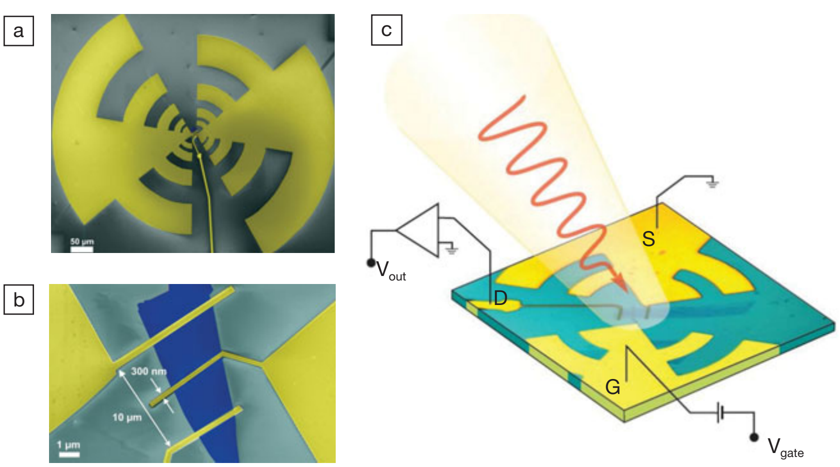
Nano Focus

Room-temperature terahertz detectors fabricated using graphene field-effect transistors

Terahertz radiation penetrates many common dielectric materials that are opaque to visible and mid-infrared light, allowing for imaging of objects and identification of substances through their molecular fingerprints. A significant factor limiting the exploitation of this effect is the slow response of commercial terahertz detectors. Describing a new approach to overcome this problem, L. Vicarelli from Istituto Nanoscienze-CNR and Scuola Normale Superiore, Italy, D. Coquillat from Université Montpellier and CNRS, France, A. Lombardo from Cambridge University, UK, and their colleagues have recently demonstrated room-temperature terahertz detectors based on antenna-coupled graphene field-effect transistors (GFETs).

This new approach incorporates field-effect transistor, wherein terahertz detection is mediated by the excitation of plasma waves in the transistor channel. Because the two-dimensional electron gas in doped graphene has very high mobility (even at room temperature) and supports plasma waves that are weakly damped, GFET plasma-based photodetectors could outperform other terahertz detection technologies.

As described in the October issue of *Nature Materials* (DOI: 10.1038/NMAT3417; p. 865), Vicarelli and co-researchers mechanically exfoliated graphene on Si/SiO_2, and then used lithography to define a single lobe of a log-periodic circular-toothed antenna as the source contact and a metal line as a drain running to the bonding pad (see figure). After depositing an insulating layer of HfO_2, the researchers then used e-beam lithography to define an identical antenna lobe for the top gate. Calculation showed that the antenna has resonant frequencies of 0.4, 0.7, 1, and 1.4 THz.



False-color scanning electron micrographs in (a) and (b) show that the detector consists of a log-periodic circular tooth antenna located between the source and gate of a graphene field-effect transistor. The line running to the bonding pad is the drain. A Cr/Au top gate is located in the middle of the graphene channel, over the insulating layer. In (c), off-axis parabolic mirrors focus the terahertz radiation. Reproduced with permission from *Nature Mater*. **11** (2012), DOI: 10.1038/NMAT3417; p. 865. © 2012 Macmillan Publishers Ltd.

The researchers then measured the conductivity and photoresponse to terahertz radiation at room temperature in single-layer and bilayer graphene devices while varying the gate voltage, and showed that even though a considerable fraction of the radiation field is not funneled into the GFETs, the nonlinear response to the oscillating radiation field at the gate electrode is exploited with both thermoelectric and photoconductive contributions. The noise equivalent powers (NEPs)—a figure of merit for photodetectors that corresponds to the lowest detectable power in a 1-Hz output bandwidth—are about 200 $nWHz^{-1/2}$ and 30 $nWHz^{-1/2}$ for single-layer and bilayer devices, respectively. Although these are one to two orders of magnitude larger than those for commercial detectors, the researchers said that these are upper limits; correcting for the coupling efficiency of the radiation into the nanosized transistor element would result in much smaller NEPs.

The researchers demonstrated that, even without optimization, their devices can perform large-area, fast imaging of realistic samples. Furthermore, the researchers said that their GFETs "have the potential for investigations of fundamental physics, such as the hydrodynamic behavior of chiral electron plasmas and their nonlinear instability, chirality-assisted electronic cloaking, and Zener-tunneling-induced negative differential conductivity."

Steven Trohalaki

Smallest ice crystal revealed

Ice crystals have small beginnings—even smaller than previously believed. Challenging the existing belief that around 1000 molecules are required to generate a particle of ice with a true crystalline structure, a team of researchers working with Thomas Zeuch from the University of Göttingen, Petr Slavíček from the Technical University in Prague, and Udo Buck from the Göttingen-based Max Planck Institute for Dynamics and Self-Organization has now shown experimentally that crystalline order starts to form with just 275 water molecules, and that only 475 can generate a real crystalline structure.

The water molecules in ice crystals arrange themselves in a hexagonal lattice in which each water molecule forms hydrogen bonds to four adjacent molecules, and which occupies more space than liquid water, which is an unusual behavior. In the experiments performed, clusters below the minimum size for a crystal are generated with temperatures of around −180°C to −160°C. As they are