# Quantum physicist uses graphene ribbons to build nanoscale power plants

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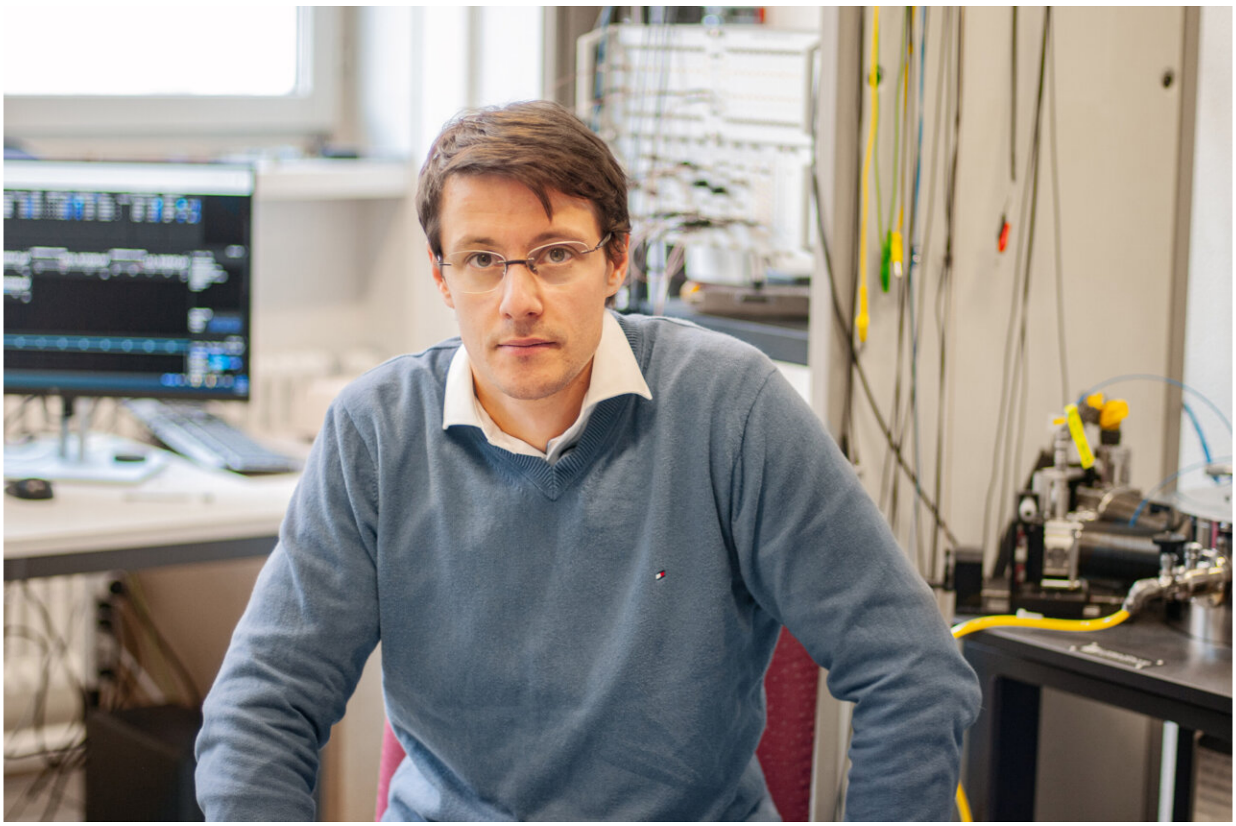

Mickael Perrin. Credit: SNF

When Mickael Perrin started out on his scientific career 12 years ago, he had no way of knowing he was conducting research in an area that would be attracting wide public interest only a few years later: Quantum electronics. "At the time, physicists were just starting to talk about the potential of quantum technologies and quantum computers," he recalls.

"Today there are dozens of start-ups in this area, and governments and companies are investing billions in developing the technology further. We are now seeing the first applications in computer science, cryptography, communications and sensors." Perrin's research is opening up another field of application: Electricity production using quantum effects with almost zero energy loss. To achieve this, the 36-year-old scientist combines two usually separate disciplines of physics: thermodynamics and quantum mechanics.

In the past year, the quality of Perrin's research and its potential for future applications has brought him two awards. He received not only one of the ERC Starting Grants that are so highly sought-after by young researchers, but also an Eccellenza Professorial Fellowship of the Swiss National Science Foundation (SNS)F. He now leads a research group of nine at Empa as well as being an Assistant Professor of Quantum Electronics at ETH Zurich.

## Ten thousand times smaller than a hair

Perrin tells us that he never regarded himself as having a natural gift for mathematics. "It was mainly curiosity that pushed me in the direction of physics. I wanted to gain a better understanding of how the world around us works, and physics offers excellent tools for doing just that." After finishing high school in Amsterdam, he began a degree in applied physics at Delft University of Technology (TU Delft) in 2005. Right from the start, Perrin was more interested in concrete applications than theory.

It was while studying under Herre van der Zant, a pioneer in the field of quantum electronics, that Perrin first experienced the fascination of engineering tiny devices at microscale and nanoscale. He soon recognized the endless possibilities presented by molecular electronics, since circuits have completely different characteristics depending on the molecules and materials selected, and can be used as transistors, diodes or sensors.

While studying for his doctorate, Perrin spent a great deal of time in the nanolab cleanroom at TU Delft—constantly enveloped in a white full-body overall to prevent the miniature electronics being contaminated by hairs or dust particles. The cleanroom provided the technological infrastructure to build machines a few nanometers in size (about 10,000 times smaller than the diameter of a human hair).

"As a general rule, the smaller the structure you want to build, the bigger and more expensive the machine you will need to do so," explains Perrin. Lithography machines, for example, which are used to pattern complex mini-circuits on microchips. "Nanofabrication and experimental physics require a lot of creativity and patience, because something nearly always goes wrong," says Perrin. "Yet it's the strange and unexpected results that often turn out to be the most exciting."

## Graphene: A miracle material

A year after completing his doctorate, Perrin obtained a post at Empa in the laboratory of Michel Calame, an expert in integrating quantum materials into nano devices. Since then, Perrin—a French and Swiss national—has lived in Dübendorf with his partner and two daughters. "Switzerland was a good choice for me for several reasons," he says. "The research infrastructure is unparalleled."

Empa, ETH Zurich and the IBM Research Center in Rüschlikon provide him with everything he needs in order to produce nanostructures, as well as the measuring instruments to test them. "Also, I'm an outdoor type. I love the mountains, and often go walking and skiing with my family." Perrin is a keen rock climber, too. He sometimes takes himself off climbing in remote valleys for weeks at a time, often in France, which is his family's country of origin.

At Empa this young researcher had the freedom to continue experimenting with nanomaterials. A certain material soon attracted his particular attention: Graphene nanoribbons, a material made from carbon atoms that is as thin as the individual atoms. These nanoribbons are manufactured with the greatest precision by Roman Fasel's group at Empa. Perrin was able to show that these ribbons have unique properties and can be used for a whole raft of quantum technologies.

At the same time, he began to take a close interest in converting heat into electrical energy. In 2018 it was in fact proved that quantum effects can be used to efficiently convert thermal energy into electricity. Up to now, the problem has been that these desirable physical properties appear only at very low temperatures—close to absolute zero (0 Kelvin; -273.15°C). This is of little relevance to potential future applications such as in smartphones or minisensors.

Perrin had the idea of circumventing this problem by using graphene nanoribbons. Their specific physical properties mean that temperature has a much smaller impact on the quantum effects—and thus the desired thermoelectric effects—than is the case with other materials. His group at Empa was soon able to demonstrate that the quantum effects of graphene nanoribbons are largely preserved even at 250 Kelvin, i.e. -23°C. In the future, the system is expected to work at room temperature, too.

## Lower power consumption thanks to nanotubes

There are still many challenges to overcome before the technology will enable our smartphones to use less power. Extreme miniaturization means that special components keep being required to ensure that the built systems actually work. Perrin, together with colleagues from China, the U.K. and Switzerland, recently showed that carbon nanotubes just one nanometer in diameter can be integrated into those systems as electrodes.

However, Perrin estimates that it will take at least another 15 years before these delicate and highly complicated materials can be manufactured at scale and incorporated in devices. "My aim is to work out the fundamental basis for applying this technology. Only then will we be able to gauge its potential for practical uses."

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