Silicon breakthrough could make key microwave technology much cheaper and better

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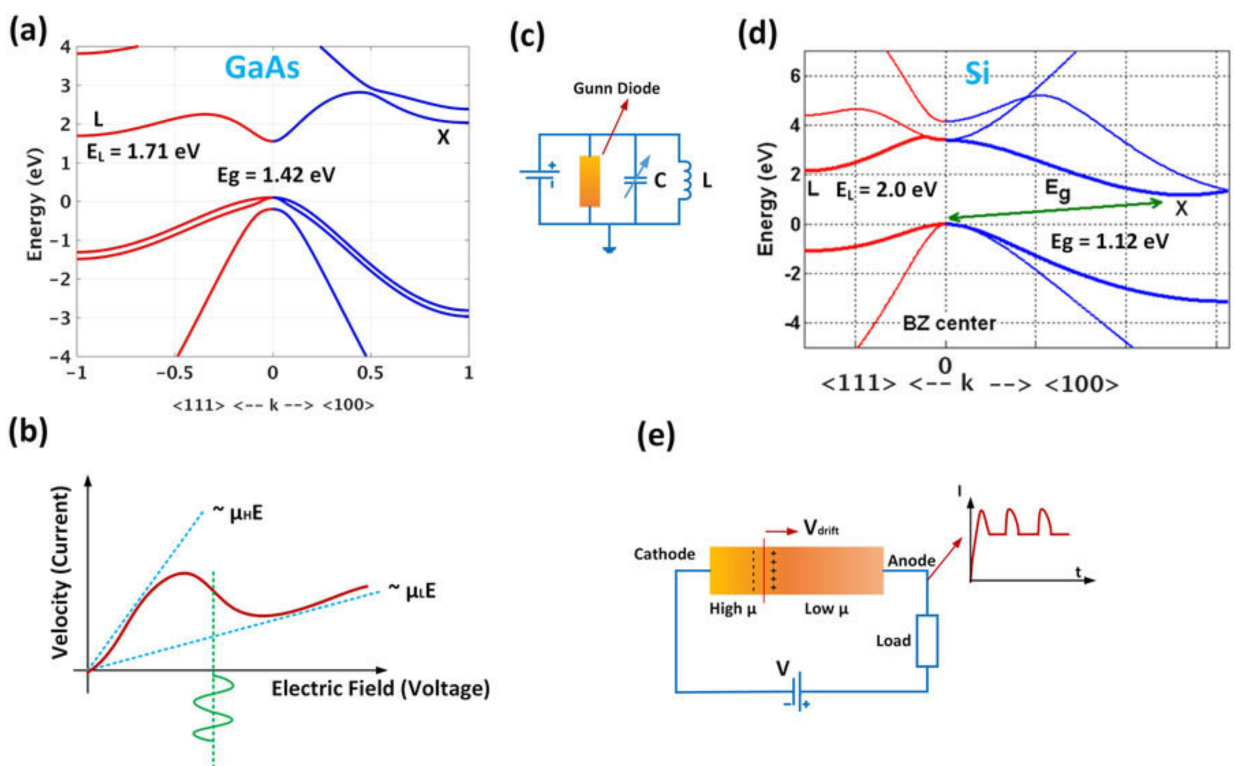

Comparing the band structure of bulk GaAs and Si and NDR-induced oscillation in a Gunn diode. Band structures of (a) Gallium Arsenide with direct bandgap. Direct and indirect sub bands are called Γ and L valley, respectively. The energy offset is 300 meV. (b) Negative Differential Resistance (NDR) for GaAs as a result of velocity drop for electrons which migrated to high effective mass (L) band. The NDR emanated from a large ratio of effective mass of indirect to direct conduction sub band which is about 100 for GaAs. (c) The electric network shows how compensating the loss of an electric LC resonator using a

Gunn diode with NDR results in a perpetual oscillation in microwave frequencies. (d) Band structure of bulk silicon with more than 1 eV offset between Γ and X valleys which explains why there is no NDR in bulk silicon. (e) The second type of Gunn oscillation (intrinsic) is a result of self-repeating formation of accumulation/depletion sandwich inside the bulk material which moves with saturated drift velocity from cathode to anode. Credit: *Scientific Reports* (2018). DOI: 10.1038/s41598-018-24387-y

Researchers using powerful supercomputers have found a way to generate microwaves with inexpensive silicon, a breakthrough that could dramatically cut costs and improve devices such as sensors in self-driving vehicles.

"Until now, this was considered impossible," said C.R. Selvakumar, an engineering professor at the University of Waterloo who proposed the concept several years ago.

High-frequency microwaves carry signals in a wide range of devices, including the radar units police use to catch speeders and collision-avoidance systems in cars.

The microwaves are typically generated by devices called Gunn diodes, which take advantage of the unique properties of expensive and toxic semiconductor materials such as gallium arsenide.

When voltage is applied to gallium arsenide and then increased, the electrical current running through it also increases—but only to a certain point. Beyond that point, the current decreases, an oddity known as the Gunn effect that results in the emission of microwaves.

Lead researcher Daryoush Shiri, a former Waterloo doctoral student who now works at Chalmers University of Technology in Sweden, used computational nanotechnology to show that the same effect could be achieved with silicon.

The second-most abundant substance on earth, silicon would be far easier to work with for manufacturing and costs about one-twentieth as much as gallium arsenide.

The new technology involves silicon nanowires so tiny it would take 100,000 of them bundled together to equal the thickness of a human hair.

Complex computer models showed that if silicon nanowires were stretched as voltage was applied to them, the Gunn effect, and therefore the emission of microwaves, could be induced.

"With the advent of new nano-fabrication methods, it is now easy to shape bulk silicon into nanowire forms and use it for this purpose," said Shiri.

Selvakumar said the theoretical work is the first step in a development process that could lead to much cheaper, more flexible devices for the generation of microwaves.

The stretching mechanism could also act as a switch to turn the effect on and off, or vary the frequency of microwaves for a host of new applications that haven't even been imagined yet.

"This is only the beginning," said Selvakumar, a professor of electrical and computer engineering. "Now we will see where it goes, how it will ramify."

Shiri also collaborated with researchers Amit Verma, Reza Nekovei, Andreas Isacsson and M.P. Anantram at universities in the United States and Sweden.

Their work was recently published in the journal *Scientific Reports*.

More information: Daryoush Shiri et al, Gunn-Hilsum Effect in Mechanically Strained Silicon Nanowires: Tunable Negative Differential Resistance, *Scientific Reports* (2018). DOI: 10.1038/s41598-018-24387-y

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