A single-sheet graphene p-n junction with two top gates

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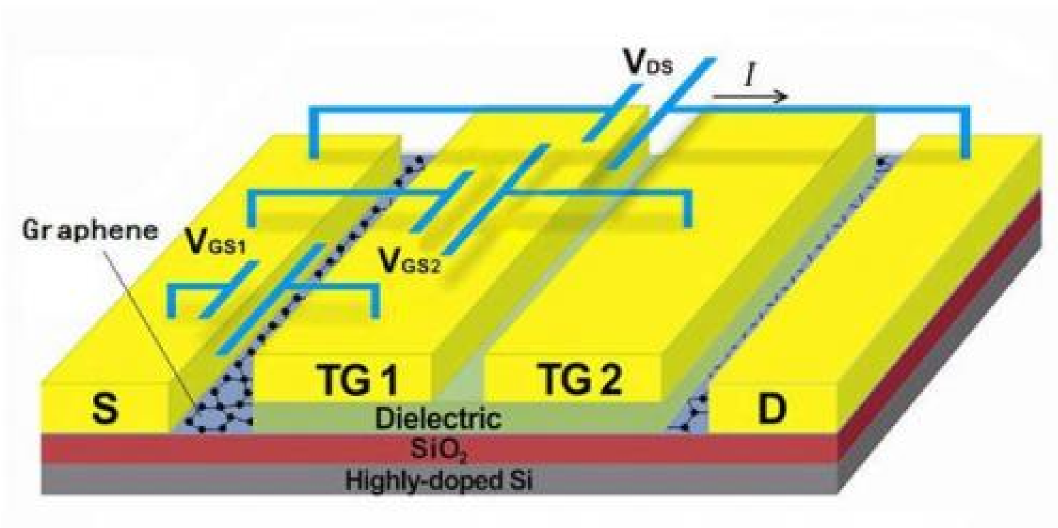


The graphene layer has two gates to create local changes in charge carrier.

Researchers in Canada have designed and fabricated a single-sheet graphene p-n junction with two top gates. The standard technique, using a top and a bottom gate, can lead to damaging of the graphene layer. This is avoided in the new method, which also offers linear I-V characteristics at low gate voltage. The two-top-gate structure is expected to be a practical route to a room-temperature terahertz source.

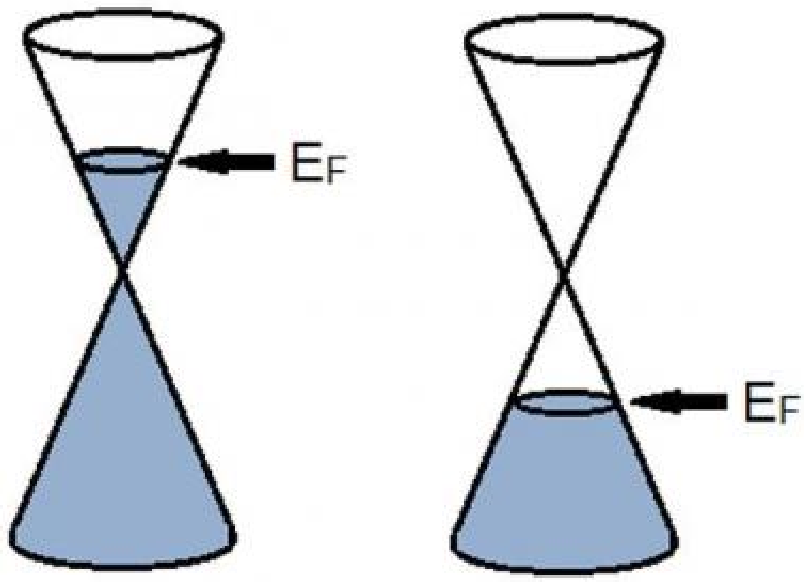
Gapless

Graphene behaves as a gapless semiconductor, with zero gap between the valence and conduction band. As a consequence, it is easy to tune between an n-type (electrons are the main charge carriers) or p-type (holes are the main charge carriers) semiconductor. Applying a positive gate voltage to the graphene will shift the Fermi level into the conduction band, creating a p-type semiconductor. A negative gate voltage will lower the Fermi level to the valence band, making holes the dominant carriers.

This property means that a single sheet of graphene can behave as a p-n junction, as shown in the bottom figure. In this case, a positive gate voltage can be applied to the first gate, and a negative to the second, shifting the Fermi levels in those regions and creating the junction.

Non-destructive

Previous attempts to manufacture single-sheet junctions have used a top-gate in conjunction with a bottom gate. These techniques used the substrate as the bottom gate, which would lower the Fermi level of the entire sheet. A single top gate could then be used to raise the Fermi level locally. However, to overcome the bottom gate potential, the top gate voltage needed to be raised so high that the graphene became damaged or the I-V characteristics became highly non-linear. As the new structure only applies one gate locally, only very low voltages are required, which preserves the material and its linear characteristics.



Applying positive or negative gate voltage shifts the Fermi level above or below the valence band

The low voltages also play a role in the device's suitability in THz production. Most semiconductors have a band-gap that is far greater than the energy associated with THz radiation. The zero-gap nature of graphene means that it can operate at these frequencies, as population inversion and electron-hole recombination can be tuned to any frequency, even the low-energy THz band.

Temperate

The operation of graphene devices in THz production were explained by Jingping Liu, the lead author of the research. The technique, known as injection, uses electron-hole recombination: "for n-type graphene, extra electrons are induced by electrostatic field and are accumulated in the graphene layer, resulting in population inversion," said Liu. After this, she explained that "with the assistance of the forward bias, the electrons of high energy level move to the p-type graphene, and recombine with the holes in p-type graphene to generate TH Z photons."

While the team have shown that their device can, in principle, be used for TH Z generation, much more research is needed to bring it to practical application. The group are now working on transport phenomena and temperature effects in graphene p-n junctions. "Through the research on the dynamic mechanism of the p-n junction with injection current, we will understand the electronic transport mechanism of the p-n junction," said Liu "and get the recombination probability and the life time of radiation recombination, phonon scattering and Auger recombination, to provide the theory evidence for the model design of the TH Z laser source."

Liu is confident that these simple devices will open up further applications for THz technology by their operation at room temperature: "THz quantum cascade lasers are promising coherent THz sources, but they cannot be operated at room temperature," she said, "however the mono-layer of graphene offers unique and new opportunities and it would be great if, one day, a TH Z source made from graphene could be operated at room temperature."

More information: "Fabrication and measurement of graphene p–n junction with two top gates." *Electronics Letters*, Volume 50, Issue 23, 06 November 2014, p. 1724 – 1726. DOI: 10.1049/el.2014.3061

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