New T-wave detector uses waves of the electronic sea in graphene

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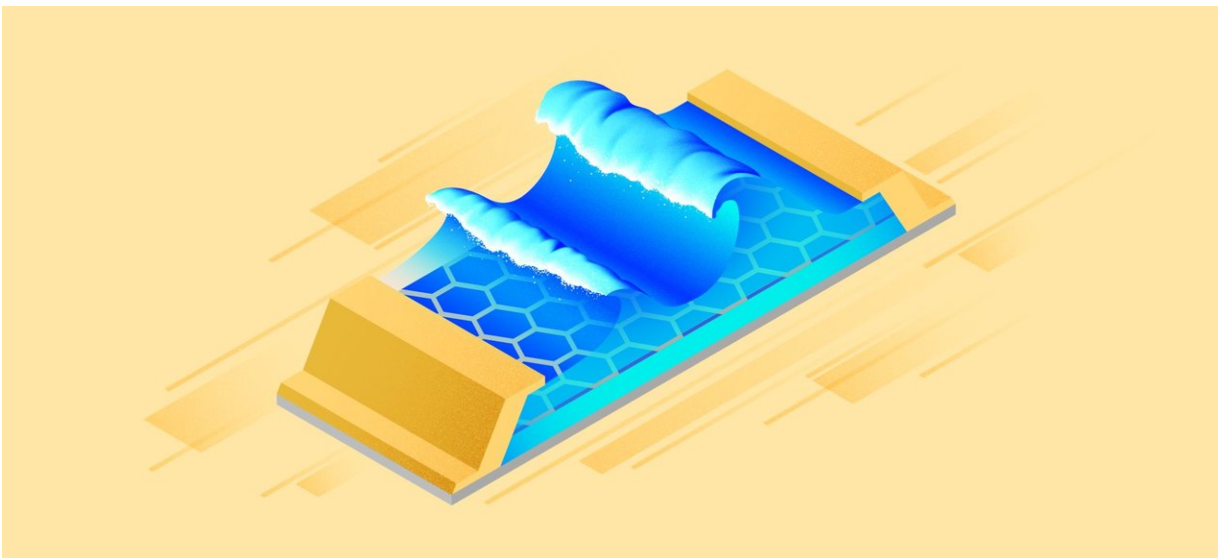


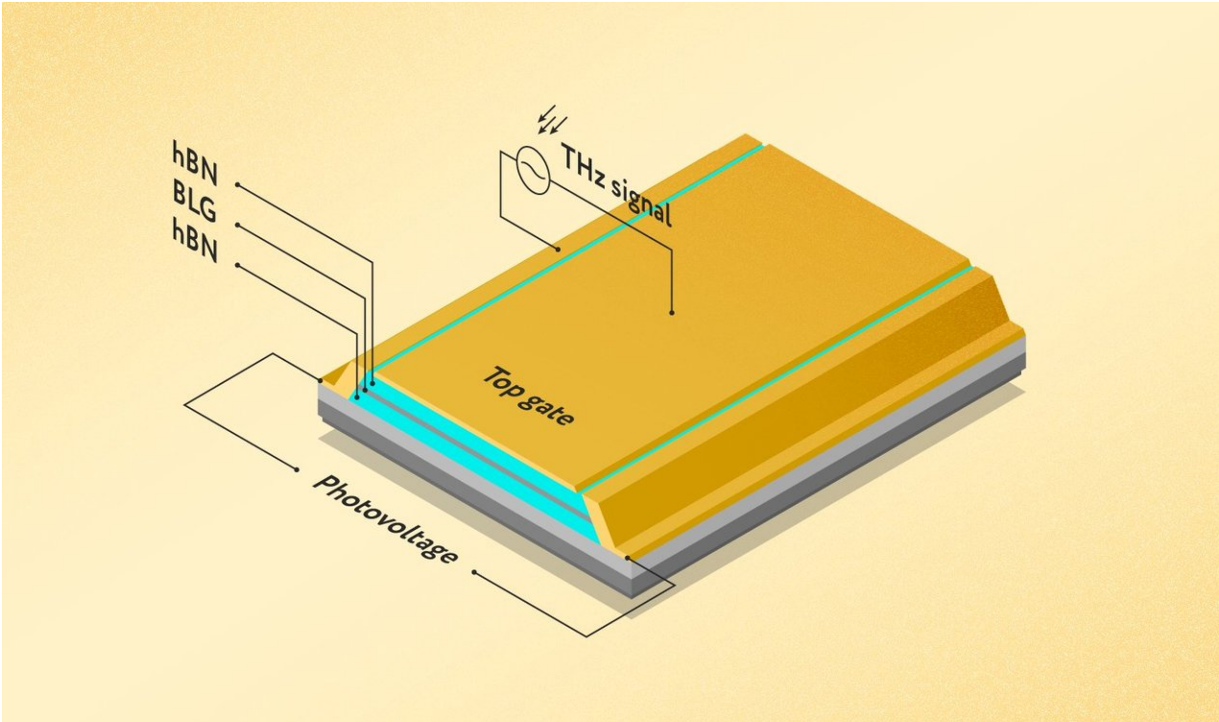
Waves in graphene. Credit: @tsarcyanide/MIPT

A team of researchers from Russia, Great Britain, Japan and Italy has created a graphene-based terahertz detector. The study was published in *Nature Communications*.

Any system for wireless data transfer relies on electromagnetic wave sources and detectors, but they are not available for every kind of waves. The existing sources of terahertz radiation, which occupies a middle ground between microwaves and infrared light, consume too much power or require intense cooling. Yet T-waves could potentially enable faster Wi-Fi, new methods of medical diagnostics, and studies of space objects using radio telescopes.

The reason for the inefficiency of existing terahertz detectors is the mismatch between the size of the detecting element, the transistor—about one-millionth of a meter—and the typical wavelength of terahertz radiation, which is some 100 times greater. This results in the wave slipping past the detector without any interaction.

In 1996, it was proposed that to address this issue, the energy of an incident wave could be compressed into a volume comparable to the size of the detector. For this purpose, the detector material should support "compact waves" of a special kind, called plasmons. They represent the collective motion of conduction electrons and the associated electromagnetic field, not unlike the surface sea waves moving together with the wind as a storm sets in. In theory, the efficiency of such a detector is further increased under wave resonance.



Detector layout. The transistor channel, made of bilayer graphene (BLG), is sandwiched between two crystals of hexagonal boron nitride (hBN). This structure is placed on an oxidized silicon substrate (shown in gray). The two sleeves of a terahertz antenna are connected between the source and the top gate — that is, the left and top electrodes shown in gold. Signal voltage is read between the source and the drain terminals — the right and left electrodes. Credit: @tsarcyanide/MIPT

Implementing such a detector proved harder than anticipated. In most semiconductor materials, plasmons undergo rapid damping—that is, they die down—due to electron collisions with impurities. Graphene was seen as a promising way out, but until recently, it was not clean enough.

The authors of the research presented a solution for the long-standing problem of resonant T-wave detection. They created a photodetector (figure 1) made of bilayer graphene encapsulated between crystals of boron nitride and coupled to a terahertz antenna. In this sandwich structure, impurities are expelled to the exterior of the graphene flake, enabling plasmons to propagate freely. The graphene sheet confined by metal leads forms a plasmon resonator, and the bilayer structure of graphene enables wave velocity tuning in a wide range.

In fact, the team has developed a compact terahertz spectrometer, several microns in size, with the resonant frequency controlled via voltage tuning. The physicists have also shown the potential of their detector for fundamental research: By measuring the current in the detector at various frequencies and electron densities, plasmon properties can be revealed.

"Our device doubles up as a sensitive detector and a spectrometer operating in the terahertz range, and it's also a tool for studying plasmons in two-dimensional materials. All of these things existed before, but they took up a whole optical table. We packed the same functionality into a dozen micrometers," said co-author Dmitry Svintsov, who heads the Laboratory of 2-D Materials for Optoelectronics at the Moscow Institute of Physics.

More information: Denis A. Bandurin et al. Resonant terahertz detection using graphene plasmons, *Nature Communications* (2018). DOI: 10.1038/s41467-018-07848-w

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