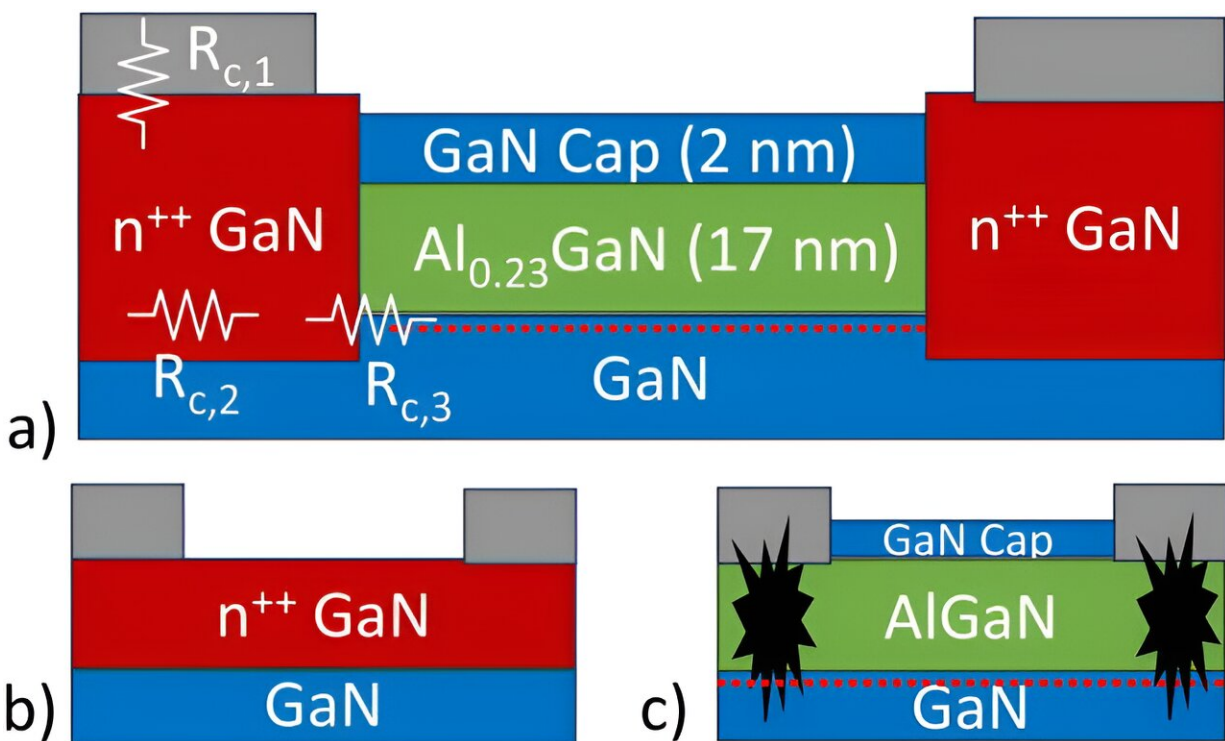


Researchers investigate properties of novel materials for electronics operating in extremely hot environments

May 23 2024, by Adam Zewe



Structures of AlGaN/GaN TLMs studied in this work. (a) Selectively regrown n^{++} ($[\text{Si}] \geq 1 \times 10^{20} \text{ cm}^{-3}$) GaN contacts in the Ohmic region only with the different contributions of the contact resistances $R_{c,1}$, $R_{c,2}$, and $R_{c,3}$ labeled. (b) Regrown n^{++} GaN over entire TLM region. (c) Ti/Al/Ni/Au alloyed contacts. Credit: *Applied Physics Letters* (2024). DOI: 10.1063/5.0191297

The scorching surface of Venus, where temperatures can climb to 480°C (hot enough to melt lead), is an inhospitable place for humans and machines alike. One reason scientists have not yet been able to send a rover to the planet's surface is that silicon-based electronics can't operate in such extreme temperatures for an extended period of time.

For high-temperature applications like Venus exploration, researchers have recently turned to gallium nitride, a unique material that can withstand temperatures of 500° or more.

The material is already used in some terrestrial electronics, like phone chargers and cell phone towers, but scientists don't have a good grasp of how gallium nitride devices would behave at temperatures beyond 300°, which is the operational limit of conventional silicon electronics.

In a [new paper](#) published in *Applied Physics Letters*, which is part of a multiyear research effort, a team of scientists from MIT and elsewhere sought to answer key questions about the material's properties and performance at extremely high temperatures.

They studied the impact of temperature on the ohmic contacts in a gallium nitride device. Ohmic contacts are key components that connect a [semiconductor device](#) with the outside world.

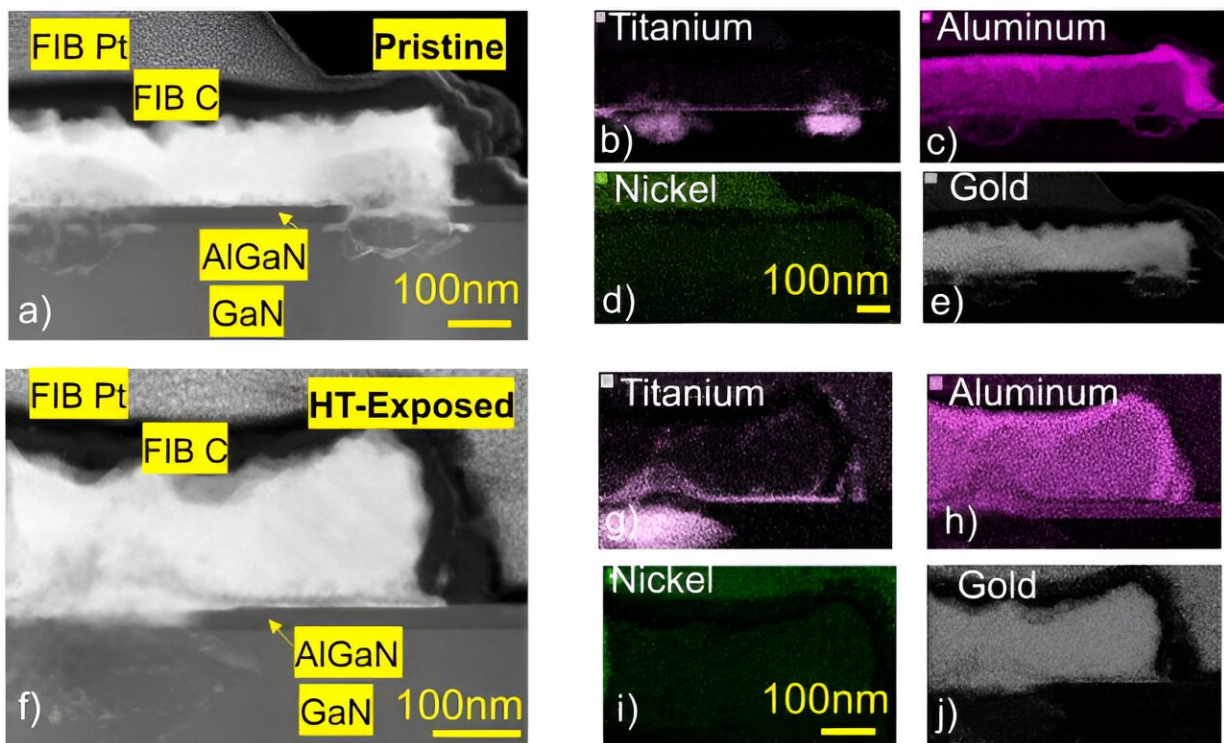
The researchers found that extreme temperatures didn't cause significant degradation to the gallium nitride material or contacts. They were surprised to see that the contacts remained structurally intact even when held at 500°C for 48 hours.

Understanding how contacts perform at [extreme temperatures](#) is an important step toward the group's next goal of developing high-performance transistors that could operate on the surface of Venus. Such transistors could also be used on Earth in electronics for applications like

extracting geothermal energy or monitoring the inside of jet engines.

"Transistors are the heart of most modern electronics, but we didn't want to jump straight to making a gallium nitride transistor because so much could go wrong. We first wanted to make sure the material and contacts could survive, and figure out how much they change as you increase the temperature.

"We'll design our transistor from these basic material building blocks," says John Niroula, an [electrical engineering](#) and computer science (EECS) graduate student and lead author of the paper.



TEM of the pristine and HT treated (72 h at 500 °C in N₂ ambient) alloyed contacts. (a) TEM image and (b)–(e) EDS elemental mappings of a pristine alloyed contact before any high temperature testing. (f) TEM image and (g)–(j) EDS element mapping of an alloyed contact TLM after 72 h at 500 °C. Credit:

Turning up the heat

While gallium nitride has recently attracted much attention, the material is still decades behind silicon when it comes to scientists' understanding of how its properties change under different conditions. One such property is resistance, the flow of electrical current through a material.

A device's overall resistance is inversely proportional to its size. But devices like semiconductors have contacts that connect them to other electronics. Contact resistance, which is caused by these electrical connections, remains fixed no matter the size of the device. Too much contact resistance can lead to higher power dissipation and slower operating frequencies for electronic circuits.

"Especially when you go to smaller dimensions, a device's performance often ends up being limited by contact resistance. People have a relatively good understanding of contact resistance at room temperature, but no one has really studied what happens when you go all the way up to 500°," Niroula says.

For their study, the researchers used facilities at MIT.nano to build gallium nitride devices known as transfer length method structures, which are composed of a series of resistors. These devices enable them to measure the resistance of both the material and the contacts.

They added ohmic contacts to these devices using the two most common methods. The first involves depositing metal onto gallium nitride and heating it to 825°C for about 30 seconds, a process called annealing.

The second method involves removing chunks of gallium nitride and using a high-temperature technology to regrow highly doped gallium nitride in its place, a process led by Rajan and his team at Ohio State. The highly doped material contains extra electrons that can contribute to 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 says.

A comprehensive approach

They tested devices in two ways. Their collaborators at Rice University, led by Zhao, conducted short-term tests by placing devices on a hot chuck that reached 500°C and taking immediate resistance measurements.

At MIT, they conducted longer-term experiments by placing devices into a specialized furnace the group previously developed. They left devices inside for up to 72 hours to measure how resistance changes as a function of temperature and time.

Microscopy experts at MIT.nano (Aubrey N. Penn) and the Technology Innovation Institute (Nitul S. Rajput) used state-of-the-art transmission electron microscopes to see how such high temperatures affect gallium nitride and the ohmic contacts at the [atomic level](#).

"We went in thinking the contacts or the gallium nitride material itself would degrade significantly, but we found the opposite. Contacts made with both methods seemed to be remarkably stable," says Niroula.

While it is difficult to measure resistance at such high temperatures, their results indicate that contact [resistance](#) seems to remain constant

even at temperatures of 500°, for around 48 hours. And just like at [room temperature](#), the regrowth process led to better performance.

The material did start to degrade after being in the furnace for 48 hours, but the researchers are already working to boost long-term performance. One strategy involves adding protective insulators to keep the material from being directly exposed to the high-temperature environment.

Moving forward, the researchers plan to use what they learned in these experiments to develop high-temperature [gallium nitride](#) transistors.

"In our group, we focus on innovative, device-level research to advance the frontiers of microelectronics, while adopting a systematic approach across the hierarchy, from the material level to the circuit level. Here, we have gone all the way down to the material level to understand things in depth.

"In other words, we have translated device-level advancements to circuit-level impact for high-temperature electronics, through design, modeling and complex fabrication. We are also immensely fortunate to have forged close partnerships with our longtime collaborators in this journey," Xie says.

More information: John Niroula et al, High temperature stability of regrown and alloyed Ohmic contacts to AlGaN/GaN heterostructure up to 500°C, *Applied Physics Letters* (2024). [DOI: 10.1063/5.0191297](https://doi.org/10.1063/5.0191297)

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