For Better Nanowires, Just Add Diamond

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Among the positive characteristics of diamond, such as its beauty and unsurpassed hardness, are less well known properties that make it a valuable material in the electronics industry. Now, according to two scientists at the University of California-Riverside, diamond can boast one more useful ability in that area: significantly increasing the current-carrying abilities of silicon nanowires. This means that diamond may play an important role in future nanoelectronic technologies.

The UCR scientists are Alexander Balandin, Professor of Electrical Engineering and Director of UCR's Nano-Device Laboratory (NDL) and Vladimir Fonoberov, a postdoctoral researcher and lecturer. In a paper published in the October 19 online edition of *Nano Letters*, they show theoretically that nanowires coated with diamond can be up to 100 times better at carrying electric current than bare nanowires at very low temperatures, and two times better at room temperature. This improvement is determined by a property known as electron mobility.

"Electron mobility is an important parameter that defines how well electrons can move within a semiconductor material such as silicon, and thus directly affects the current drive and speed of a device," said Balandin to *PhysOrg.com*. "Therefore, finding ways to increase electron mobility is one key to improving electronic devices."

Currently, he adds, many researchers are engaged in studies aimed at finding new ways to increase electron mobility or, in the least, prevent it from degrading as devices get smaller and smaller. However, some of the existing techniques used to improve electron mobility create heat-removal problems within circuits. One method, for example, involves adding a layer of a silicon-germanium compound to a silicon transistor, a very common circuit component – typically composed of layers of silicon – that is used to control electricity flow. In this method, the layers of silicon (which serve as the transistor's conducting channels) are grown on top of the silicon-germanium layer, and this produces an increase in the electron mobility in the channels. But the silicon-germanium compound is a poor heat conductor, and it presents thermal management problems.

The diamond-coating technique suggested by Balandin and Fonoberov enhances electron mobility in a very different way: "phonon engineering." Phonons are basic units, or "quanta," of mechanical vibration; sound waves are examples of acoustic phonons. Phonons play a bothersome role in semiconductor devices by scattering electrons. These problems are compounded when the features of electronic devices are reduced to the nanometer scale.

A silicon nanowire can be thought of as a scaled-down transistor channel. Balandin and Fonoberov argue that the mobility degradation and heat removal problems can be avoided by surrounding the nanowires with a diamond shell. "Diamond is an 'acoustically hard' material that strongly changes phonon properties inside a nanowire," said Balandin. "So when a silicon nanowire is surrounded by diamond, the electron-phonon scattering inside the nanowire is suppressed and, as a result, the electron mobility is increased. This is an absolutely new method of mobility enhancement."

An added bonus of diamond is that it is an excellent conductor of heat, which could allow it to impart valuable thermal management properties to circuits.

"Our result revises the long-standing belief that spatially confining phonons is always detrimental to the electron mobility," Balandin said.

Balandin and Fonoberov acknowledge that the cost of crystalline diamond and the processing temperature it requires may complicate its incorporation into circuit designs. But according to prior experimental research conducted by Balandin and his NDL group, less-perfect polycrystalline diamond (diamond that is not one continuous crystal, but is rather composed of individual crystalline grains) would likely produce similar results, as would other types of acoustically hard materials.

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