu bonding wires.

What about the commercial point of view?

The Al/Cu-compound wires we are working on are meant for the assembly and connection of power electronic modules. Power electronics are used, for example, as voltage converters that transform the DC power generated from wind or solar energy into the AC power that can be fed into our power grid.

Power electronic modules can make an important contribution to our attempts to reduce our carbon footprint, with loss-free conversion promising lower energy consumption.

The same applies to voltage converters in the field of electric mobility. For today's and tomorrows electric cars to have all the functions we expect, like autonomous driving, we need to save weight, increase performance, and/or scale down their components.

What's the future of wire bonding? Will it still be relevant in 15 years?

I can tell you an anecdote about that: When I started working here at Fraunhofer IZM 22 years ago, the head and founder of the Institute at the time, Professor Reichl, told Professor Lang, his eventual successor and, back then, head of the wire bonding group, that he should start to look for a new research interest, because wire bonding would soon be dead in the water.

And yet today – to give you a roughly estimate – over 75% of microelectronic products are wire-bonded, exactly because it is such a flexible and low-cost technology.[1]

0.5 mm

diameter of the bonding wires

> 75 %

of microelectronic products are wire-bonded

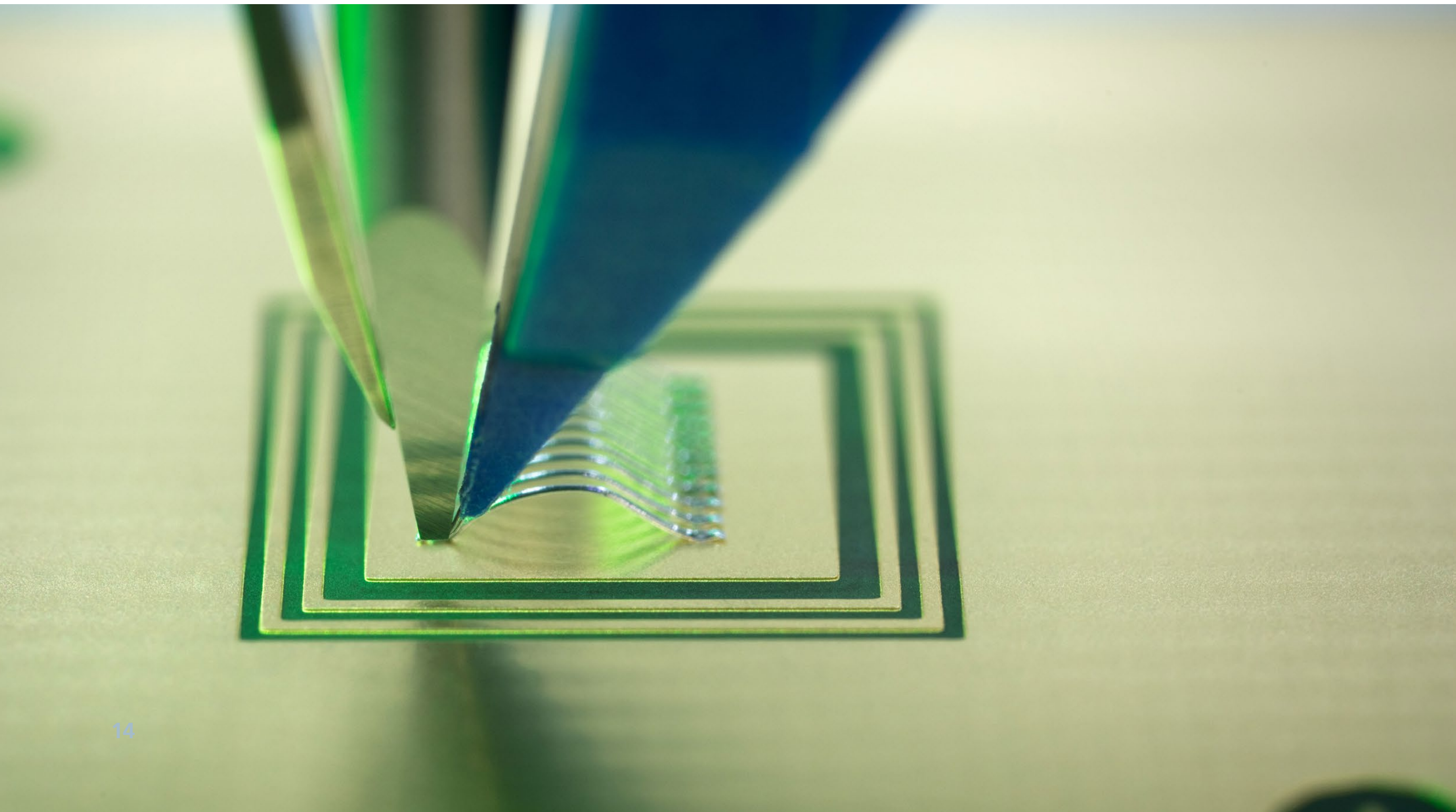
I assume that wire bonding technology will continue to stay relevant going forward. Wire bonding will make significant progress with thinner standard wires, supported by a greater choice of different and high-precision machines. Innovations are already happening, especially in the field of flip chip bonding, chiplets, or embedding technologies. But all of this will need time.

Thank you very much for the interview!

First published
on 11/26/2020

The aluminum-copper-bimetal bonding wire transfer project was funded by the DFG.

Source:
[1] Yole Report 2019: Automotive Packaging Market & Technology Trends



Detailed view of a thick-wire bonding tool with wire guide and blade (front cut) during a bond wire test
© Fraunhofer IZM I Volker Mai

Rechargeable Bees? The Surprising Uses of Miniature Batteries

Author: Jacqueline Kamp

Fraunhofer IZM is pushing the boundaries for extremely small lithium-ion batteries, with the tiniest battery coming in at only one square millimetre. These super-small batteries are used in tiny in-ear devices or, unexpectedly, on the backs of worker bees.

Dr. Robert Hahn from Fraunhofer IZM tells us more about the bees and why they are wearing tiny backpacks stuffed with miniature sensors.

_Real_IZM: Let's start at the beginning: What exactly are lithium-ion batteries and what is special about them?

Dr. Robert Hahn: Lithium-ion batteries are the most widespread rechargeable batteries today. They were first installed in mobile phones, and later also in notebooks and tablets. Now, they can even be found as the main battery of electric cars.

What is Fraunhofer IZM focussing on in the development of lithium-ion batteries?

At Fraunhofer IZM, we are focusing on these very, very small batteries that no one else can develop, except for us. To develop them, we are using our silicon wafer-level processes, which take place here in the clean room. These batteries are really very small indeed: only 1×1 mm². Because of this tiny size, a few thousand of them can be produced on a single wafer. However, there are not yet that many users who need such extremely small batteries. But we have already had a project with a large medical manufacturer who wanted to fit electronics onto a contact lens. Another project involved very small hearing aids that are placed directly on the eardrum.

At the moment, we are developing batteries that fit into very small sensors for bee research. The bees will be fitted with sensors to capture data as they fly around. Our innovation is this small housing. The battery materials we are using are actually exactly the ones used in mobile phones or electric cars. With lithium batteries, you get many subgroups and different electrolytes, and we always try to use the latest and best developments.

Can you tell us a bit more about the bees with the mini-batteries on their backs?

The project Sens4Bee is funded by the Federal Ministry of Agriculture and Food here in Germany and is currently still active. Our partners are a company that makes electronics, beekeepers, and people who make the hives and frames for the colonies.

And Fraunhofer IZM is producing the small batteries for this project?

Exactly, we are producing tiny batteries and, in this case, even a very small solar module that is attached to the bees. Since the bees are usually in flight during daytime when the sun is shining, the battery can be charged on the go. It would be difficult to connect the bees to a charger.

We chose silicon solar cells that are essentially similar to the solar panels you see on people's roofs. In this case, however, silicon has the added good property of reacting sensitively to infrared radiation. Bees cannot perceive

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infrared radiation at all. That is why the batteries can be recharged with infrared in the hive if the time in flight was not long enough for recharging. In this way, sensor data can still be collected in the beehive.

You just said that the researchers at Fraunhofer IZM are the only ones in the world who can manufacture these super-small batteries. Can you describe in more detail how they are produced?

There may, of course, be other companies that can do this, but they simply haven't published anything yet. One can never be sure. I could well imagine that as soon as there are more applications for these miniature batteries, other companies will turn up that can produce them. But as it is now, it is an ideal area of application for us.

1 x 1 mm²

size of the batteries developed by Fraunhofer IZM

The lithium in the battery is very sensitive to humid air, so the battery has to be completely hermetically sealed. Larger batteries have pretty good casings. They are welded into a composite film of polymer and aluminium, with a polymer-on-polymer weld. The polymer itself is not 100% waterproof. A few molecules always diffuse into it, but that doesn't matter for a large battery.

With very small batteries, the story is different: Every water molecule that enters the system will react with a lithium atom, so that the capacity of the battery becomes smaller and smaller. That's why the housing must be hermetically sealed in any case.

Up to now, we simply did not have such super-small, but hermetic cases. One area where we had something of the sort is pacemakers. There are batteries that are used for implants and for other applications in the body.

These batteries, however, are actually welded in with glass feed-throughs, small glass discs with a welded-in wire and a welded-on titanium housing around the unit. Metal and glass together seal well. But this lead-through alone has a diameter of at least 2 millimetres. If the whole battery is supposed to be smaller than one millimetre, this is just too large. This is a problem; the smaller the battery, the more space the housing technology takes up and the space left for actual battery material becomes smaller and smaller. There are technologies with silicon where vias are made in the silicon from one side to the other. Copper is passed through vertically and goes through the lithium. This can also be used for normal circuits to pass through for the battery.

The battery only needs two poles. Silicon has the advantage that it can be structured far more finely than most other materials, which is why it is used for semiconductor technology. The existing structures are already in the nanometre range; you can actually structure it that finely. We don't need it to be that fine yet, but we could, if we wanted to, make silicon sensors for the battery housing that are perhaps 50 micrometres wide. But it is important that it also remains mechanically stable.

That is why the lid and the top and bottom of the batteries are about 40 micrometres thick. Although this technology is thinner than a human hair with such small batteries on a millimetre scale, most of the battery's body is active material, such as the anode and cathode, which are filled with lithium. The casing around it is very small. That's why we use silicon. But then, silicon is not such an ideal material for the housing, because it has to be passivated very well, as it could react with the lithium otherwise. Glass would be better, but it cannot be structured that finely.

Therefore, it's a question of making a silicon substrate that has recesses for the anode and cathode, and walls that are as thin as possible all around. We then make the hermetic encapsulation by first gluing a lid onto it, which is still a polymer. Then everything should be metallised again. After that it's coated with a 5-micrometre metal layer and completely sealed at the end.

What were the biggest challenges in the development of this technology?

The most difficult thing about it all is that the liquid electrolyte still has to go into each of these millimetre-scale batteries. I don't think anyone can do that except Fraunhofer IZM.

The Sens4Bee project: Micro integration of solar cells, miniaturized batteries and sensors to investigate and monitor the well-being of bees and how it is influenced by the environment
© Fraunhofer IZM I Volker Mai

Droplets of electrolyte have to be poured into each of the thousands of batteries on the wafer. When the lid is then glued on, the electrolyte must not combine with the adhesive, otherwise it would not stick properly.
On the other hand, the available space should be as full as possible with electrolyte, so that the internal resistance of the battery is low, and it has high ionic conductivity. This is extremely complex technology.

Another difficulty was that batteries are not particularly temperature-stable. They can withstand 80 degrees for an hour or so, but if it is this warm or warmer for longer, they degrade quite quickly. That's why it's not good to leave a mobile phone in a warm car with the sun shining in.

When it gets that warm, the battery ages quite a bit. It's also bad for manufacturing if batteries get too warm. In the clean room, with all the processes and machines that are used for the final metallisation, for example, it can quickly get over 80 degrees. These processes have to be optimised so that they work at as cold a temperature as possible. That was a lot of work.

What are future areas of application for these super-small batteries?

We can think of it as three different areas: The biggest market will probably be in medical technology. Very small electronic sensors will be placed somewhere on or in the patient's body, for example. They would then be linked to artificial intelligence or the Internet of Things. In this way, vital parameters such as eye pressure or various other things could be measured. That is not yet possible at this point.

We have already received many enquiries about sensors for use in the mouth. They could measure certain things, for example, via implants in the gaps between teeth or in a kind of dental chip with very small electronics built in. Of course, the electronics have to be very thin, otherwise the wearer would notice. It also works in the ear. There are very small hearing aids that sit directly on the eardrum, so that you no longer have tiny versions of regular loudspeakers, but a piezo actuator that moves the actual eardrum. This is very effective and uses less energy overall.

This goes as far as implants, for example pacemakers, which are located directly in the heart at the point where the impulse should be delivered. These implants are only as big as a slightly larger grain. However, they would have to be charged differently; there are also projects to charge them directly via the pressure fluctuations in the heart itself, so that energy is generated again by mechanical conversion.

To some extent, this is still a vision for the future. But there are already products for

Right side: Rechargeable micro batteries 1.5 x 3 mm²
© Fraunhofer IZM

hearing aids and braces. The technology is still a bit bigger right now, but it will probably become smaller in the future. Many things could also be considered for a possible contact lens. A display in the eye that can show you something for example, like in James Bond. Ophthalmic diseases could be treated better with such technology. There are many things that could be included, up to and including the electronic lens itself. This could replace today's varifocals.

The second area would generally be research, where you just want to have tiny sensors that measure something somewhere without affecting the environment themselves. Even if you only want to track the temperature on a very small object, a thermocouple would perhaps already falsify the measurement. So very small sensors are used. But this applies not only to temperature, but also to all kinds of other sensors that would otherwise be difficult to get at.

In the project with the bees, for example, we want to look at the behaviour of the bees themselves and how endangered they are by environmental toxins, or how the performance of the bees can be increased. In addition, bees have already become a kind of farm animal, which can be seen as mass farming.

This might be ethically questionable. Nevertheless, there is good monitoring to make sure that the bees' welfare is not affected. The difference to other farm animals, which are bred with virtually 100% human control, is that this is not possible with bees yet, because the queen bee meets drones in the air, and this is difficult to control. But it should at least be observed better to understand what is happening. That is why such sensors are needed, which are attached to the drones.

On the other hand, bees, bumblebees, and other insects are also used as carriers. Sensors are attached to them which can take different environmental measurements. They fly around everywhere, all over the country, so thousands of measurements could be analysed, also with artificial intelligence. This is another area of research for which these small sensors could be needed.

Then there is a third area of application that will become even more interesting in the future. Electronics are increasingly present in all areas of life. Accordingly, it is also becoming more and more important that these electronics cannot be tampered with or hacked. All kinds of processes must function smoothly, which is why there are many encryption systems. The electronics should therefore be completely secure and reliable. One way to better protect current encryption systems or the keys themselves is through hardware. You could attach one of these super-small batteries to an integrated circuit on which the key is stored. The battery can then permanently monitor whether someone is trying to read the key without authorisation and destroy the key. This is part of a particularly tamper-proof electronic system and a realistic area of application for these small batteries.

So far, we have had projects in two of these areas. One is for small sensors in research, and the other is for medical technology. We have also looked at safe electronics, but have not yet had an active project on that side.

What medical technology projects have you used these batteries with at Fraunhofer IZM?

We already had a project for these small hearing aids that sit on the eardrum. The internal resistance of our battery was still a bit too high, because they wanted the battery to recharge as quickly as possible.

A good way to charge it would be with a small solar cell and infrared radiation. For this, you would put an infrared plug in your ear to recharge the device. But the company wanted the recharging to work within 15-60 minutes, and we haven't managed that yet. Now, we are working on improving the internal resistance and fast-charging capabilities. Another thing is capacity, which gets smaller when the battery gets smaller. That's why it's also important for us to always use the latest materials with the highest energy density. We put a lot of work into getting the highest possible energy density in our small batteries. To that end, we employ larger or more energy-rich

#waferlevel-packaging

Wafer Level Packaging is a synonym for the whole technology spectrum enabling direct chip attachment on PWB or other substrates by Flip Chip Interconnection.

In contrast to pure bumping processes additional thin film wiring layers are required featuring a higher level of integration by embedding active or passive devices onto the chip.

The technology is feasible for any kind of CMOS wafers but also for III/V or even sensors.

»We put a lot of work into getting the highest possible energy density in our small batteries. To that end, we employ larger or more energy-rich materials than those used in regular batteries today, in order to compensate for the scaling effect that very small batteries can also store less energy.«

materials than those used in regular batteries today, in order to compensate for the scaling effect that very small batteries can also store less energy. The hearing aid, for example, must last at least 12 hours before it needs recharging.

Is cost optimisation always considered when new materials are used?

The complex process with silicon wafer production is quite expensive, but since the batteries are so small, the materials really don't play a role. In addition, you can get quite good prices in medical technology. This preform of the hearing aid, in which our battery might be used in the next generation, costs €80 or so for a rechargeable battery, I think.

First published
on 01/13/2022

When we produce batteries on a contract basis, it's usually a few thousand pieces. The price per battery ends up around €50 to €100. That is acceptable in any case. After all, we are not a factory, but only produce small series and prototypes.

Microbattery line
at Fraunhofer IZM
© Fraunhofer IZM I Volker Mai

High Speed with Optical Signals: Will the Printed Circuit Board of the Future Be Made of Glass?

Author: Katja Arnhold

The backbone of our digital world is made of glass: A network of optical fibers spans the globe and lets data criss-cross our globe. We also experience the digital world through a pane of glass: We interact with the online world every day through the glass display of our smartphones. For almost 20 years, Fraunhofer IZM has been working on giving glass an even greater role in data transmission. But even today, copper cables are used when data has to be transmitted over short distances in the centimeter range, for example on printed circuit boards.

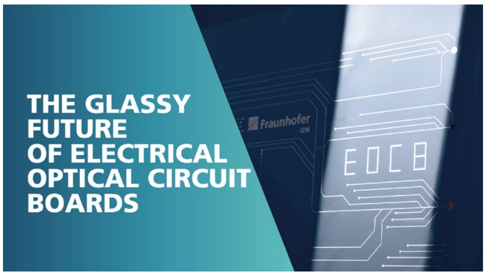
In order to use optical signals for these short distances just as they are used in longer-distance fiber optic cables, Fraunhofer IZM invented the electrical optical circuit board (EOCB). And in close cooperation with research and industry partners, a complete process was developed to manufacture EOCBs from glass. *Real*IZM has met Julian Schwietering to speak about the fascinating material that is glass, the advantages of electro-optical circuit boards, and the future applications for this photonic assembly technology.

The idea of integrating an optical layer into printed circuit boards was first published by Fraunhofer IZM scientists in 1999. In 2003, it was decided to use glass as the material for the optical layer. The waveguides for this optical layer are fitted in the glass with an ion exchange process, a process that has been known since the 1970s, but was only used on small-format glass.

A team at Fraunhofer IZM transferred the technology to large-format thin glass to make it usable for printed circuit boards. To date, IZM is a leader in the production of electrical-optical circuit boards on formats up to 457 mm x 303 mm.

How are optical waveguides integrated into glass? What are the individual process steps involved?

Julian Schwietering, head of the EOCB team in the Optical Interconnection Technologies group at Fraunhofer IZM, knows the answers: »You need quite a long process chain to integrate optical waveguides into glass. This is the process that was developed by us for commercial, mostly closed systems in cleanrooms. Getting people to know about this process is a major concern for me, which is why we created a short film on the subject.«



Video on Youtube

Electro-optical circuit boards enjoy all the benefits that optical signals have over electrical transmission. In addition, glass-based

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In glass integrated waveguides © Fraunhofer IZM I Volker Mai

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long single-mode waveguides were realized in thin glass by Fraunhofer IZM.

EOCBs also have all the advantages of glass as a material: very good dielectric properties – especially for high-frequency applications – as well as great dimensional stability, biocompatibility, and high chemical resistance.

For Schwietering, it all starts with the very basics: »Glass is one of the oldest materials known to mankind. Although it has been used in various forms for thousands of years, many effects in glass are still not fully understood. This makes it an exciting material to work with for us researchers.«

Glass: Solid and flexible at the same time

Unlike crystals, glass has no long-range periodicity in its atomic structure. Thanks to the periodic atom structure of a crystal, you can be sure that its fundamental structures (lattice cell) will be the same even after millions of atoms. This makes crystals more predictable. Glass, on the other hand, is amorphous: Its structure consists of three-dimensional connected rings of different sizes, which are arranged unevenly. Many theories from solid-state physics therefore do not work for glass.

Much research is still needed on the fundamental properties of glass, Schwietering admits: »At this year's conference marking the 100th anniversary of the German Glass Technology Society, a leading glass researcher concluded that the solution to the current challenges in the theory behind the chemical hardening of glass will lie in artificial intelligence. The conventional research methods used so far have not helped us make sufficient progress. There is still much to discover, and glass has incredible potential!«

It is no surprise that the UN declared 2022 the International Year of Glass. A leading manufacturer of specialty glass even declared our current times the Glass Age.

The glass future: Larger, thinner and bendable

In the production of EOCBs, the IZM research group uses commercially available borosilicate glass in half-format sizes. This corresponds roughly to the size of a DIN A3 sheet and has a thickness of 550 µm. Borosilicate glass is inexpensive and, unlike expensive specialty glasses, readily available in large formats.

»Fraunhofer IZM is, as of now, the only research institute in the world that can functionalize such large-format glass electrically and optically«, Julian Schwietering says. From laminating additional electrical layers onto the glass to processing the glass itself, the researchers* have extensive process knowledge for manufacturing printed circuit boards from glass. »Our goal is to double the size to the so-called full format and, at the same time, make it even thinner to produce flexible EOCBs.«

The integration of waveguides now works in a processing-ready manner. This technology could be transferred to industrial use at any time. Nevertheless, the research work is far from complete. Work is currently underway to integrate additional functions in glass.

»We are in the midst of implementing multimode interference couplers with our process that split light from a single to multiple waveguides. Furthermore, we are working to automate characterization methods and the permanent coupling to optical fibers.

We have already developed an automated measurement station to determine the insertion loss of hundreds of waveguides on one panel. Such equipment is essential if the technology is to be used in industry«,

The technology of the future for data centers, (autonomous) e-vehicles, and quantum technology

Electro-optical printed circuit boards are not yet used in commercial production. In addition to telecommunications, the first potential applications for the photonic packaging technology are sensors and quantum packaging.

»We expect EOCBs to be used first in data centers or wherever there is an extremely large amount of data to be processed securely in a very short period of time«, the scientist estimates. It will be a while before EOCBs are also required in consumer products. However,

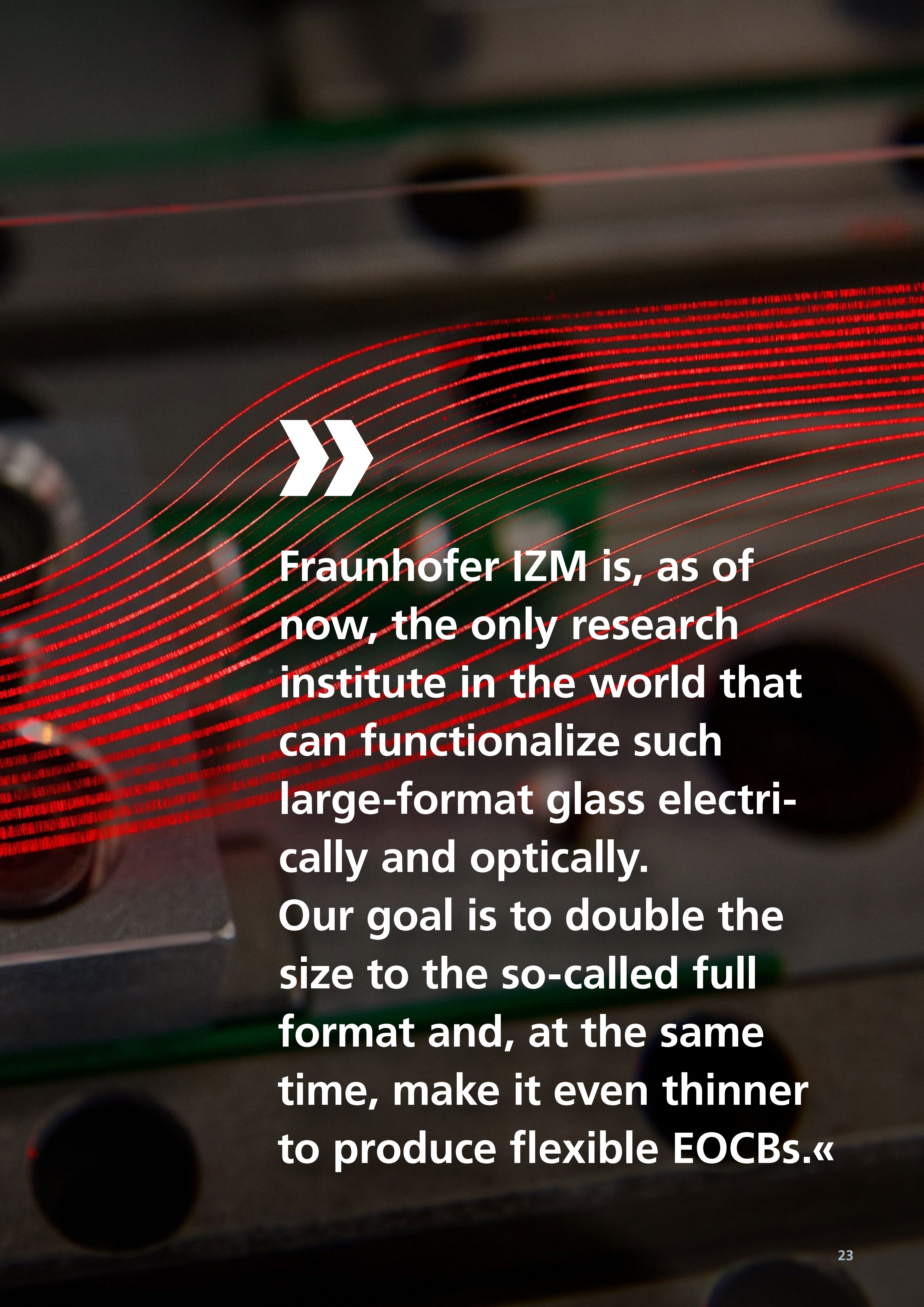
#glasssubstrates

Common sizes of glass substrates:

In progress
515 mm x 510 mm

Current development status
457 mm x 303 mm

Current standard size
303 mm x 227 mm



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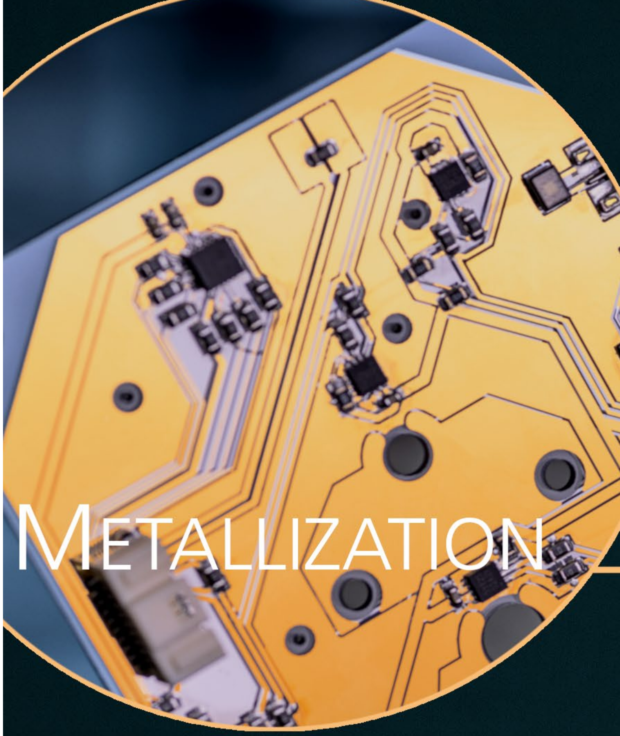
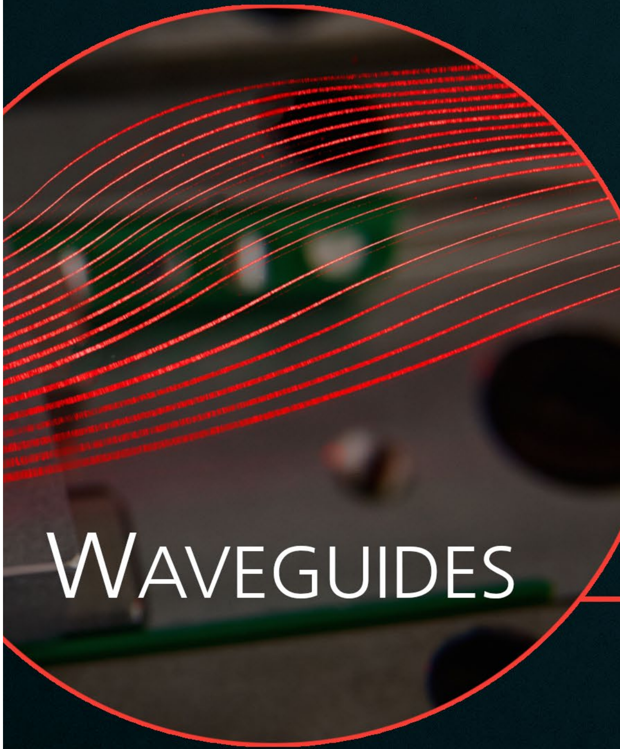
Fraunhofer IZM is, as of now, the only research institute in the world that can functionalize such large-format glass electrically and optically.
Our goal is to double the size to the so-called full format and, at the same time, make it even thinner to produce flexible EOCBs.«

Right: Electrical-Optical Circuit Board made of glass © Fraunhofer IZM / Volker Mai





it is only a matter of time before electrical signal transmission will reach its limits there as well.

In addition to the higher data rates, there are other advantages that speak in favor of its use in certain applications. Optical signal transmission is playing an increasingly important role in e-cars when compared to conventional cars with combustion engines.

Modern vehicles are increasingly resembling supercomputers. In a battery-powered car, it is important that the individual components, the control elements, and all safety-relevant components are galvanically, i.e. electrically isolated from the battery and the battery management system.

In the event of an accident or damage, the safety systems must not be affected by electrical short circuits. The use of optical fibers or waveguides in glass, which do not conduct any electricity, has safety advantages in this respect.

Fraunhofer IZM scientists are currently building a QuantumPackagingLab at the Berlin site, which is funded by the European Union and the state of Berlin to the tune of 3.39 million euros.

The lab will develop new quantum technologies based on glass. Using highly specialized equipment, the researchers will be able to e.g. produce hermetic packages made from glass and to functionalize them electrically and optically. Laser structuring of glass will also advance, and the coating of glass with nanometer-precise layer thicknesses will become possible at Fraunhofer IZM.

First published
on 12/15/2022

#photonic-integration

Photonics have established themselves as an essential pillar of modern and efficient lighting, ultra-high-speed data transmission and processing, and modern sensor technology for environmental, traffic, industrial, and medical applications.


Fraunhofer
IZM
EOCB

Electrification in the Fast Lane: How SiC is Driving Power Electronics Forward

Author: Katja Arnhold

The new generations of semiconductors with a wider band gap (WBG), such as silicon carbide (SiC), have the potential to put electric mobility in the fast lane. This is because they yield significantly higher efficiency compared to conventional silicon IGBT circuits and offer numerous other advantages, such as better temperature stability and less power loss.

In his interview with *Real*IZM, Lars Böttcher, head of the »Embedding and Substrate Technologies« working group at Fraunhofer IZM, spoke about the challenges of packaging SiC power semiconductors for the electric vehicle industry.

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***Real*IZM: Starting with the basics: What are the advantages of SiC power semiconductors for electric vehicles, and where are they mainly used?**

Lars Böttcher: To date, SiC power semiconductors have primarily been used in traction converters and inverters for electric vehicles. First, you want to convert the DC current from the high-voltage battery into AC power for the electric engines. Second, you need a way to convert the AC current that electric vehicles get from their chargers into direct current for the HV batteries. SiC power semiconductors do not yet play a major role in the battery management systems of electric vehicles. For cost reasons, silicon technology is still used there.

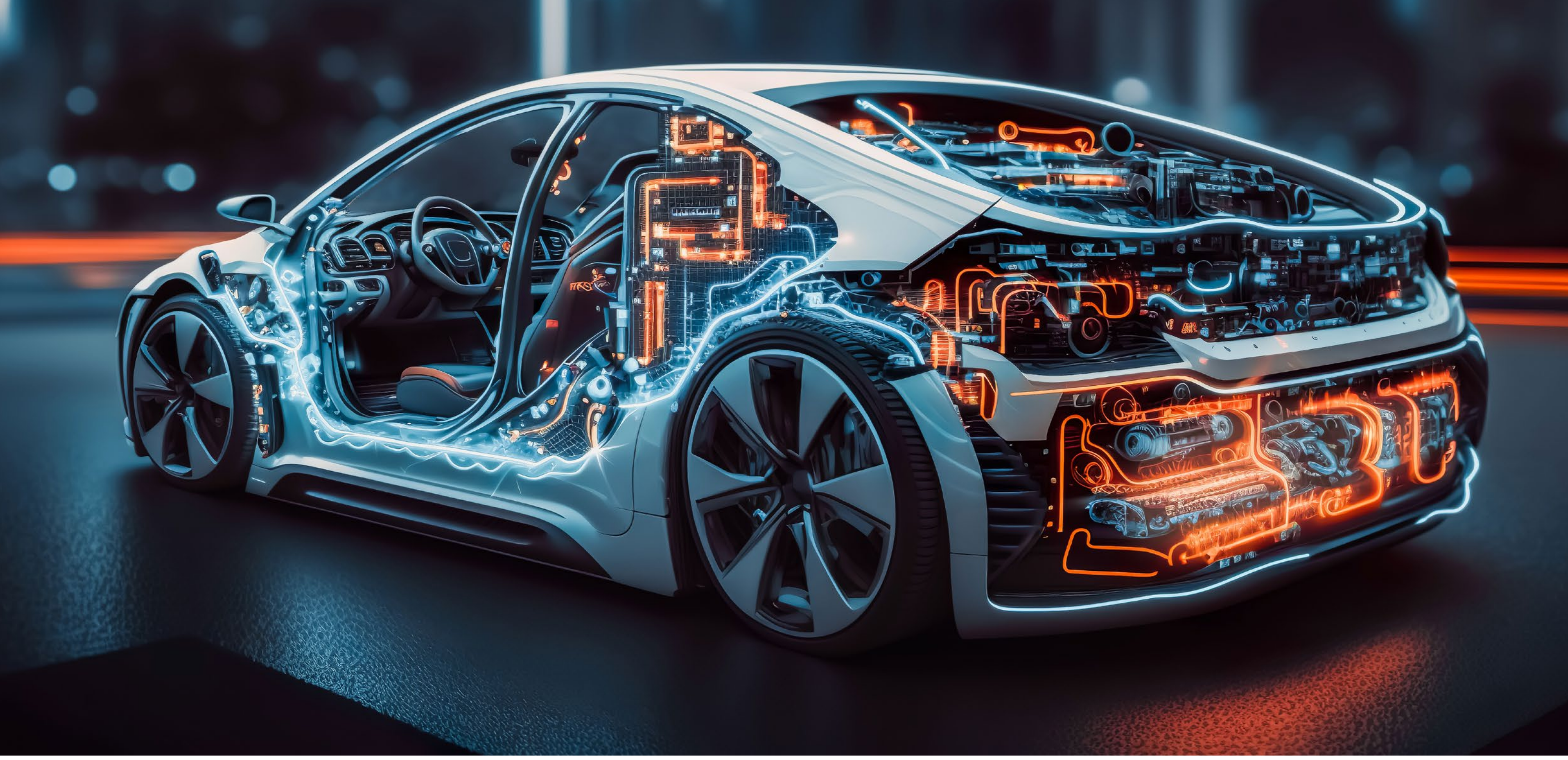
SiC power MOSFETs are a very good option for the highly efficient drive converters with high power density you get with electric vehicles. Put simply: they are efficient, reliable, and compact. Compared to silicon IGBT circuits, silicon carbide (SiC) gives you significantly higher efficiency.

SiC is more reliable in terms of temperature stability, allows higher operating temperatures, and has higher dielectric strength.

Optimizing efficiency is not only important for faster switching, but also for improved range and for a longer service life of the batteries in electric vehicles. Another decisive advantage is the lower power loss, which makes it possible to significantly reduce power densities. In the engine compartment of a vehicle, every cubic centimeter is worth its weight in gold. The ability to minimize volume and weight via the traction converters and control inverters gives you a competitive advantage.

But the high efficiency of SiC also poses exciting challenges for us technologists. The dielectric properties of SiC directly impact the development of gate drivers and protective devices, among other things. In addition to design challenges, we have to make sure that the drive converters are properly isolated from the sensitive low-voltage electronics of the vehicles.

Wherever power is converted, heat gets generated. Understanding and mastering the thermal design of SiC modules for the specific application is essential when you compare



E-powered car
© Limitless Visions – adobe.stock.com

it to traditional IGBT modules. We have to match the materials – the electrical insulation and the thermal path – up with each other.

You can add to this the innovative nature of this technology. All materials surrounding the semiconductor must be resilient, and the individual components must withstand temperatures of up to 175 °C over their entire life cycle.

What role does packaging technology play in the functionalization of SiC chips?

To put it bluntly: I can't just plug a piece of silicon carbide into a socket. Chips have to be functionalized using packaging and interconnection technologies. This can be done either with classic wire, ribbon or clip bonding technologies, or with innovative techniques like PCB-based embedding, SKiM or eMPack technology from Semikron Danfoss.

The world of packaging and interconnection, in which our research institute has been operating successfully for over 30 years, is a key bridge between the wafer world – the fabs that produce the wafers equipped with semiconductors – and the actual applications.

The fabs supply the semiconductors, which are at first of no use to Tier 1 suppliers or vehicle manufacturers without the corresponding packaging and interconnection. The packaging and interconnection is the basic prerequisite for creating individual packages from the devices and, in turn, build an inverter from the individual packages.

In my working group »Embedding and substrate technologies«, we focus on the technological approach. We have many years of experience with embedding Si, SiC, and GaN chips, and we have a complete state-of-the-art processing line.

One of Fraunhofer IZM's strengths lies in our interdisciplinary collaboration. We cooperate very closely with the »Power Electronics Systems« working group headed by Professor Eckart Hoene. This enables us to design SiC modules for our clients, from the electrical switching technology to the structure of the layers.

Our research institute has experts in material properties as well as teams that carry out load change tests and reliability assessments and investigations, such as the change from storage temperature to high temperature, according to customer-specific requirements. With each new generation of power electronics, we can get better functionality and lower costs.

At the same time, this always brings greater challenges in terms of reliable insulation and thermal management. For new types of semiconductors with extremely high bandwidths, standard tests with rigid test methods will not (or no longer) be sufficient for evaluating the

> 1 mio.
load cycles
test series for
service life of
semiconductors

(remaining) service life; instead, custom »application profiles« are likely to dominate this area of activity.

Fraunhofer IZM has been involved in the development and implementation of embedding technologies for inverter structures in high-voltage traction inverters for automotive applications. We do this on behalf of our industrial customers and as part of several publicly funded projects like SiCModul, SiCefficient, and HiEFFICIENT.

From the feasibility assessment for a new technology to the actual implementation of a traction inverter structure, we check the technological feasibility of customer-specific requirements in terms of thermal and electrical design. We are able to produce prototypes and a manageable number of samples and provide support for a rapid transfer to industrial production in Europe with our cooperation partners.

Why are innovative packaging processes needed for SiC semiconductors?

Traditional wire-bonded modules very quickly reach the limits of what is physically possible in terms of power density and electrical properties. Wire bonds only have a limited service life during active power cycles, as each component is actively energized and heated by 100 to 120 Kelvin in a very short time.

Compared to other connection technologies, wire bonds are also much more limited in their electrical properties. You cannot achieve the fast switching speeds and low losses with wire bonds, where relatively strong parasitic effects occur in terms of inductance due to the electrical connection to the semiconductor itself. This means that existing packaging processes must either be improved to suit SiC, or we need completely new processes.

The focus tends to be on the development of new methods. A reference example from current technical literature would be the eMPack power module platform for automotive applications made by Semikron Danfoss. This involves wiring via a flexible substrate, which is placed on both the front and back of the semiconductor using silver sintering.

Conventional packaging processes using wire bonds and frame modules on ceramic substrates are two-dimensional. It is not possible to integrate additional current-carrying layers directly above the semiconductors in order to apply additional components, which would favor lower-loss switching by reducing parasitic effects.

In our experience, PCB embedding technology is the best option for a three-dimensional design. We are also seeing increasing interest in this from Tier 1 and OEM partners. This process allows us to optimize electrical performance, thermal management and insulation reliability and to minimize parasitic effects and switching and conduction losses.

As technologists, we can make numerous adjustments. The two key aspects that speak in favor of PCB embedding technology are: the significant improvement in electrical switching behavior due to the low-inductance connection and the significant increase in reliability.

It has been proven that direct copper metallization for silicon carbide power semiconductors leads to a significant increase in active load change cycles, which translates into a longer service life. As part of one project, for example, we eventually aborted a test series after more than a million load cycles. With wire bonds, significant failures usually occur after around 100,000 to 120,000 cycles.

The industry is showing increasing interest in embedded SiC power semiconductors for high-power electric drives, particularly traction inverters for hybrid and all-electric vehicles. There are many reasons for this. Embedded SiC modules do not differ fundamentally from wire-bonded SiC inverter modules in terms of switching capacity. The latter are used in vehicles.

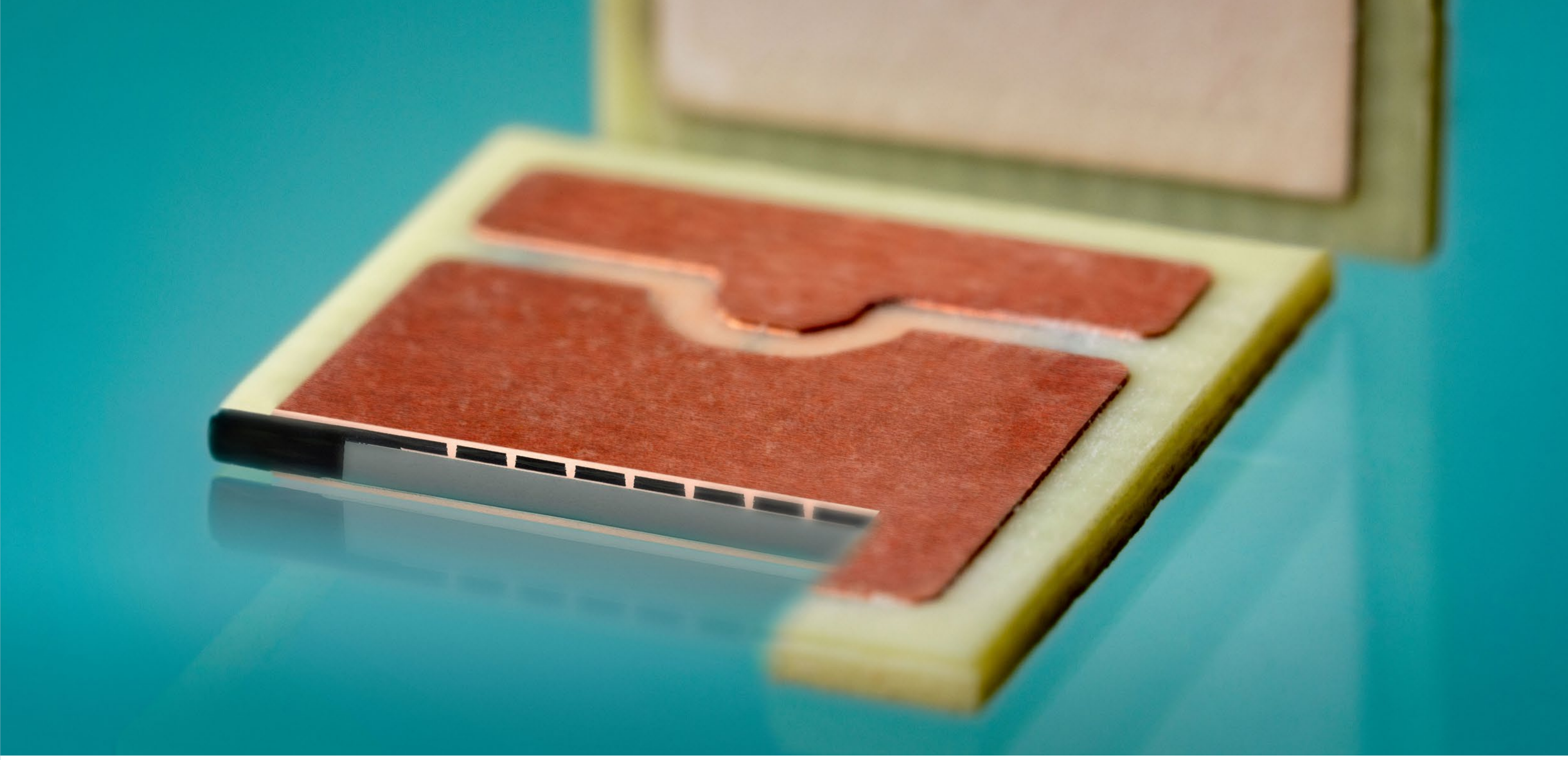
The difference lies in their efficiency. Embedded SiC modules offer improved electrical switching. The reduction in parasitic inductances reduces switching losses. In addition, the volume and height of the embedded

#powerelectronics

The (energy) efficiency of power-consuming products, from switched-mode power supplies, to electric and hybrid cars and railway traction drives, through to large industrial drives, is crucial.

All of the latter technologies areas and more rely on power electronics, and each makes individual demands on the system, which have to be taken into account during the circuit design and layout.

Good solutions for improving energy efficiency and miniaturization of inverters include wide-bandgap (WBG) semiconductors like silicon carbide (SiC) and gallium nitride (GaN).



Cross section of a power chip-scale package with embedded SiC power MOSFETs © Fraunhofer IZM I Volker Mai

modules and, by implication, their weight can be minimized. Saving just one or two SiC semiconductors per module means real cost advantages.

What are the advantages of pre-packaging SiC modules in terms of reducing losses or the risk of individual modules failing?

Let's take a fictitious example: A 3-phase inverter with three half bridges is equipped with over 20 SiC power semiconductors per half bridge. If just one of these SiC modules fails or is damaged, the entire half bridge would be unusable. Economically, this would be a major loss.

In our opinion, SiC pre-packaging is recommended to significantly increase the yield, e.g. on a ceramic insulation. In the SiCeffizient and DauerPower research projects, we used this method to form inverter modules on a high-current PCB, implemented with a low-inductance connection.

During pre-packaging, the SiC modules are assembled analogously to a complete half-bridge, then embedded in the PCB material and wired to the outside with micro-via copper metallizations. The result is individual chips that are 100 percent robustly packaged and tested in the material, which can then be used on either SMDs or high-current PCBs.

With the pre-packaging approach, the risk of losing over 20 other modules at the same time in the event of a single faulty SiC module is low. One disadvantage that should not go unmentioned is that pre-packaging limits what you can do in terms of a reduction in volume and the level of power density.

What further developments and research can be expected with regard to alternative semiconductor materials with a large band gap?

On top of its electrical properties, SiC has the advantage that it is ideally suited for high-voltage applications in the automotive sector. For example, a 1200 V SiC MOSFET enables very efficient operation at battery voltages in the 850 V range. GaN semiconductors, on the other hand, are so far mainly used in the lower voltage range with very low voltages, for example in high-performance chargers for cell phones that switch up to 100 watts.

Occasionally, GaN semiconductors are available for applications in the 850 volt range. However, the idea of 1,200 volts is still being developed. Should such semiconductors based on GaN be available in the future, they would be a good and inexpensive alternative to SiC.

Research is also being carried out into alternative semiconductor materials with a large band gap, such as synthetic diamonds, gallium oxide (Ga_2O_3) and aluminum nitride (AlN). To our knowledge, no semiconductors ready for series production have yet been realized.

What is your forecast for the market for SiC semiconductors, and how has demand developed in recent years?

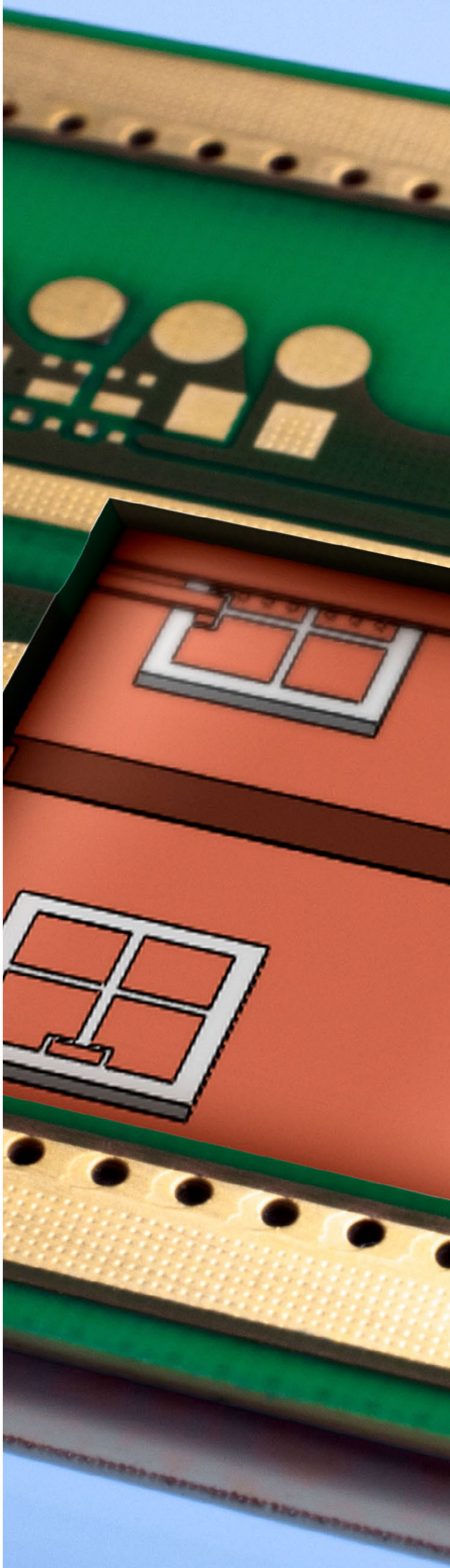
SiC technology has become more mature. Nevertheless, the challenge is that the single crystals still have many flaws even under optimal growing conditions. Manufacturers are well on the way to increasing the yield per wafer and reducing production costs. The demand for SiC is actually higher than existing production capacities allow.

Semiconductor manufacturers are therefore investing heavily into existing and new wafer production sites in order to be able to manufacture formats of at least 150 mm and 200 mm in diameter. Yole forecasts a market volume of around 1.5 billion US dollars for SiC in 2022, with the volume expected to quadruple over 6 billion US dollars in 2027.[1]

First published
on 01/18/2024

Source:

[1] Market and Technology Report - Power SiC 2022, Yole



Inside view (model) of a 90A embedded power module (HHK-project)
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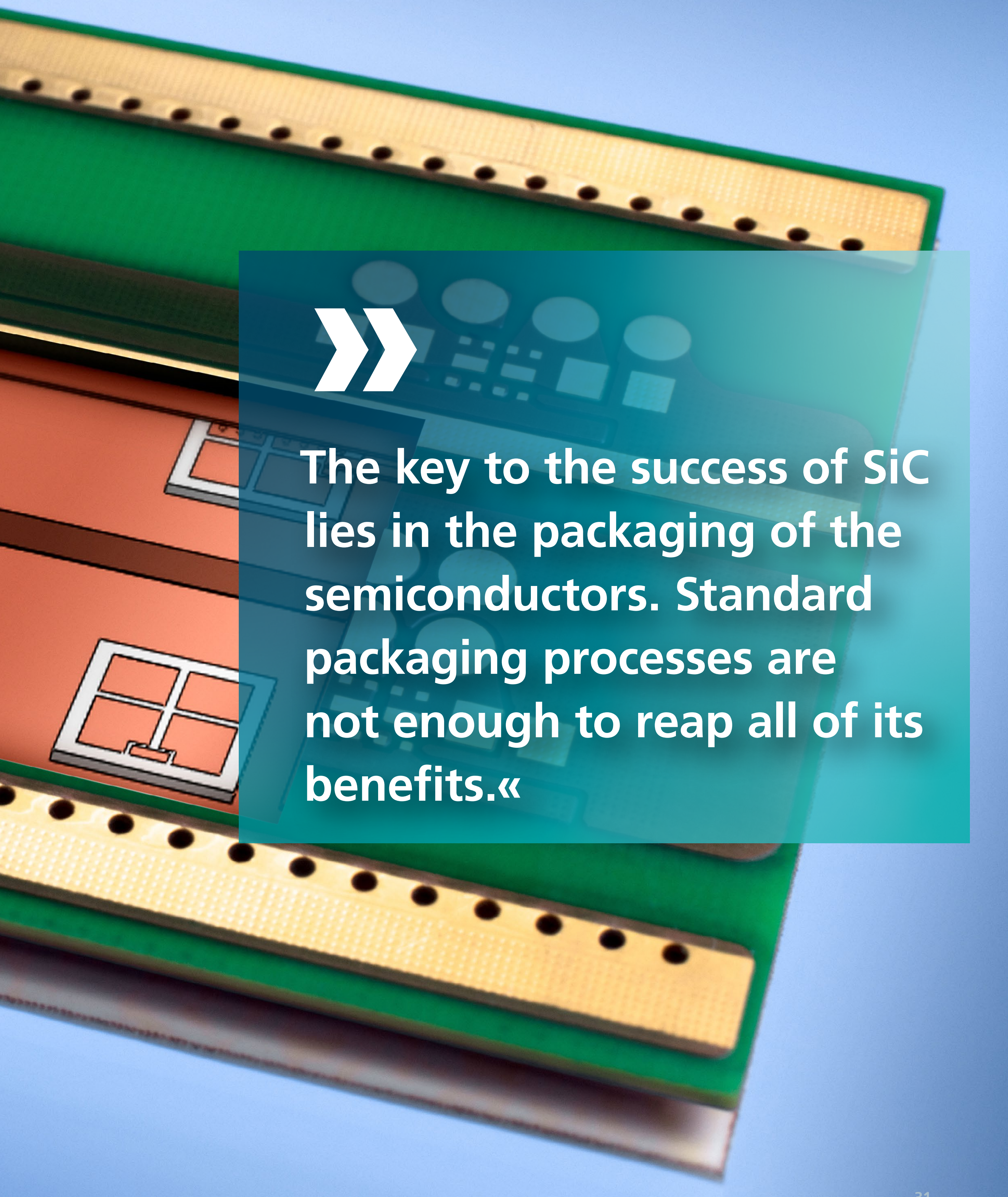

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The key to the success of SiC lies in the packaging of the semiconductors. Standard packaging processes are not enough to reap all of its benefits.«