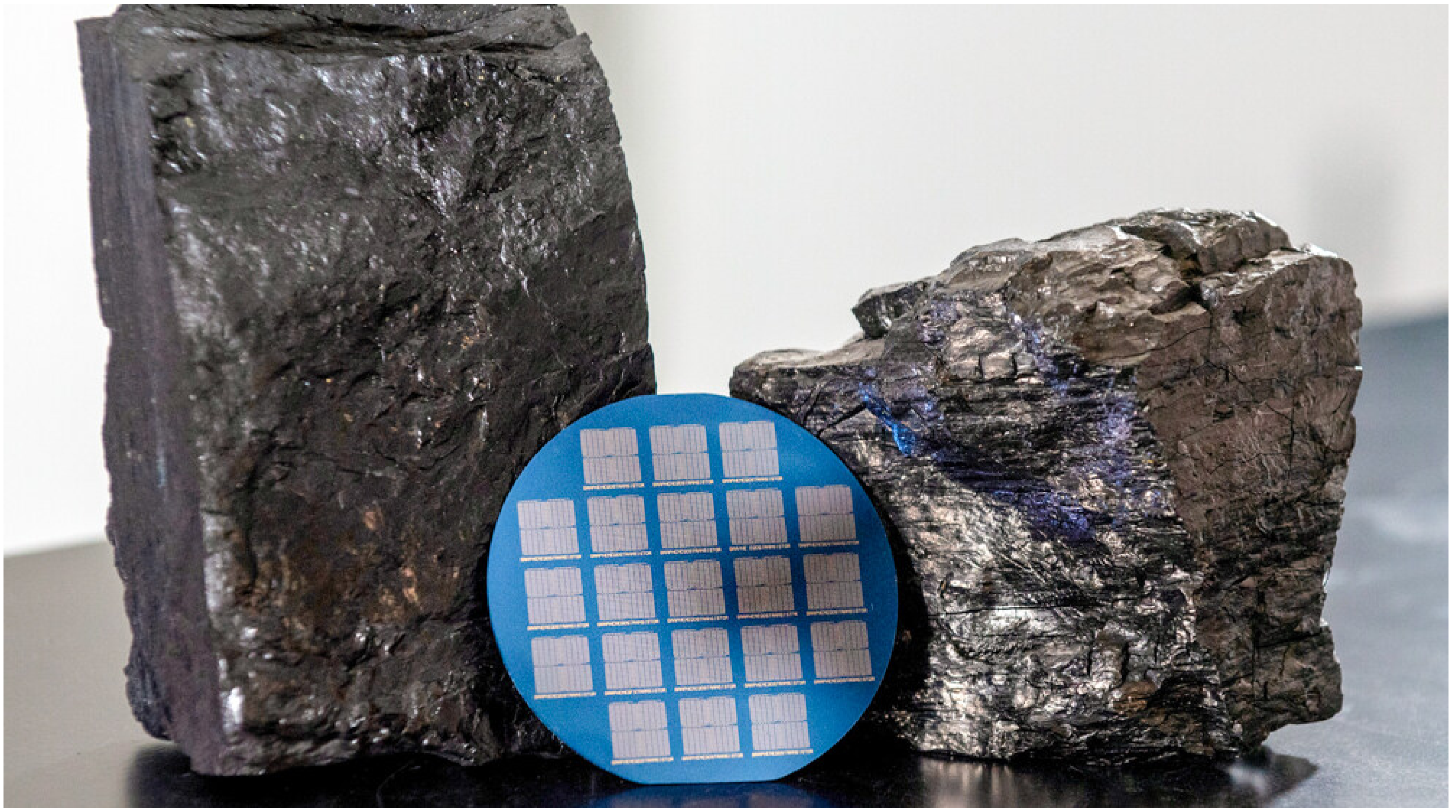
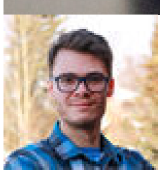
Metal Tech News - The Elements of Innovation Discovered

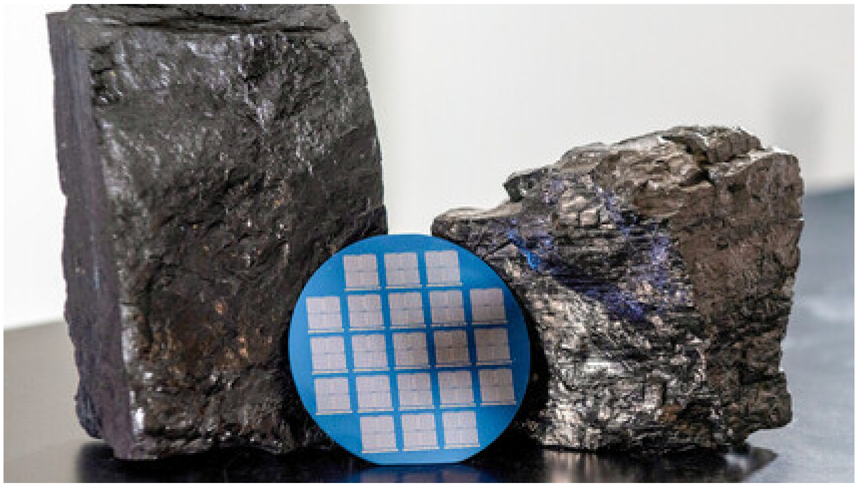




By A.J. Roan
Metal Tech News

Low-tech coal sees high-tech applications

Scientists find way to use coal in future 2D electronic devices Metal Tech News - January 5, 2023



The Grainger College of Engineering at University of Illinois Urbana-Champaign

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.

As the world continues to shift away from older technologies and carbon-emitting energy production, researchers have sought ways to reimagine their uses and align them with modern ideals. The number one candidate – coal – has been an energy lynchpin and an economic keystone for more than a century. Instead of cutting away the lifeline, science seeks to utilize this ancient material in new, high-tech ways.

With companies turning coal into clean technologies such as building components or alternative battery materials, one group of researchers has opted to explore its carbon qualities.

Despite being consumed as fuel for centuries, coal remains abundant in the United States. Unfortunately, however, it has contributed significantly to climate change through its emissions as a fossil fuel.

Due to the world's transition to cleaner energy, it is growing increasingly important to reconsider and reevaluate coal's economic role.

A joint research effort from the University of Illinois Urbana-Champaign, the National Energy Technology Laboratory, Oak Ridge National Laboratory, and the Taiwan Semiconductor Manufacturing Company has shown how coal can play a new vital role in next-generation electronic devices.

"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 materials science & engineering professor at University of Illinois 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 state-of-the-art."

A process developed by NETL first converts coal char into nanoscale carbon disks referred to as "carbon dots" that the U. of I. research group demonstrated can be connected to form atomically thin membranes for applications in both two-dimensional transistors and memristors, technologies that are becoming increasingly critical to constructing more advanced electronics.

The answer again is carbon

In the ongoing search for smaller, faster, and more efficient electronics, the final step will be devices no larger than one or two atoms thick.

Seeing as it is physically impossible for devices to be any smaller than the particles they are built from, the smallest scale will ultimately make them operate much quicker and consume far less energy.

While ultrathin semiconductors have been extensively studied, as part of the mechanical structure of a semiconductor, they require atomically thin insulators to throttle or block electrical currents to initiate binary – the language of computers (simply put, zeroes and ones or ons and offs) to build working electronics like transistors and memristors.

Atomically thin layers of carbon with disordered atomic structures can function as an excellent insulator for constructing two-dimensional devices.

The researchers in the collaboration have shown that such carbon layers can be formed from carbon dots derived from coal char. To demonstrate their capabilities, the U. of I. group led by Cao developed two examples of two-dimensional devices.

"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," said Cao.

Low-tech becomes high-tech

Cao's group used coal-derived carbon layers as the gate dielectric (an insulating material) in 2D transistors built on the semimetal graphene or semiconductor molybdenum sulfide to enable more than two times faster device operating speed with lower energy consumption.

Like other atomically thin materials, the coal-derived carbon layers do not possess "dangling bonds" or electrons that are not associated with a chemical bond. These sites, which are abundant on the surface of conventional three-dimensional insulators, alter their electrical properties by effectively functioning as "traps," slowing down the transport of electrons and, thus, the transistor switching speed.

However, unlike other atomically thin materials, the new coal-derived carbon layers are amorphous, meaning that they do not possess a regular, crystalline structure.

They, therefore, do not have boundaries between different crystalline regions that serve as conduction pathways leading to "leakage," where undesired electrical currents flow through the insulator and cause substantial additional power consumption during device operations.

New memristor avenue

Another application Cao's group considered is memristors, switches that can remember which electric state they were toggled to after their power is turned off. Being increasingly crucial in artificial intelligence applications, memristors have been found to greatly enhance AI capabilities due to their ability to remember previous electrical states.

The researchers found that adopting ultrathin coal-derived carbon layers as the insulator allows the fast formation of such filament with low energy consumption to enable high device operating speed with low power.

Moreover, atomically-sized rings in these coal-derived carbon layers confine the devices to enhance the reproducible device operations for enhanced data storage fidelity and reliability – in layman's, coal-based memristors are more sturdy.

Next steps

While devices developed by the Cao group provide a proof-of-principle for using coal-derived carbon layers in 2D devices, what remains is to show that such devices can be manufactured at a larger scale.

"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 will continue collaborating with NETL to develop a fabrication process for coal-based carbon insulators that can be implemented in industrial settings."