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New materials rival graphene as contenders for post-silicon throne

More conductive, easier to work with compounds to be commercialized soon

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Waiting in the wings
New electronic materials on the block

	Electron speed	Strong suits
Graphene	10-100 times that of silicon	Electrons travel fast
Bismuth-selenium	10 times that of silicon	Large single crystals, magnetic, superconductive
Zinc oxide	10 times that of silicon	Transparent, so suited for displays
Carbon nanotubes	Faster than amorphous silicon	Chips can be made by printing

Source: The Nikkei Business Daily

Silicon's days as the go-to raw material for semiconductor makers could be numbered. Newer, more conductive materials have already been developed, and scientists around the world are now busy trying to take them out of the lab and into the factory.

Graphene — an elemental carbon in the form of a single-atom-thick sheet — is a promising candidate that could take tomorrow's smartphones, tablet computers and flat-panel TVs to new performance levels. It is important enough to have been the object of last year's Nobel Prize in physics.

But several other materials that outperform silicon have debuted in recent times and are considered graphene rivals as the material of choice of the likely post-silicon era.

Superconducting material

One such material is a bismuth-selenium (Bi-Se) compound with some unique properties.

At the International Symposium on Superconductivity in Tsukuba, Ibaraki Prefecture, in early November graduate students of the Tokyo Institute of Technology were kept busy explaining the poster exhibit of Associate Prof. Takao Sasagawa to one visiting scientist after another.

What they were explaining was a new superconducting material based on a Bi-Se compound. The Sasagawa research team did not discover this new superconductor; that recognition goes to Prof. Robert Cava of Princeton University in the U.S., who reported last February that adding copper to Bi-Se yielded a material that exhibits superconductivity at extremely low temperatures. The Sasagawa team lays credit to being the first to successfully reproduce the phenomena.

The new superconducting material has a layered structure, made from a stack of sheets of bismuth and selenium atoms. The Sasagawa team thoroughly investigated the correlation between the electrical properties and the changes to crystal structure that take place when copper is added. What they found is that the compound becomes a superconducting material when the copper atoms are sandwiched between the sheets and there is a partial deficiency of selenium in the sheets.

The Bi-Se compound is unique because in addition to behaving as a superconductor, groups from Japan and the U.S. have confirmed that electrons can travel on the surface of this material roughly 10 times faster than they can inside silicon. Electron travel speed is directly related to the performance of a material as a semiconductor, and in this regard the Bi-Se compound approaches the performance of graphene.

"We have already completed the development of a technology for growing large single crystals. For electronic device applications this material is better than graphene," Sasagawa asserted.

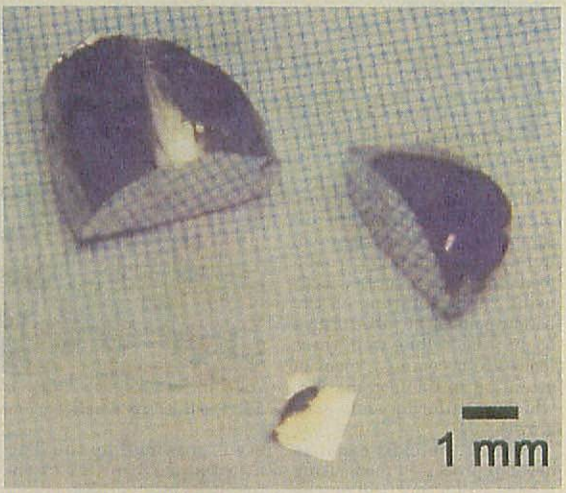
Graphene is related to graphite, which is composed of stacked sheets of carbon atoms. In fact, the Nobel Prize-winning discovery of graphene by researchers at the University of Manchester in 2004 was made by using adhesive tape to peel off single-atom-thick layers from graphite.

Because electrons in graphene can travel at speeds more than 10 times faster than they can in silicon, graphene has been trumpeted as a promising material for energy-saving electronic devices. However, it has proven difficult to create large defect-free sheets of graphene.

Zinc oxide contender

Another contender to the post-silicon crown has popped up in the form of zinc oxide, a compound already commonly used for cosmetics.

In October, a Japanese team led by Prof. Masashi Kawasaki of Tohoku University and Lecturer Atsushi Tsukazaki of the University of Tokyo succeeded in prototyping a thin-film transistor made from a modified zinc oxide compound in which electrons travel 10 times faster than inside silicon. The advantage of zinc oxide is that it is transparent, so one promising application would be to use zinc oxide TFTs to control pixel display on liquid-crystal display and organic electroluminescent panels.



A sliced single crystal of Bi-Se compound made at the Tokyo Institute of Technology. The compound exhibits superconductivity at low temperatures.

Among elemental forms of carbon, the elder brother to graphene is the carbon nanotube, also a promising electronic material. "We have prototyped TFTs using printed carbon nanotubes in which electrons travel faster than in amorphous silicon," said Nagoya University Assistant Prof. Yasumitsu Miyata. Applications research on carbon nanotubes for electronic devices is being carried out throughout the world, but until recently there were no reports of devices that outperform silicon devices.

Miyata, working with Prof. Hisanori Shinohara and colleagues at Nagoya University, achieved their success by using surfactants and ultrasound to isolate semiconducting nanotubes from metallic nanotubes with 99% purity or higher. Using these high-purity semiconducting nanotubes, the team reported in September that it had successfully fabricated TFTs in which electrons travel an order of magnitude faster than they do in amorphous silicon.

"We are continuing to obtain higher performance," Shinohara said. Miyata added, "Companies are sure to like the fact that the devices can be made using printing techniques."

Stuck in the lab

Despite the debut of so many promising new electronic materials for the post-silicon era, there is no guarantee that any of them will ever get out of the lab.

No matter what fantastic properties are demonstrated in the lab, if the work cannot translate to industry that will be the end of them. A large industry has been built around the use of silicon, and the production systems using silicon are fully established. The seeds have been planted. Now academia and industry need to do some serious collaboration.