2D materials

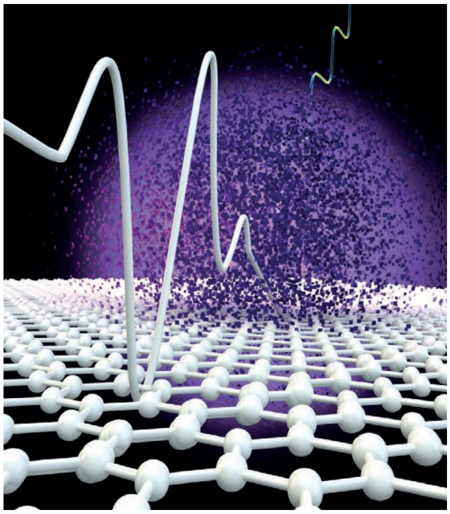
Australians call it sticky tape, English name it Sellotape, and some say Scotch tape. Whatever you call it, it is arguably responsible for the theme of this month's focus issue.

Graphite layers just a few atoms thick were observed in the first half of the twentieth century, but over half a century later there was still not a lot of success in reliably making graphite just one atom thick, a material structure now known as graphene. That was until 2004 when Andre Geim and Kostya Novoselov used sticky tape to peel of flakes from a lump of graphite, a process that managed to yield atomically thin samples.

So we know graphene is thin (3.35 Å to be exact), but how is the material relevant for photonics? To start with, light interacts strongly with graphene, compared with other materials of the same dimensions. Despite its vanishing thickness graphene absorbs ~2.3% of incoming visible light. Another optically important fact is that graphene's bandgap can be actively tuned from 0 to 0.25 eV. Giant nonlinear Kerr coefficients have been suggested in graphene and perhaps the most exploited nonlinear characteristic is its absorption that saturates above an optical intensity threshold. This saturable absorption has been utilized for mode locking in lasers.

Investigation into photonics applications of graphene is still a highly active area of research with a Google Scholar search for 'graphene' yielding ~140,000 works since the beginning of 2012 until now. The activity does not appear to be trailing off yet, with 35,000 works since the beginning of 2015. Of course not all of those 'hits' are directly relevant to optics, but there is no doubt that graphene is still garnering significant interest. In this issue we are publishing two manuscripts related to this topic: on page 244 Guangxin Ni, Lei Wang and colleagues report ultrafast switching of infrared plasmons in graphene, and on page 239 Alexey Nikitin *et al.* describe edge plasmon modes in graphene resonators.

Although graphene is probably the best known 2D material relevant to photonics, its success has spawned enthusiastic research into other atomically thin materials. And this is a good thing. Investigating other materials expands the options available for meeting desired optoelectronic properties and wavelengths of interest, and we should keep in mind that graphene does have limitations. One example is that from the point of view of plasmonics, graphene is only really useful for wavelengths longer than visible ones, due to the lack of metallic behaviour at such high frequencies (to be fair, this is an issue common to many semiconductors).



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Researchers are now actively focusing on a suite of atomically thin allotropes and compounds based on carbon (graphene and graphyne), boron (borophene), germanium (germanene), silicon (silicene), tin (stanene), phosphorus (phosphorene) and hexagonal boron nitride, or hBN. Speaking of hBN, on page 262, Guillaume Cassabois, Pierre Valvin and Bernard Gil show evidence for an indirect bandgap at 5.955 eV, possibly settling an ongoing debate on the nature of the bandgap.

Then there are also the transition metal dichalcogenides (TMDCs) such as molybdenum disulfide and tungsten diselenide. On page 216, Kin Fai Mak and Jie Shan provide a detailed review of TMDCs and their application to photonics and optoelectronics and discuss the physics of their excitonic effects and spin- and valley-dependent properties.

Research on atomically thin layers of metals such as palladium[1] and rhodium[2] has also recently been reported. And interesting results have come from studies investigating combinations of the new materials such as TMDCs on graphene. Such heterostructures are highlighted on page 227 by Zhipei Sun, Amos Martinez and Feng Wang. In their Review on optical modulators based on 2D materials such as graphene, TMDCs, black phosphorus and heterostructure combinations, they explain that the performance of these optical modulators deserves to be taken seriously.

To get a broader perspective of how the field of 2D materials is evolving we interviewed Fengnian Xia from Yale University (page 205), who not only comments on the achievements of researchers exploiting graphene but also explains why other materials such as black phosphorus and silicene are interesting from an optical point of view.

For more detail on this new family of 2D semiconductors and their prospects refer to the Commentary on page 202 where Andres Castellanos-Gomez provides an introduction to the materials and explains why there is so much excitement surrounding 2D semiconductors other than graphene, such as silicene and hexagonal boron nitride.

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One thing is clear, as Castellanos-Gomez explains, there is reason to be excited, but we need to remember that we are in a stage of experimental infancy with regard to practical exploitation of many of the interesting properties of these materials. We eagerly look forward to seeing what the materials and optics communities deliver over the coming years and hope that authors will consider *Nature Photonics* as an outlet for the exciting findings in the area. ❒

References

1. Yin, X., Liu, X., Pan, Y. T., Walsh, K. A. & Yang, H. *Nano Lett.* **14,** 7188–7194 (2014).
2. Daun, H. *et al. Nature Commun.* **5,** 3093 (2014).