Market Insights

Could Coal Be the Holy Grail of Nanoelectronics?

January 16, 2024 by Jake Hertz

By turning coal into a 2D insulator, researchers devised nanoscale transistors with improved performance characteristics.

In nanoelectronics, the holy grail is 2D electronics: devices with a thickness of one or two atoms. However, while much research focuses on developing semiconductor materials, a less discussed aspect is the need for ultra-thin insulators that can operate effectively at the nanoscale. These ultra-thin insulators are essential for maintaining electrical integrity between closely packed components, preventing unwanted current leakage, and ensuring overall device reliability.

Coal. Image used courtesy of EPA

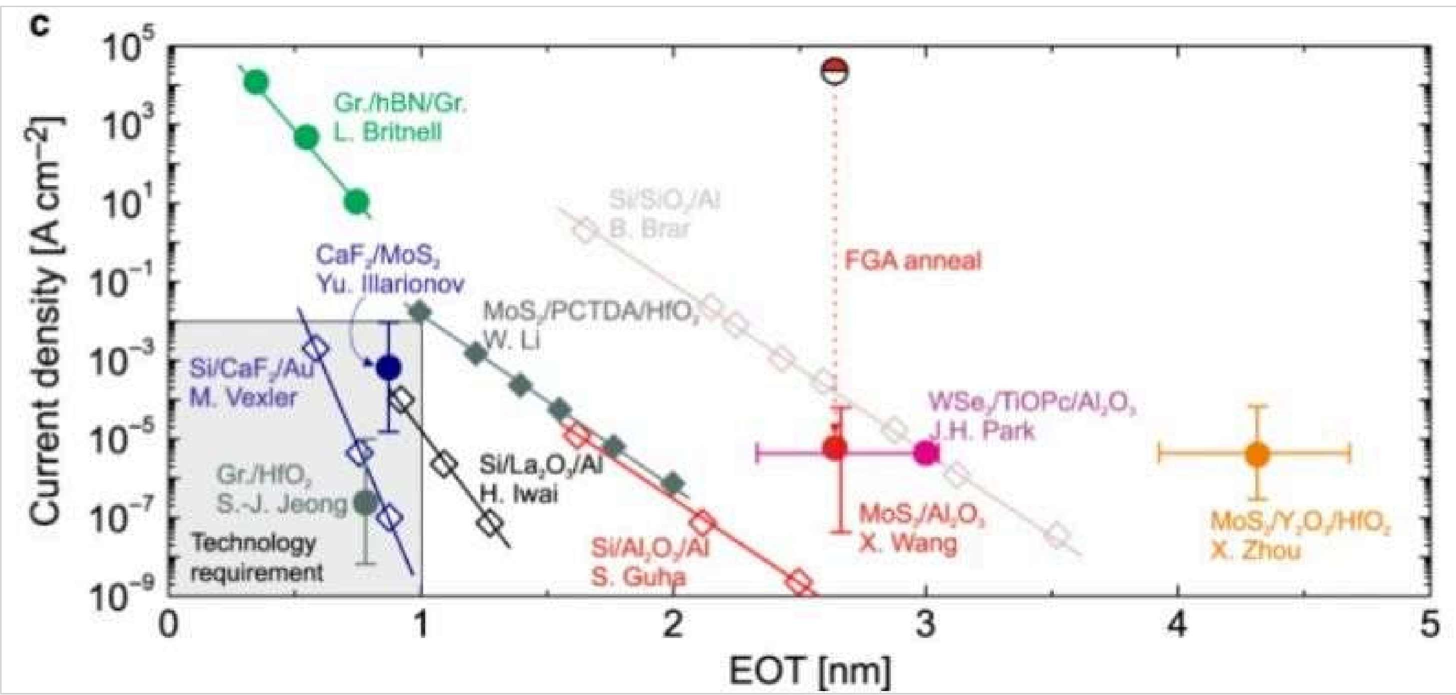
Recently, researchers from the University of Illinois sought to solve this challenge from an unlikely source: coal. Why does coal hold so much promise in this field, and how did researchers harness this potential?

Insulators for 2D Nanoelectronics

One key challenge in 2D nanoelectronics is developing insulators that can withstand high electric fields without breaking down while also being thin enough to fit into the ever-shrinking architectures of modern nanoelectronics. Additionally, these materials must be uniform in thickness and free from defects to prevent performance degradation.

Unfortunately, traditional insulator materials, such as silicon dioxide, have limitations regarding how thin they can be made without losing their insulating properties. This has led researchers to explore alternative materials that meet next-generation electronics' stringent demands.

Surprisingly, coal, a material traditionally associated with energy production and environmental concerns, is emerging as a potential solution.



Transistor gate leakages versus equivalent oxide thickness. Image used courtesy of Illarionov et al.

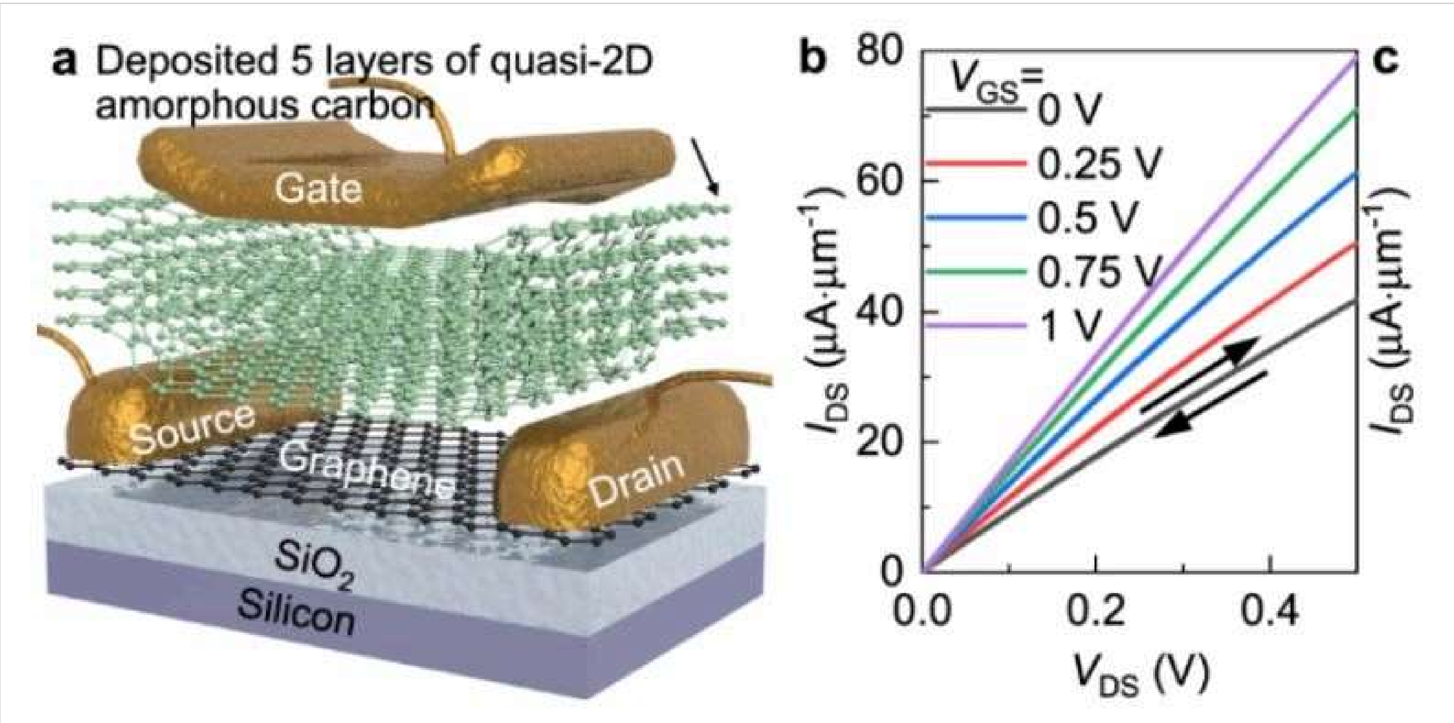
Coal contains carbon, a versatile element that forms the basis of many advanced materials, including graphene. Innovative processing techniques can transform coal into carbon-based materials suitable for ultra-thin insulators. These carbon derivatives possess the desired properties for nanoelectronics: they can be made atomically thin, are electrically robust, and can be produced with high uniformity and low defect density.

Furthermore, using coal for nanoelectronics could provide an environmentally friendly way to repurpose this abundant natural resource, aligning technological advancement with sustainability goals.

Coal as an Insulator

Recently, researchers developed a method to transform coal into ultra-thin, highly efficient insulating layers for use in nanoelectronics.

Their research focused on converting coal char into carbon dots, which are then used to create atomically thin carbon nanomembranes. These membranes, with a thickness of just 1-2 atomic layers, are derived from high-purity coal char mined from angstrom or nanometer-sized aromatic sp2 carbon domains. The carbon dots, averaging 0.42 nm thick, are assembled into a quasi-monolayer via spin coating on a wafer substrate. This process results in films with a uniform thickness fluctuation of 1-2 atomic layers.



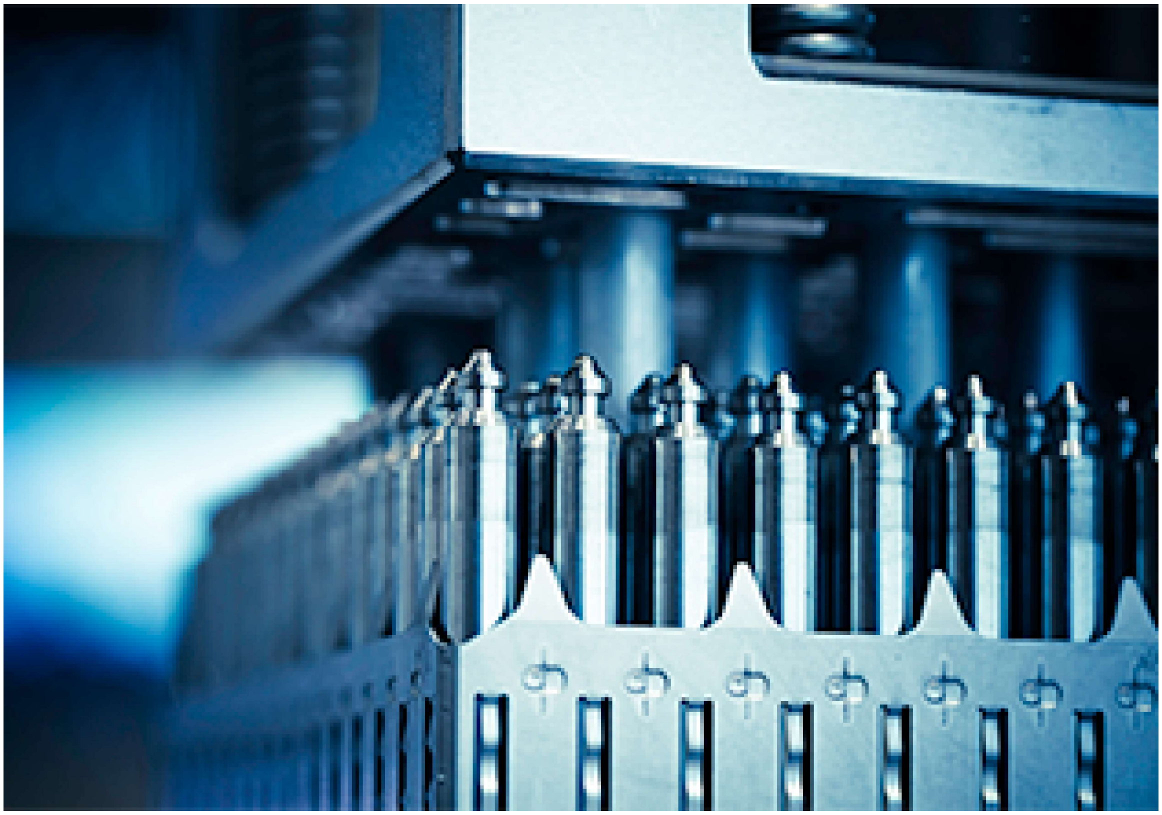
Schematic of the coal-based transistor and the device's output characteristics. Image used courtesy of An et al.

A key aspect of this research is the scalability and uniformity of film production. The process enables the creation of large-area freestanding carbon films, covering 3-inch wafers with a dielectric strength above 20 MV cm−1 and leakage current density below 10−4 A cm−2. These films demonstrate impressive mechanical strength with Young's modulus of approximately 400 ± 100 GPa.

With a total thickness of approximately 2.4 nm, these films were integrated as top-gate dielectrics in graphene transistors. The resulting device showed an on-state conductance above 250 µS µm−1, a 10x better transconductance, and reduced hysteresis compared to traditional dielectrics.

Impacting Nanoelectronics

The research could significantly impact the nanoelectronics industry. The quasi-2D amorphous carbon films created from coal-derived carbon dots exhibit exceptional dielectric properties, making them ideal for use in transistors and memristors. Additionally, this approach has the benefit of repurposing a traditional fossil fuel in a sustainable and cost-effective way.



Small Modular Reactors Demand Advanced Data-Acquisition

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