Innovative Portuguese research centre offers material benefits

Director Elvira Fortunato introduces the Institute of Nanostructures, Nanomodelling and Nanofabrication

Bringing together scientists from two of Portugal's top research units, the Institute of Nanostructures, Nanomodelling and Nanofabrication (i3N) develops advanced functional materials. An official Associate Laboratory of the Portuguese government, i3N is a partnership between the Materials Research Centre at NOVA University of Lisbon and the Physics of Semiconductors, Optoelectronics and Disordered Systems Centre at the University of Aveiro. Materials scientist Elvira Fortunato has directed the institute since 1998. In 2008, she led a team that developed the world's first paper transistor: a flexible, environmentally friendly and low-cost alternative to silicon. She is a world-leading researcher in the field of transparent electronics — thin-film transistors based on oxide semiconductors — and has received several national and international awards for her work. In 2020, Fortunato won both the European Commission's Horizon Impact Award for her work on transparent electronics (project Invisible 2008 ERC grant), and the Pessoa Prize, a prestigious prize in Portugal granted annually for excellence in science, art or literature. This year she won the 2021 World Federation of Engineering Organization Women in Engineering Award.

What does i3N work on?
At i3N we work in four main areas — Sustainable Micro and Nanofabrication; Green and Clean Energy Systems; Nanomaterials Engineering and Functional Interfaces; and Biomedical devices and Systems.

For most of these areas, displays are needed as an interface for us to acquire and communicate information. We are all surrounded by displays in phones, televisions, or computers. Each pixel in these displays usually relies on an amorphous silicon transistor.

Transistors for the next generation of displays will certainly be based on the metal oxides, processed at low temperatures, away from silicon, like we are developing. The technology to be used to make these new transistors will be based on eco sustainable materials, using rigid and flexible substrates and low-cost technologies, such as printing.

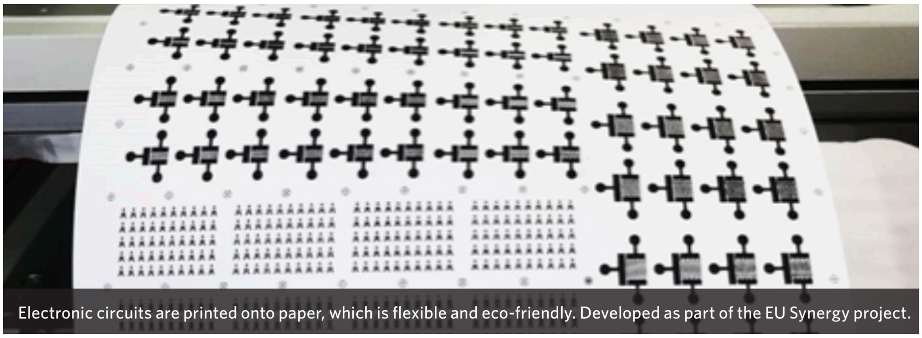
How will you develop this technology?
We transfer our knowledge to industry. There is a lot of interest in developing products related to paper electronics, and we have established a collaborative laboratory, called AlmaScience, that merges industry with academia to develop research in this area. We also work to ensure the scientific community and industry have access to infrastructure and equipment aiming to support creative developments at a nanoscale for which proper nanoanalysis and nanofabrication tools are required.

How is the institute organised?
We have around 280 researchers, including more than 100 PhDs. They work across the four broad research areas described above. We develop smart materials for applications across the energy, optoelectronics and electronic sectors. And we also develop innovative biomedical devices and services, which have the potential to help advance precision medicine and tailored therapies.

How does i3N engage with wider society?
This is very important. We aim to develop stronger relationships with society to foster public awareness, engagement and understanding of advanced materials and nanoscale science. We run different projects with school students, under the umbrella of the Portuguese programme "Ciência Viva". Every year we close our activities for a week and invite pupils to meet our Masters and PhD students and to learn about advanced materials and applications. At the end they have a small project which they present to us. It's really inspiring for us to see how interested and keen this next generation of science students are. ■

Credit: i3N

Elvira Fortunato is Director of the i3N.



Electronic circuits are printed onto paper, which is flexible and eco-friendly. Developed as part of the EU Synergy project.

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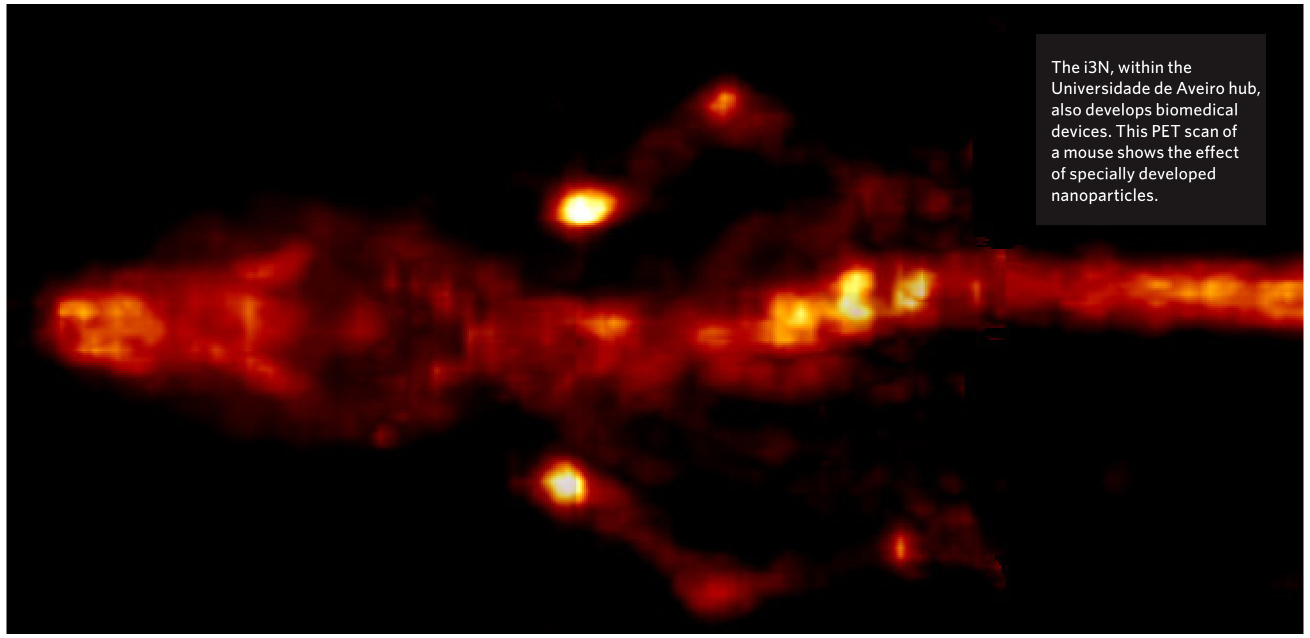
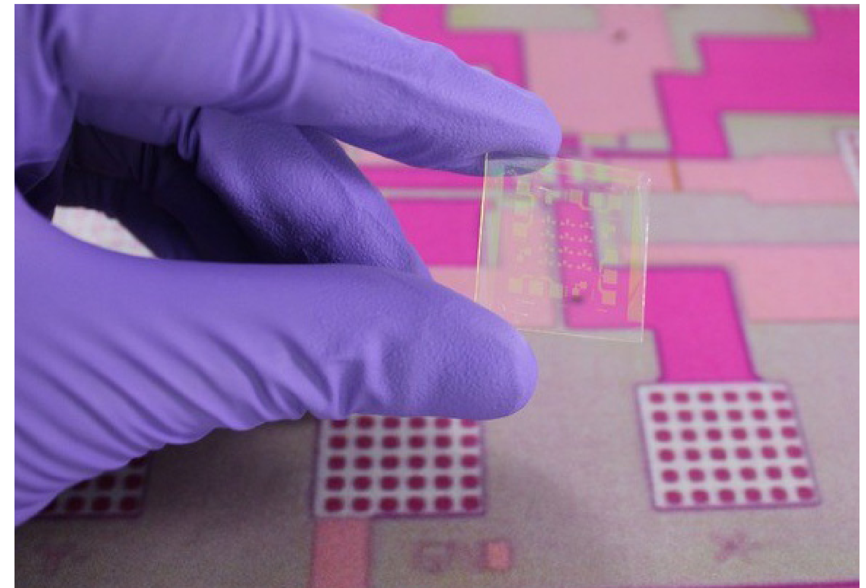


The i3N, within the Universidade de Aveiro hub, also develops biomedical devices. This PET scan of a mouse shows the effect of specially developed nanoparticles.

Credit: i3N



Transparent integrated circuits based on metal oxide materials.

Credit: i3N

In 2008, sales of televisions with liquid crystal displays (LCDs) overtook those that relied on cathode ray tubes for the first time. Thinner and lighter, LCD displays have continued to improve since. But behind the scenes, and behind the screens, the technological ground is shifting again.

Televisions and other electronic devices have relied on silicon transistors to shuffle electric current around for decades. But many experts now argue that silicon has run its course. It's rigid, expensive, hard to recycle, and its manufacture is difficult — well controlled atmospheres, such as those in clean rooms are essential, and polluting — highly toxic gases, such as diborane, phosphine, and silane are involved in its production. Scientists are racing to find alternative materials and low-cost process technologies to replace it.

"We think we can exploit materials like metal oxides to replace silicon, which would come with many advantages," says Rodrigo Martins, a materials scientist at NOVA University of Lisbon and a member of the Institute of Nanostructures, Nanomodelling and Nanofabrication (i3N). "We can process metal oxides at much lower temperatures than silicon. And another big advantage is their conduction mechanism, which is completely different from the classical covalent materials, in which the role of disorder does not interfere with the conduction mechanism."

Silicon has sp^3 covalent bonds, which weakens its ability to conduct electricity when its crystal structure becomes disordered. Because ionic metal oxides have isotropic, spherical bonds, they allow electrons to flow more easily, and can continue to conduct electricity well even within a disordered structure.

Martins and his colleagues at the i3N are using this property of metal oxides to build and explore ultra-thin semi-conductors. Just a nanometre thick, these materials are flexible and transparent, which, Martins says, raises some extraordinary possibilities, allowing for the fabrication of transistors, the key LEGO block for electronics, and from this, CMOS and memristor devices, from materials other than silicon, serving clearly the commitments towards sustainable circularity.

"You could have a roll-up computer," he says. "Or we can weave metal oxide fibres into textiles and mount them on any surface."

These applications are not ready for consumers yet, but commercial companies including Sharp and Samsung have already started to use metal-oxide based displays in a handful of consumer products.

Energy reduction

Researchers are still working on the best ways to manufacture and maximize the performance of these silicon replacements. But scientists at i3N have already demonstrated one important feature. While silicon semiconductors must be processed at 1200°C, which consumes great large energy and limits the type of substrate materials that they can be mounted upon, the Portuguese group has shown that metal oxide versions can be made at room temperature[1].

"Because we do this process at very low temperatures, we can use smaller amounts of low-cost materials as substrates," Martins says. "We can even put transparent electronics on to paper. You could have bright wallpaper that changes colour or shows pictures."

Paper is the original display material and has been used to save and transmit information for more than a thousand years. It's cheap enough to make disposable devices and can be recycled. And because it's made from cellulose, the most abundant organic polymer on Earth, there is no shortage of raw materials. But when it comes to making electronic gadgets there is a problem: paper doesn't conduct electricity.

Research at the i3N, led by its director Elvira Fortunato, head of the Materials Research Centre at NOVA University of Lisbon, got around this conduction problem. Using a new low-temperature processing technique they developed, the team showed how semi-conducting metal oxides could be successfully mounted on paper[2].

Then they went further. "Since we knew that paper has an insulating effect, we also wondered if we could use paper as an active element inside a transistor," Fortunato says. Transistors act as tiny electronic switches and need an insulating layer between their electrical connections. Usually pure silicon oxide, the i3N team swapped in a very thin sheet of paper[3].

"I thought there was a very low probability it would work," she says. "We were really happy when it did."

Paper renaissance

The breakthrough expanded a nascent field of research: papertronics. Targeted at applications that cost little and need to be produced in large quantities, researchers at i3N, and colleagues around the world, are investigating how paper transistors, paper sensors, could be combined with solar cells and developed into everyday devices as part of the Internet-of-Things. Examples include price tags on supermarket goods that update to reflect sales and reductions, or business cards that switch language depending on who you hand them to.

"THE GREATEST BENEFIT OF USING PAPER IN THE ELECTRONICS SECTOR IS THE FACT THAT IT'S RENEWABLE"

Research aiming to push to the energy conversion efficiency to the limit is now being realized, so have available low-cost and flexible solar cells are now available to power all these commodities[5].

"The greatest benefit of using paper in the electronics sector is the fact that it's renewable," Fortunato points out. "And the material is already there. Paper doesn't need to be invented."

There could be healthcare applications as well. Paper electronics could act as cheap and widely available biosensors to detect the presence of bacteria or viruses or simple diagnostic tests for glucose or other relevant biomarkers.

Physicist, João Veloso's team at i3N, University of Aveiro, is developing functionalized nanoparticles that can simultaneously act as a label and deliver a drug. "This nanoparticle will fix in the place that you want to treat. And then you are treating and observing the impact of the treatment at the same time," he says. They developed a super-resolution PET (easyPET technology) capable of efficiently assessing the effect of such nanoparticles in the subject.

Cancer treatment, television screens and supermarket labels are very different applications. But according to Fortunato, these and other projects at i3N to address technological, medical and societal challenges are united by a common goal.

"We are trying to improve the world," she says. "To use new materials to address the challenge of how to enjoy more comfortable lives while respecting the environment. That means making sustainable products to shape the future." ■

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