Detecting light with graphene

Will graphene optoelectronics be able to displace silicon technology? Thomas Mueller explains that a new design of graphene photodetector is showing great promise.

What is the current situation for graphene research?

The work done at IBM by Fengnian Xia, Phaedon Avouris and myself is concerned with exploiting graphene as a photodetector. Until recently, graphene device research has mainly concentrated on electronics, not optoelectronics. This is driven by the fact that graphene offers the possibility of creating high-frequency transistors that are faster than today's state-of-the-art high-electron-mobility transistors. The study of graphene optoelectronic devices, on the other hand, is a relatively young field. Graphene is currently mainly used as an optically transparent electrode in liquid-crystal displays, organic light-emitting diodes and solar cells. It is also used as a saturable absorber in mode-locked lasers. It is becoming apparent that the optical, not just electrial, properties of graphene are attractive for photonic applications. Owing to the absence of a bandgap, graphene does not exhibit a cut-off wavelength as semiconductors do, and hence offers the possibility of realizing devices that can operate at any optical wavelength from the far infrared to the ultraviolet.

Concerning graphene photocurrent experiments, IBM and other groups have studied the channel potential profile of graphene transistors using a scanning photocurrent imaging technique. The scheme involves focusing a laser spot onto graphene and then scanning it across a bias region to obtain a photocurrent image. One thing we noticed is that the photoresponse can be quite strong compared with carbon nanotubes. We looked at the high-frequency properties and found that the photoresponse extends as high as 40 GHz, but you can probably go much higher than that. These measurements motivated us to develop graphene-based photodetectors; they demonstrate that a graphene transistor can be used as a photodetector and that the internal quantum efficiency can be as large as 10–30%.

Why move away from silicon and III–V materials for detectors?

Silicon, germanium and III–V photodetector research has made huge progress over the past 40 years, but there still remain some challenges that need to be overcome. Integration of electronics with optoelectronics is still difficult, and there is also a lack of fast photodetectors and other optoelectronic devices in the long-wavelength regime (the mid- to far-infrared). Graphene could help to overcome these obstacles. Moreover, in most optoelectronic devices, speed is often limited by 'slow' holes. In graphene, the mobility of holes can be as high as the mobility of electrons. Also, the light–matter interaction in graphene is stronger and may allow for smaller optoelectronic devices with larger resistor–capacitor bandwidths and hence also higher speeds.


IBM

Researchers at the IBM Thomas J. Watson Research Center are actively exploring graphene-based optoelectronics.

Integration of graphene with silicon electronics is in fact potentially easier than integration of silicon with III–V components. Large-area graphene flakes can be grown by chemical vapour deposition on metals and then transferred to any target substrate. The graphene itself can be patterned into any arbitrary shape. Also, integrated electronic–photonic systems that consist entirely of graphene are possible.

Tell us about your recent success.

Photocurrent imaging experiments have shown a strong photoresponse near the interface between graphene and the metal electrodes. However, the external efficiency and also the absolute magnitude of the photocurrent were small, in the nanoampere range. It was not clear whether such devices could be useful in photonic applications. There was clearly a need to increase the active photodetection area. In a photodetector application, for example, the signal strength must be larger than the noise in the detection system. In our study, we managed to scale up the photodetector area by using an arrangement of titanium and palladium electrodes. In this way, we were able to obtain photocurrents as large as 0.2 mA, allowing for the accurate detection of 10 Gbit s^{-1} optical data streams. Our device hence constitutes the first practical graphene photodetector. Using this design, the detector can in principle be scaled to millimetre-size areas, making it also interesting for mid- to far-infrared or terahertz detection.

Are there other photonic applications for graphene?

Graphene can be doped electrostatically, and it has been shown that its absorption range can be tuned by applying an external gate voltage. This could be exploited to realize electro-optic modulators. The linear dispersion relation of graphene also leads to an unequally spaced Landau level spectrum. This is a very important property because it could enable the implementation of a three-level system, which could form the basis of a new type of laser. Another promising application of graphene could be in far- and mid-infrared photonics. Very recently IBM demonstrated a significant transport (electrical) bandgap (>130 meV) in such biased bilayer graphenes (*Nano Lett.* **10,** 715–718; 2010). This discovery provides exciting new possibilities for tunable light emitters and photodetectors in the mid- and far-infrared.

What are the remaining challenges in making graphene devices a commercial reality?

Industrial production will require large-area, wafer-scale graphene films. Promising approaches involve graphene synthesis by the thermal decomposition of silicon carbide or by chemical vapour deposition on thin metal film catalysts (mainly copper and nickel). Fully controlled homogeneous growth has not yet been achieved, but given the pace at which graphene research progresses, these problems may soon be solved.

INTERVIEW BY DAVID PILE

Thomas Mueller and his co-workers have a Letter on their graphene photodetector on page 297 of this issue.

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