Graphene could revolutionize the Internet of Things

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PFL researchers have produced a tunable, graphene-based device that could significantly increase the speed and efficiency of wireless communication systems. Their system works at very high frequencies, delivering unprecedented results.

Wireless communications come in many forms - such as mobile phones using 4G or 5G connectivity, GPS devices, and computers connected via Bluetooth to portable sensors - and operate in different frequency bands. To work across multiple platforms, connected objects have to be compatible with a whole range of frequencies without being weighed down by excessive hardware.

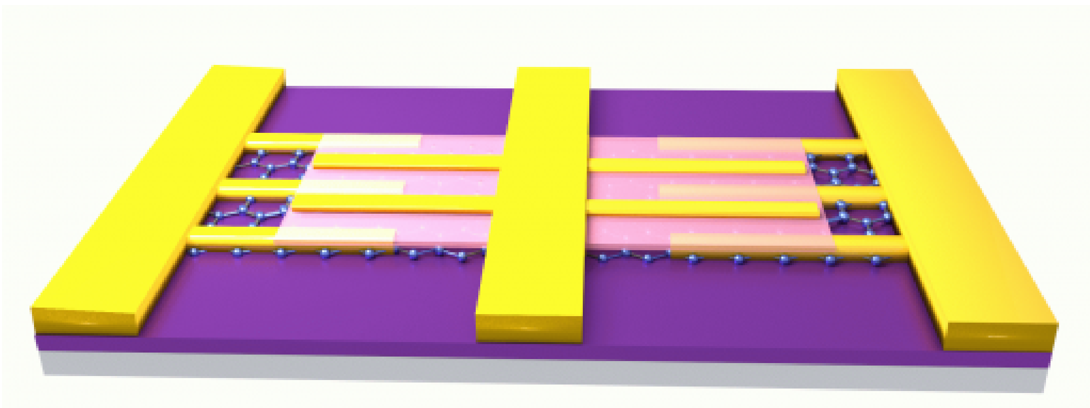
Most portable, wireless systems currently come equipped with reconfigurable circuits that can adjust the antenna to transmit and receive data in the various frequency bands. The only problem is that the technologies currently available like MEMS and MOS, using silicon or metal, do not work well at high frequencies. And that's where data can travel much faster.

EPFL researchers have come up with a tunable graphene-based solution that enables circuits to operate at both low and high frequencies with unprecedented efficiency. Their work has been published in *Nanoletters*.

The new graphene-based solution, which was developed in the Nanoelectronic Devices Laboratory, is designed to replace tunable capacitors, which can be found in all wireless devices. The new device "tunes" the circuits to different frequencies so that they can operate across a wide range of frequency bands. It also meets other needs that neither MEMS nor MOS capacitors can: good performance at high frequency, miniaturization and the ability to be tuned using low energy.

The EPFL researchers overcame these obstacles with a graphene-based capacitor that is compatible with traditional circuits. The device consumes very little energy and, above 2.1 GHz, easily outperforms its competitors and has a miniaturized design. "The surface area of a conventional MEMS system would have to be a thousand times greater to get the capacitance value," said Clara Moldovan.

How does it work?



Credit: Ecole Polytechnique Federale de Lausanne

The researchers' breakthrough is based on a clever sandwich structure that takes graphene's unique characteristics into account. "When graphene was discovered more than 10 years ago, it caused a real stir," said Moldovan. "It was considered a miracle material: it is a very good electrical and thermal conductor and it is flexible, lightweight, transparent and sturdy. But researchers discovered that it was difficult to integrate into electronic systems because its atomic thickness gives it high effective resistance."

The sandwich-shaped structure takes advantage of the fact that a two-dimensional gas of electrons in a quantum well can behave like a quantum capacitance. This is because it follows the Pauli Exclusion Principle, according to which a certain amount of energy is needed to fill a quantum well with electrons. Quantum capacitance can be easily measured in a single-atom layer of graphene, and the key advantage is that it is tunable by varying the charge density in graphene with a very low voltage.

"It's by applying voltage that we can 'tune' our capacitors to a given frequency, just like tuning a radio to get different stations," said Moldovan, the lead author of the article.

Many advantages

The EPFL researchers' device, which is only several hundred micrometers (around 0.05 cm) long and wide, can be stiff or flexible, is easily miniaturized, and uses very little energy. Potential applications are numerous. In addition to improving the flow of data between connected devices, it could extend battery life and lead to ever more compact devices. In its flexible state, it could be easily used in sensors placed in clothes or directly on the human body. "Our results confirm that graphene could truly revolutionize the future of wireless communications," said Moldovan.

The end technology will be a hybrid in which graphene will be paired with advanced silicon technologies. "Some have claimed that graphene will one day replace silicon technology," said Adrian Ionescu, the head of the Nanolab. "But in reality, graphene is most effective in the realm of electronics when it is combined with functional silicon blocks."

More information: Clara F. Moldovan et al. Graphene Quantum Capacitors for High Frequency Tunable Analog Applications, *Nano Letters* (2016). DOI: 10.1021/acs.nanolett.5b05235

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