Could the Next Generation of Microelectronics Be Made From Coal?

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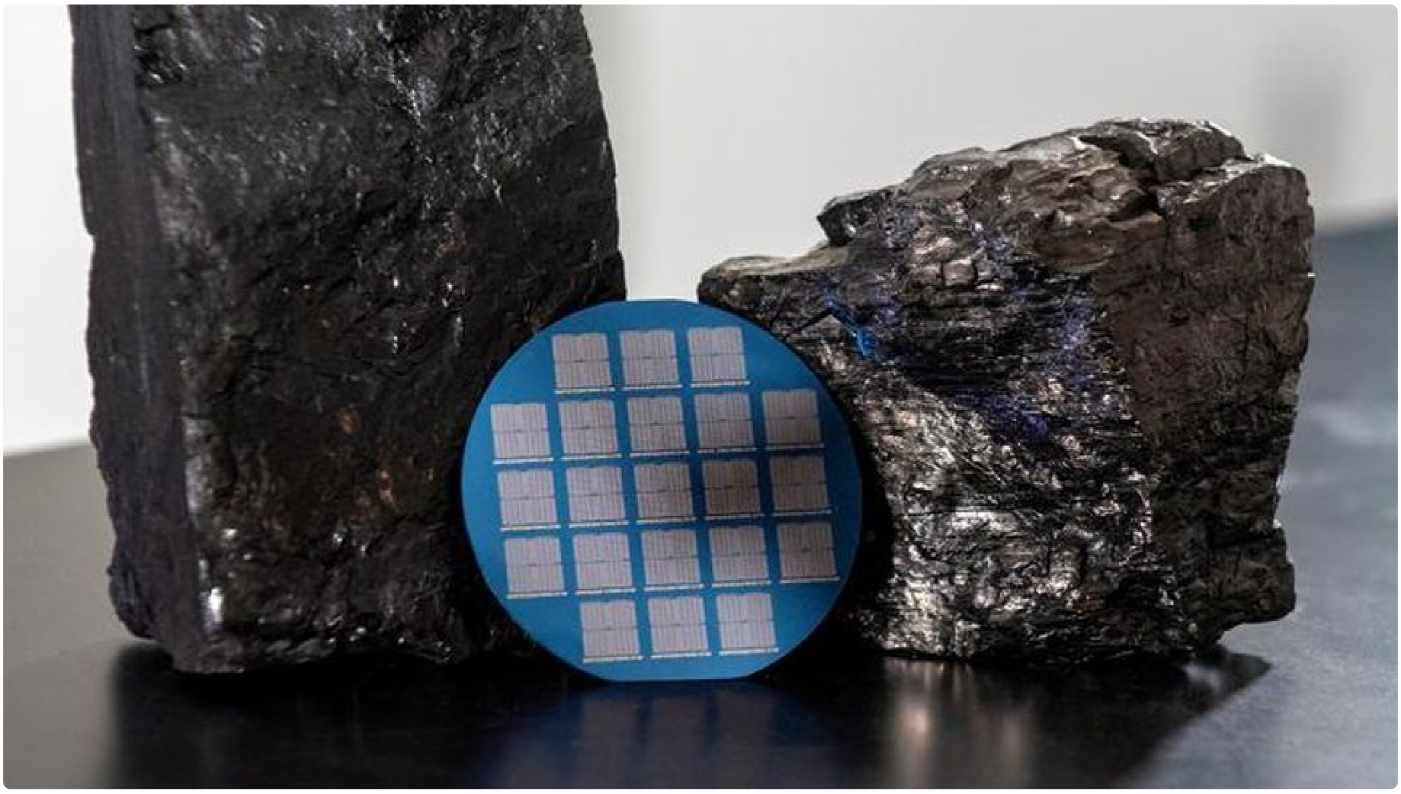

A wafer containing memristors fabricated with high-quality two-dimensional carbon processed from bituminous Blue Gem coal mined in southeastern Kentucky, two samples of which are shown here. Credit: The Grainger College of Engineering at University of Illinois Urbana-Champaign.

Despite supplying just over a third of global electricity generation, coal's status as the most carbon-intensive fossil fuel is driving many countries to reevaluate the role that it plays in energy production and national economies.

In a new paper, published in *Communications Engineering*, researchers suggest that coal could continue to be used to power our modern devices – just in a more creative way. Rather than being used as a fossil fuel to produce electricity, coal can be transformed via a new processing technique into extremely high-purity materials that can be used to build electronic components.

The researchers say that their new research is an effective proof-of-principle and could have significant implications for the semiconductor industry.

The next frontier: 2D electronics

Against a backdrop of demand for increasingly faster, smaller, more powerful electronics, the natural conclusion of such a push is the development of electronic parts from ultra-small materials – possibly just one or two atoms thick. This concept of “two-dimensional electronics” is the limit for electronics miniaturization and promises incredibly small devices that consume tiny amounts of energy but still operate remarkably quickly.

Ultrathin semiconductors have been a major research frontier for 2D electronics over the past few years. But it is also necessary to develop other ultrathin materials – such as insulators that block electric current – to build a 2D device that functions properly.

Ultrathin sheets of carbon with disordered atomic structures could be an excellent example of such an insulator. And that is where the coal comes in.

“Coal is usually thought of as something bulky and dirty, but the processing techniques we’ve developed can transform it into high-purity materials just a couple of atoms thick,” said Qing Cao, a professor of materials science and engineering at the University of Illinois Urbana-Champaign and a co-lead of the collaboration. “Their unique atomic structures and properties are ideal for making some of the smallest possible electronics with performance superior to the state of the art.”

Building transistors and memristors from coal

To build functional electronics parts from coal, the researchers first convert coal char – the solid material left behind after coal gases have been burned or driven out of the coal – into carbon disks measuring just a few nanometers in size. These “carbon dots” are a type of quantum dot, which have very unique electronic properties.

With their new process, the research group was able to turn these carbon dots into wafers of ultrathin amorphous carbon with a thickness as low as 1–2 atomic layers.

The researchers were also able to successfully incorporate these quasi-2D carbon layers into two different proof-of-concept nanoelectronic devices – a transistor and a memristor.

“It’s really quite exciting, because this is the first time that coal, something we normally see as low-tech, has been directly linked to the cutting edge of microelectronics,” Cao said.

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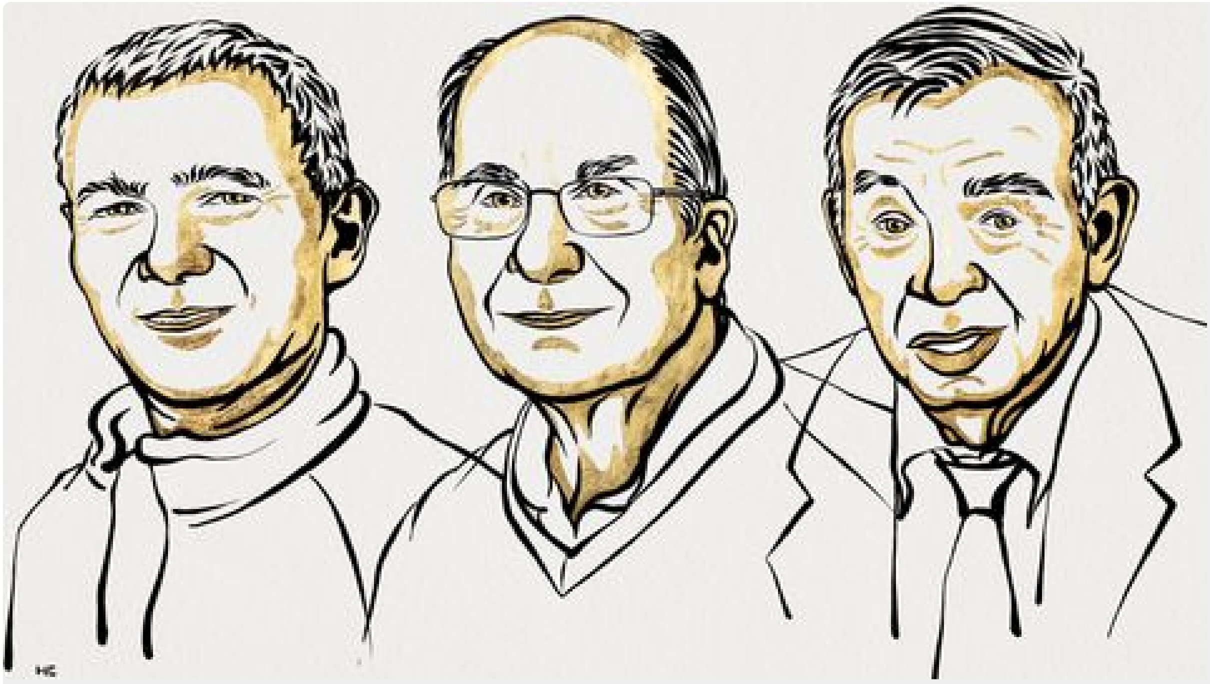

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The transistor – a component that controls current or voltage flow, essentially acting as a switch in electronic systems – was made from semimetal graphene and the coal-derived two-dimensional carbon layer as the insulator in the switch.

This breakthrough is significant, as conventional three-dimensional insulators will have “dangling” chemical bonds at the edges of their crystal structure that can “trap” electrical charges as they move and slow down the speed of the transistor. In contrast, the new coal-derived carbon layer is amorphous and so lacks any kind of regular crystalline structure. This reduces the possibility of charges getting trapped or electrical current leaking through boundaries in the insulator, resulting in significant improvements in power consumption and other performance metrics.

Memristors are a slightly more complex component, as they should be capable of both storing and operating on data. Memristors are a relatively new type of nanodevice and have significant potential within the artificial intelligence space.

To store and represent data, memristors modulate a conductive filament that is formed by electrochemical reactions between two electrodes separated by an insulator. The research team found that their ultrathin coal-derived carbon layers were also a suitable insulator for these devices, allowing for the fast formation of filament with very low energy consumption. They also found that introducing atomic-sized rings into the carbon layers could help to confine the filament to certain regions, enhancing the data storage fidelity and reliability of the device.

Could coal-derived devices be the next big thing in electronics?

These two new devices developed by the group are a good proof-of-concept for the use of coal as a feedstock for high-purity materials, the researchers say. Next, the team hopes to prove that such 2D devices can be manufactured on the sort of large scale that would be needed for commercialization.

"The semiconductor industry, including our collaborators at Taiwan Semiconductor, is very interested in the capabilities of two-dimensional devices, and we're trying to fulfill that promise," Cao said. "Over the next few years, the [University of Illinois Urbana-Champaign] will continue to collaborate with NETL to develop a fabrication process for coal-based carbon insulators that can be implemented in industrial settings."

Reference: An F, Wang C, Pham VH, et al. Ultrathin quasi-2D amorphous carbon dielectric prepared from solution precursor for nanoelectronics. *Commun Eng*. 2023;2(1):1-17. doi:10.1038/s44172-023-00141-9

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