A peek into the solar oven

For the ITER international fusion research project, Fraunhofer scientists are working on a sensor capable of withstanding extreme conditions.

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In theory, solving the energy problems posed by our planet's ever increasing population isn't that hard. All you really need is hydrogen, an element that is abundant throughout the universe. Fusing the nuclei of hydrogen atoms together produces helium – and releases energy. Lots of energy. A single gram of hydrogen contains as much energy as more than eight tons of crude oil. And since this fusion process has been generating light and heat within stars for millions of years, we know that it works.

No surprise, then, that scientists all over the world dream of tapping into this virtually inexhaustible energy source here on Earth. As you might expect, the only way to do it is to create conditions similar to those found in a solar oven – the hydrogen has to be heated to over a hundred million degrees Celsius and then compressed. It takes such extreme temperatures and pressures to overcome the repelling force that normally keeps the positively charged atomic nuclei apart.

Small-scale research reactors have already managed to concentrate hydrogen briefly to the point at which it fuses to form helium. But these efforts failed to have the desired effect – it took more electricity to power the reactors than the reactors themselves produced. The search continues for proof that hydrogen fusion can actually be used to generate power for the grid.

Fusion on Earth: an expensive goal

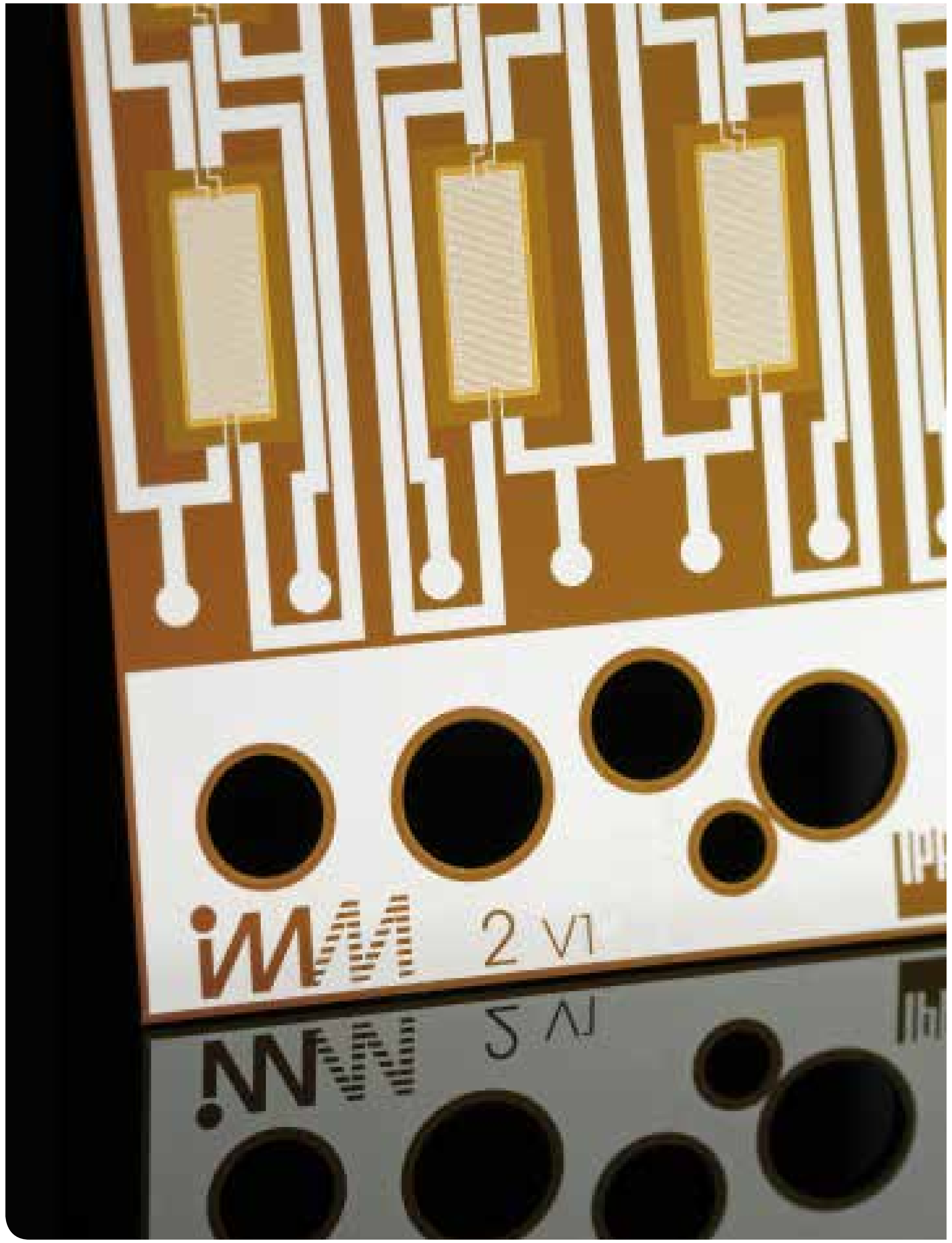
Hopes for a breakthrough are now pinned on ITER, the International Thermonuclear Experimental Reactor. ITER is a huge project bringing together the expertise of research partners from Europe, Japan, Russia, the USA, China, South Korea and India. Together the partners are investing 5.5 billion euros in ITER, and hundreds of international teams are involved in planning and execution. The reactor is scheduled to go into operation at Cadarache in the south of France early next decade. If all goes according to plan, each ignition of the reactor will be followed by up to 60 minutes of stable fusion.

The centerpiece of the reactor is its circular vacuum vessel – which on the blueprints resembles an oversized donut – surrounded by superconducting magnets. Scientists plan to create sun-like conditions inside this donut by using microwave radiation to excite the gas inside the vacuum vessel. This will cause the hydrogen present to discard its electrons and become a plasma composed of positively charged ions, which in turn will be accelerated around the magnetic field loop as if they were cars going round and round a racetrack. The increasing temperatures and pressures will ultimately cause the nuclei to fuse.

Ions on the racetrack

None of this is possible, however, except under precisely the right conditions. "When operating a fusion reactor, plasma confinement has to be monitored and controlled. The conditions inside can be adjusted by varying the strength of the magnetic field, the level of input energy, or the particles themselves," explains Dr. Peter Detemple, a physicist at the Fraunhofer Institute for Chemical Technology ICT-IMM in Mainz, near Frankfurt. "It's particularly important to make sure there's no sudden collapse in plasma confinement. This would cause all the energy stored in the plasma to be transferred almost immediately to the vacuum vessel wall, which would damage the reactor."

On behalf of European ITER partner Fusion for Energy, Detemple's team is working with scientists from the Max Planck Institute of Plasma Physics (IPP) in Garching, near Munich, on a measuring technique for the new reactor. This is no easy task, considering the sensors have to be able to withstand the extreme conditions inside the vacuum vessel – wall temperatures of 450 degrees Celsius and the constant bombardment of neutrons and X-rays unleashed by the fusion reaction. "There's no doubt about it: these are harsh conditions," says Detemple.



Prototype of the bolometer chip. © *Fraunhofer ICT*

Exceptional conditions call for exceptional technology. Bolometer cameras – developed at the IPP – turned out to be ideal. Each one features an elaborate aperture system that keeps out scattered light and concentrates on a tiny area. "This lets us observe the plasma in a certain direction," reports Detemple. His team is developing the chip that goes inside the bolometer camera to detect the plasma's radiation and convert it into measurement signals. This, too, is by no means easy – the spectrum involved ranges from long-wave infrared to extremely hard X-rays.

Small sensor, huge insight

The prototype is now finished – a small silicon chip, measuring approximately 2.5 by 3 centimeters, with window openings covered with an ultra-thin membrane. On the front of this membrane is an absorber made of platinum, a material capable of resisting the neutron radiation released during fusion. On the back is a precise resistance thermometer.

When radiation strikes, the platinum absorber heats up and the detector on the reverse shows increased resistance. "This allows us to determine the intensity of the radiation the plasma is giving off over a broad spectrum," explains Detemple. "Knowing these values is essential for properly controlling and monitoring fusion reactors." The plan is to install several hundred of these bolometer cameras in ITER. Positioned all around the vacuum vessel, they will determine the plasma's position and intensity distribution.

At research facilities across the world – including Garching, home of the ASDEX Upgrade fusion device – the sensors have already passed the first round of endurance tests. The next challenge is to make the technology more robust, mainly with a view to withstanding ITER's extreme temperatures. "Luckily we can draw on our experience in developing thin film sensors for customers in the medical technology and chemical industry sectors, where sensors also have to work under extreme conditions," says Detemple. But he and his team are now having to push themselves further than they have ever gone: "We've never had to meet higher demands than in the ITER project."

And let's not forget that we're dealing with something really important: this technology is a key piece of the vast research puzzle that is ITER. Hopes are high that the sensors will someday have a hand in solving humanity's energy problems. ■