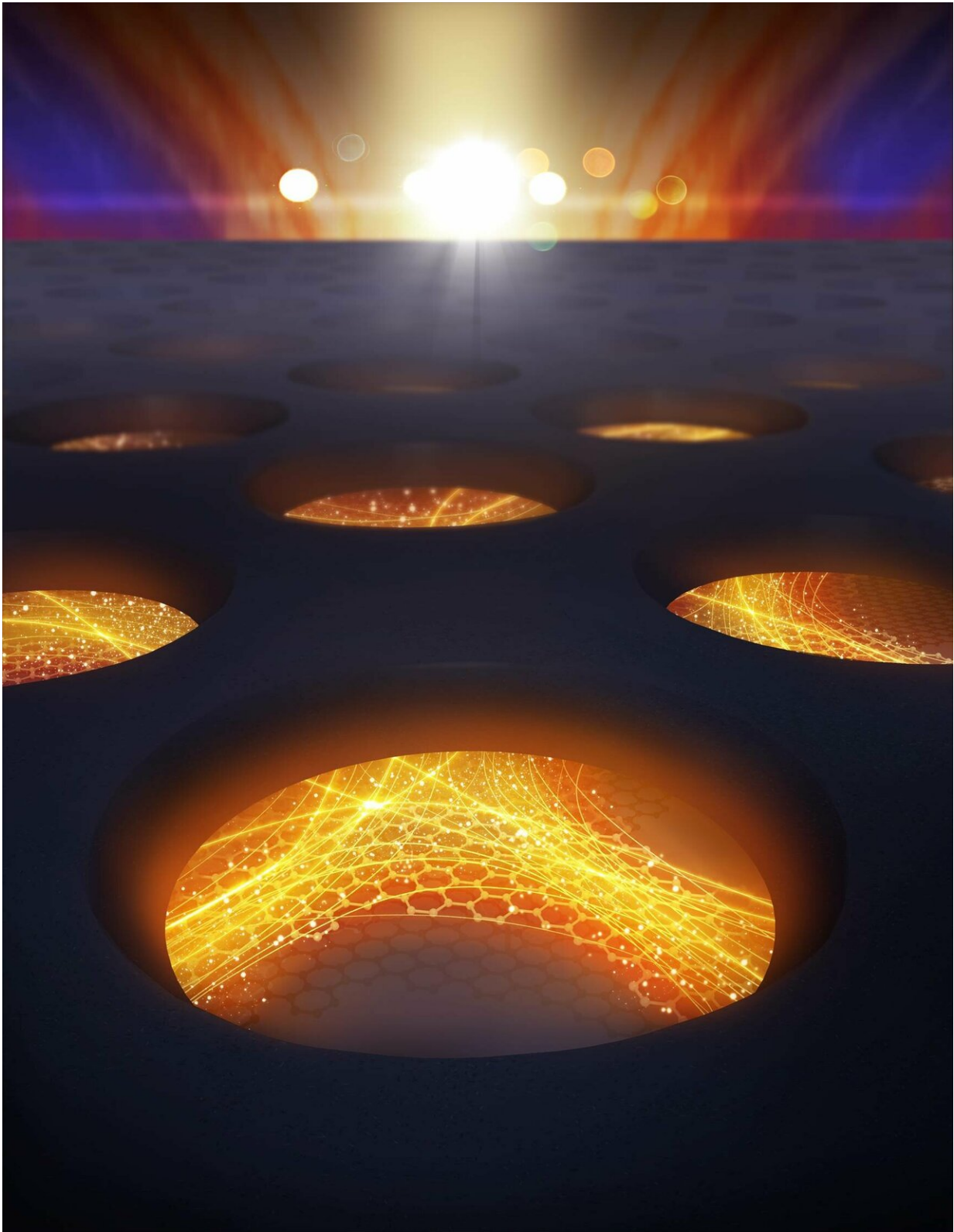


Breakthrough in the search for graphene-based electronics

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Nanostructured graphene. Credit: Carl Otto Moesgaard

For 15 years, scientists have tried to exploit the "miracle material" graphene to produce nanoscale electronics. On paper, graphene should be great for just that: it is ultra-thin—only one atom thick and therefore two-dimensional, it is excellent for conducting electrical current, and holds great promise for future forms of electronics that are faster and more energy efficient. In addition, graphene consists of carbon atoms – of which we have an unlimited supply.

In theory, graphene can be altered to perform many different tasks within e.g. electronics, photonics or sensors simply by cutting tiny patterns in it, as this fundamentally alters its [quantum properties](#). One "simple" task, which has turned out to be surprisingly difficult, is to induce a band gap—which is crucial for making transistors and optoelectronic devices. However, since graphene is only an atom thick all of the atoms are important and even tiny irregularities in the pattern can destroy its properties.

"Graphene is a fantastic material, which I think will play a crucial role in making new nanoscale electronics. The problem is that it is extremely difficult to engineer the electrical properties," says Peter Bøggild, professor at DTU Physics.

The Center for Nanostructured Graphene at DTU and Aalborg University was established in 2012 specifically to study how the electrical properties of graphene can be tailored by changing its shape on an extremely small scale. When actually patterning graphene, the team of researchers from DTU and Aalborg experienced the same as other researchers worldwide: it didn't work.

"When you make patterns in a material like graphene, you do so in order to change its properties in a controlled way—to match your design.

However, what we have seen throughout the years is that we can make the holes, but not without introducing so much disorder and contamination that it no longer behaves like graphene. It is a bit similar to making a water pipe that is partly blocked because of poor manufacturing. On the outside, it might look fine, but water cannot flow freely. For electronics, that is obviously disastrous," says Peter Bøggild.

Now, the team of scientists have solved the problem. The results are published in *Nature Nanotechnology*. Two postdocs from DTU Physics, Bjarke Jessen and Lene Gammelgaard, first encapsulated graphene inside another two-dimensional material—[hexagonal boron nitride](#), a non-conductive material that is often used for protecting graphene's properties.

Next, they used a technique called [electron beam lithography](#) to carefully pattern the protective layer of boron nitride and graphene below with a dense array of ultra small holes. The holes have a diameter of approx. 20 nanometers, with just 12 [nanometers](#) between them – however, the roughness at the edge of the holes is less than 1 nanometer, or a billionth of a meter. This allows 1000 times more [electrical current](#) to flow than had been reported in such small graphene structures. And not just that.

"We have shown that we can control graphene's band structure and design how it should behave. When we control the band structure, we have access to all of graphene's properties—and we found to our surprise that some of the most subtle quantum electronic effects survive the dense patterning—that is extremely encouraging. Our work suggests that we can sit in front of the computer and design components and devices—or dream up something entirely new—and then go to the laboratory and realise them in practice," says Peter Bøggild. He continues:

"Many scientists had long since abandoned attempting nanolithography

in graphene on this scale, and it is quite a pity, since nanostructuring is a crucial tool for exploiting the most exciting features of graphene electronics and photonics. Now we have figured out how it can be done; one could say that the curse is lifted. There are other challenges, but the fact that we can tailor electronic properties of [graphene](#) is a big step towards creating new electronics with extremely small dimensions," says Peter Bøggild.

More information: Bjarke S. Jessen, Lene Gammelgaard et al. Lithographic band structure engineering of graphene, *Nature Nanotechnology* (2019). [DOI: 10.1038/s41565-019-0376-3](https://doi.org/10.1038/s41565-019-0376-3)

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