Arizona State University developing transistors made of diamond and boron nitride

Advanced Materials, Processes and Energy Devices Science and Technology Center working on project with Northrop Grumman Mission Systems.

Power transistors to regulate the flow of electrical power have traditionally been made with silicon, while more advanced transistors are made of silicon carbide (SiC) or gallium nitride (GaN). But Trevor Thornton, a professor of electrical engineering in Arizona State University's School of Electrical, Computer and Energy Engineering (part of the Ira A. Fulton Schools of Engineering), is leading a team researching the use of two new transistor materials: diamond and boron nitride (BN).

Thornton's team is conducting its research through ASU's Advanced Materials, Processes, and Energy Devices Science and Technology Center (AMPED STC). AMPED's goal is to develop materials and technologies with industry partners to support the mission of Arizona's New Economy Initiative, which aims to improve Arizona's competitiveness in developing advanced technology. AMPED specifically looks to develop technologies and materials used in the construction of batteries, solar electricity generation and power electronics.

The research team includes Thornton and other ASU faculty members including Terry Alford, a professor of materials science and engineering, Stephen Goodnick, a professor of electrical engineering, and Robert Nemanich, a Regents Professor of physics, as well as doctoral students in electrical engineering and materials science and engineering. They are working with Northrop Grumman Mission Systems as the industry partner for the project.

Diamond efficiency shines

Thornton says that diamond is under investigation as a material for transistors because of its high thermal conductivity compared with existing materials, e.g. 8–10 times greater than gallium nitride. Harnessing diamond's full potential could shrink the size of transistors by 90%, it is reckoned.

Diamond also has a high breakdown field — i.e. it can handle a high voltage relative to most materials before failure — suitable for applications that handle large amounts of power.

While diamond is the team's chosen material for the main body of a transistor, they are investigating the use of boron nitride for the transistors' electrical contacts.

Like diamond, boron nitride has a high breakdown field and high thermal conductivity. Goodnick's role is concerned primarily with computer modeling and simulation of the use of boron nitride transistors.

The team expects that, by combining their knowledge of how diamond and boron nitride work as transistor materials, they can create transistors made from both materials. The hope is that the materials complement each other and work even better together than individually.

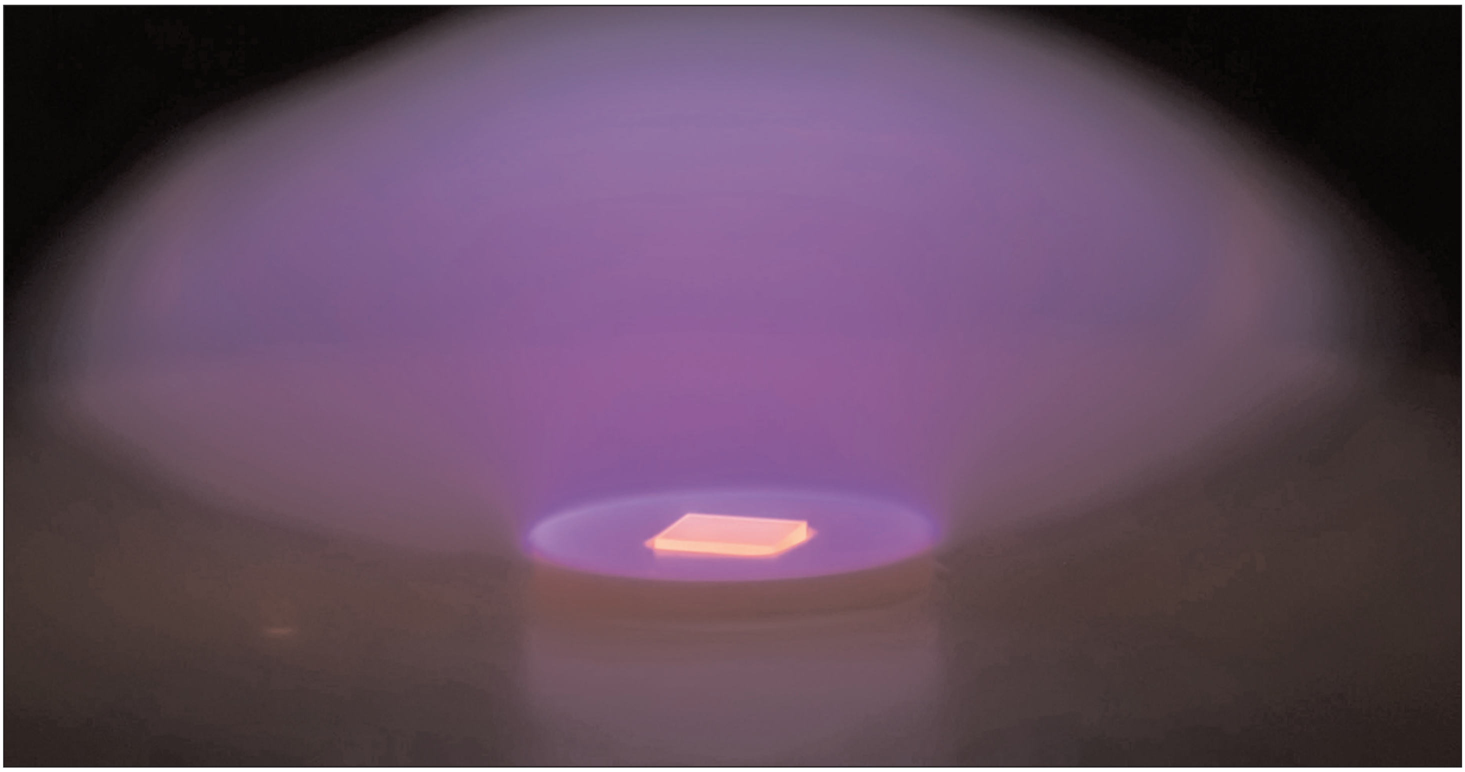
"Ultra-wide-bandgap semiconductor materials like diamond and boron nitride are expected to lead to more efficient energy conversion using less power with much smaller components," Goodnick says. "This improves the future energy grid, which is essential for the ongoing transition toward renewable energy and electrification of the transportation sector."

Better heat dissipation to improve communication

This research has applications that would be especially useful to communications technologies, says the team Many satellites run on solar power, which requires transistors to turn the electricity into a form usable by the satellite. "You can't launch a power substation into space," Thornton says. "Any improvement on size and weight in a satellite has a huge impact."

Another communications technology the transistors could improve is the cell-phone tower. Transistors convert power to the form needed to produce radio frequency waves that cell phones use.

One of the biggest challenges faced when designing and operating cell-phone towers is keeping them cool, notes Thornton. This is especially the case in a hot environment like Phoenix.



The power transistors in older cell-phone towers are typically made from silicon, while those in newer 5G systems will use gallium nitride. Thanks to its improved heat dissipation, Thornton's team expects transistors made from diamond and boron nitride to greatly reduce the cooling power needed for cell towers, making it far easier to prevent them from overheating.

Shrinking substations

While the project with Northrop Grumman Mission Systems focuses on communications technology, transistors made from diamond and boron nitride also have applications in power conversion for electrical systems and for the electricity grid. These more efficient materials could reduce the size requirements for electricity grid substations, which typically occupy an area of land the size of a building.

Nemanich, a faculty member in the ASU Department of Physics, leads the 'Ultra Materials for a Resilient, Smart Electricity Grid' (ULTRA) Energy Frontier Research Center (EFRC) conducting research on power electronics. He also leads a lab for growing artificial diamond materials, which will be used by Thornton's team in their research.

"We have been growing diamond for electronic devices for the last 10 years," Nemanich says. "Our diamond deposition lab has unique capabilities for the development of electronic materials and devices," he believes.

Interdisciplinary effort

In addition to Thornton's electrical engineering expertise and Nemanich's work with diamond as an electronic material, Alford, a faculty member in the School for Engineering of Matter, Transport and Energy (part of the Fulton Schools), provides his expertise on materials science.

Alford is working on materials characterization, analyzing the properties of the materials that the team is investigating. He also leads a part of the research looking into the use of new types of metallic electrical contacts connected to diamond as a substrate, and he co-advises a materials science and engineering doctoral student involved in the research with Thornton.

Working with Thornton's team at the AMPED STC has given Alford the chance to conduct research that differs from his normal topics. He believes that his perspective as a materials scientist can help the team to achieve its goals. "We bring to the table a desire to understand the impact of a material's defects," Alford says. "We want to be able to understand those defects and how they impact a device's performance."

Looking to the future of electronics

The transistor research project is funded for two years through the AMPED STC partnership with Northrop Grumman Mission Systems. However, to fully realize the transistors' potential for widespread applications, Thornton says it could take longer.

"We'll have breakthroughs, but I don't see it being widely adopted in the way we're talking about for five to 10 years," he says. "It's that kind of medium- to long-term research of which some applications will happen quicker, while others will be 10 years for widespread consumer applications." ■

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