

Device could dramatically cut energy waste in electric vehicles, data centers, and the power grid

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MIT postdoc Yuhao Zhang, handles a wafer with hundreds of vertical gallium nitride power devices fabricated from the Microsystems Technology Laboratories production line. Credit: Yuhao Zhang

Power electronics, which do things like modify voltages or convert between direct and alternating current, are everywhere. They're in the power bricks we use to charge our portable devices; they're in the battery packs of electric cars; and they're in the power grid itself, where they mediate between high-voltage transmission lines and the lower voltages of household electrical sockets.

Power conversion is intrinsically inefficient: A power converter will never output quite as much power as it takes in. But recently, power converters made from [gallium](#) nitride have begun to reach the market, boasting higher efficiencies and smaller sizes than conventional, silicon-based power converters.

Commercial gallium nitride power devices can't handle voltages above about 600 volts, however, which limits their use to household electronics.

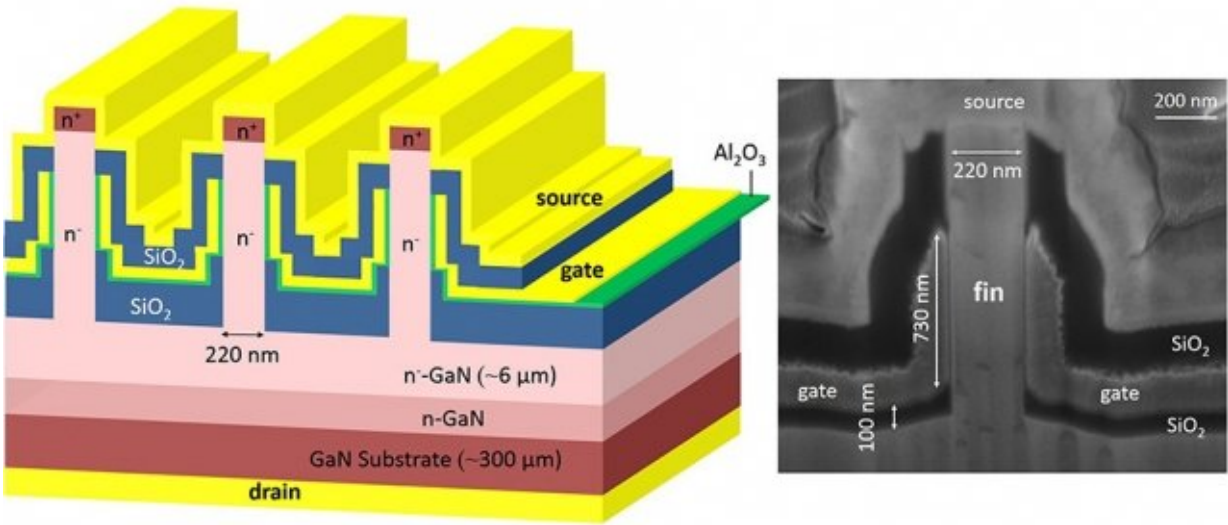
At the Institute of Electrical and Electronics Engineers' International Electron Devices Meeting this week, researchers from MIT, semiconductor company IQE, Columbia University, IBM, and the Singapore-MIT Alliance for Research and Technology, presented a new design that, in tests, enabled gallium nitride power devices to handle voltages of 1,200 volts.

That's already enough capacity for use in electric vehicles, but the researchers emphasize that their [device](#) is a first prototype manufactured in an academic lab. They believe that further work can boost its capacity to the 3,300-to-5,000-volt range, to bring the efficiencies of gallium nitride to the [power electronics](#) in the electrical grid itself.

That's because the new device uses a fundamentally different design from existing gallium nitride power electronics.

"All the devices that are commercially available are what are called lateral devices," says Tomás Palacios, who is an MIT professor of electrical engineering and computer science, a member of the Microsystems Technology Laboratories, and senior author on the new paper. "So the entire device is fabricated on the top surface of the gallium nitride wafer, which is good for low-power applications like the laptop charger. But for medium- and high-[power](#) applications, vertical devices are much better. These are devices where the current, instead of flowing through the surface of the semiconductor, flows through the wafer, across the semiconductor. Vertical devices are much better in terms of how much voltage they can manage and how much current they control."

For one thing, Palacios explains, current flows into one surface of a vertical device and out the other. That means that there's simply more space in which to attach input and output wires, which enables higher current loads.



“Instead of doing the complicated zigzag path for the current in conventional vertical transistors,” Professor Tomás Palacios says, “let’s change the geometry of the transistor completely.” Their vertical gallium nitride transistors have bladelike protrusions on top, known as “fins.” The narrowness of the fin ensures that the gate electrode will be able to switch the transistor on and off. Credit: Massachusetts Institute of Technology

For another, Palacios says, "when you have lateral devices, all the current flows through a very narrow slab of material close to the surface. We are talking about a slab of material that could be just 50 nanometers in thickness. So all the current goes through there, and all the heat is being generated in that very narrow region, so it gets really, really, really hot. In a vertical device, the current flows through the entire wafer, so the heat dissipation is much more uniform."

Narrowing the field

Although their advantages are well-known, vertical devices have been difficult to fabricate in gallium nitride. Power electronics depend on transistors, devices in which a charge applied to a "gate" switches a semiconductor material—such as silicon or gallium nitride—between a conductive and a nonconductive state.

For that switching to be efficient, the current flowing through the semiconductor needs to be confined to a relatively small area, where the gate's electric field can exert an influence on it. In the past, researchers had attempted to build vertical transistors by embedding physical barriers in the gallium nitride to direct current into a channel beneath the gate.

But the barriers are built from a temperamental material that's costly and difficult to produce, and integrating it with the surrounding gallium nitride in a way that doesn't disrupt the transistor's electronic properties has also proven challenging.

Palacios and his collaborators adopt a simple but effective alternative. The team includes first authors Yuhao Zhang, a postdoc in Palacios's lab, and Min Sun, who received his MIT PhD in the Department of Electrical Engineering and Computer Science (EECS) last spring; Daniel Piedra and Yuxuan Lin, MIT graduate students in EECS; Jie Hu, a postdoc in Palacios's group; Zhihong Liu of the Singapore-MIT Alliance for Research and Technology; Xiang Gao of IQE; and Columbia's Ken Shepard.

Rather than using an internal barrier to route current into a narrow region of a larger device, they simply use a narrower device. Their vertical [gallium nitride](#) transistors have bladelike protrusions on top, known as "fins." On both sides of each fin are electrical contacts that

together act as a gate. Current enters the transistor through another contact, on top of the fin, and exits through the bottom of the device. The narrowness of the fin ensures that the gate electrode will be able to switch the transistor on and off.

"Yuhao and Min's brilliant idea, I think, was to say, 'Instead of confining the current by having multiple materials in the same wafer, let's confine it geometrically by removing the material from those regions where we don't want the current to flow,'" Palacios says. "Instead of doing the complicated zigzag path for the current in conventional vertical transistors, let's change the geometry of the transistor completely."

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