How Gallium Nitride Could Transform Space Exploration

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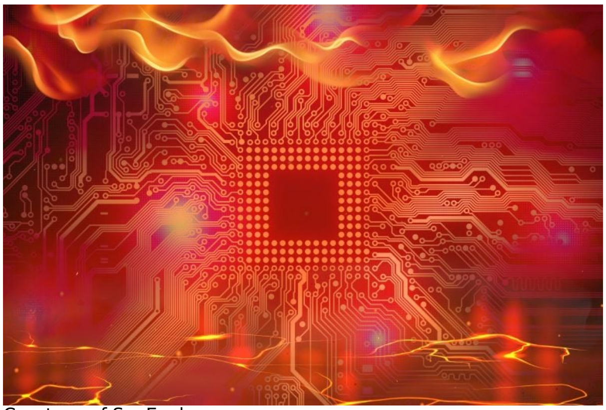
Courtesy of SynEvol

A recent study by MIT and other institutions demonstrated that this material, together with its ohmic connections, remained structurally robust at these high temperatures. The work involves creating gallium nitride devices and testing them at high temperatures, which yielded encouraging results for future electronics in severe situations.

Venus' scorching surface can reach temperatures of 480° Celsius /900° Fahrenheit, which is hot enough to melt lead. This makes it unfriendly to both humans and machines. One reason scientists have not yet been able to send a rover to the planet's surface is that silicon-based electronics cannot operate in such severe temperatures for long periods of time.

For high-temperature applications like as Venus exploration, researchers have recently turned to gallium nitride, a unique material that can tolerate temperatures of 500 degrees or higher.

The material is already used in some terrestrial electronics, like as phone chargers and mobile phone towers, but scientists aren't sure how gallium nitride devices will perform at temperatures above 300 degrees, which is the operational limit of traditional silicon electronics.

In a new paper published in the journal Applied Physics Letters as part of a multiyear research effort, scientists from the Massachusetts Institute of Technology (MIT) and other institutions attempted to answer key questions about the material's properties and performance at extreme temperatures.

They investigated the effect of temperature on the ohmic connections in a gallium nitride device. Ohmic contacts are essential components that connect a semiconductor device to the outside environment.

The researchers discovered that severe temperatures did not significantly degrade the gallium nitride material or connections. They were shocked to see that even after 48 hours at 500 degrees Celsius, the connections remained structurally intact.

Understanding how contacts behave at extreme temperatures is a key step toward the group's next goal, which is to construct high-performance transistors capable of operating on Venus's surface. Such transistors could also be employed in Earth-based electronics for applications such as geothermal energy extraction and monitoring the innards of jet engines.

"Transistors are at the heart of most modern electronics, but we didn't want to rush into developing a gallium nitride transistor because so many things could go wrong. We first wanted to ensure that the material and contacts could survive, as well as determine how much they changed as the temperature increased. We'll develop our transistor from these basic material building parts," explains John Niroula, a graduate student in electrical engineering and computer science (EECS).

His co-authors include Qingyun Xie PhD '24; Mengyang Yuan PhD '22; EECS graduate students Patrick K. Darmawi-Iskandar and Pradyot Yadav; Gillian K. Micale, a graduate student in the Department of Materials Science and Engineering; senior author Tomás Palacios, the Clarence J. LeBel Professor of EECS, director of the Microsystems Technology Laboratories, and a member of the Research Laboratory of Electronics; and collaborators Nitul S. Rajput of the Technology Inno

While gallium nitride has recently received a lot of attention, scientists still don't fully grasp how its characteristics alter under different conditions. One such feature is resistance, which refers to the flow of electrical current through a substance.

The overall resistance of a device varies inversely with its size. However, gadgets such as semiconductors include connections that allow them to communicate with other electronic components. Contact resistance, induced by these electrical connections, is constant regardless of the device's size. Too much contact resistance can cause increased power dissipation and slower operating frequencies in electrical circuits.

"Contact resistance frequently limits a device's performance, especially when dimensions decrease. People have a decent understanding of contact resistance at ambient temperature, but no one has researched what occurs when the temperature rises to 500 degrees," Niroula explains.

For their investigation, the researchers employed MIT.nano resources to construct gallium nitride devices known as transfer length method structures, which are made up of a series of resistors. These gadgets allow them to measure the resistance of both the substance and the contacts.

They introduced ohmic connections to these devices using two standard approaches. The first step is to deposit metal onto gallium nitride and heat it to 825 degrees Celsius for around 30 seconds, a process known as annealing.

The second way includes removing portions of gallium nitride and replacing them with highly doped gallium nitride using high-temperature technology, which is being spearheaded by Rajan and his Ohio State team. The heavily doped material includes extra electrons, which can help with current conduction.

"The regrowth method typically leads to lower contact resistance at room temperature, but we wanted to see if these methods still work well at high temperatures," Niroula told me.

They tested the devices in two ways. Their Rice University collaborators, led by Zhao, conducted short-term testing by placing devices on a hot chuck heated to 500 degrees Celsius and measuring resistance immediately.

At MIT, they carried out longer-term trials by inserting gadgets into a previously created specialized furnace. They placed devices inside for up to 72 hours to see how resistance changes with temperature and time.

Microscopy scientists at MIT.nano (Aubrey N. Penn) and the Technology Innovation Institute (Nitul S. Rajput) employed cutting-edge transmission electron microscopes to investigate how high temperatures affect gallium nitride and ohmic connections at the atomic level.

"We expected the connections or the gallium nitride material to degrade dramatically, but we observed the reverse. "Contacts made using both methods appeared to be remarkably stable," says Niroula.

While it is difficult to measure resistance at such high temperatures, their findings show that contact resistance appears to remain constant for approximately 48 hours at temperatures of 500 degrees. And, like at ambient temperature, the regeneration process resulted in improved performance.

Although the material began to disintegrate after 48 hours in the furnace, the researchers are now striving to improve its long-term performance. One method is to install protective insulators to prevent the material from being directly exposed to the high-temperature environment.

The scientists intend to leverage what they learnt in these tests to construct high-temperature gallium nitride transistors.

"Our group focuses on innovative, device-level research to advance the frontiers of microelectronics, while using a methodical approach across the hierarchy, from material to circuit level. We've gone all the way down to the material level to have a thorough understanding. In other words, we used design, modeling, and complicated fabrication to transfer device-level advancements into circuit-level impact for high-temperature electronics. We are also really lucky to have formed deep relationships with our long-term collaborators on this trip," Xie says.
