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Discovery in gallium nitride a key enabler of energy efficient electronics

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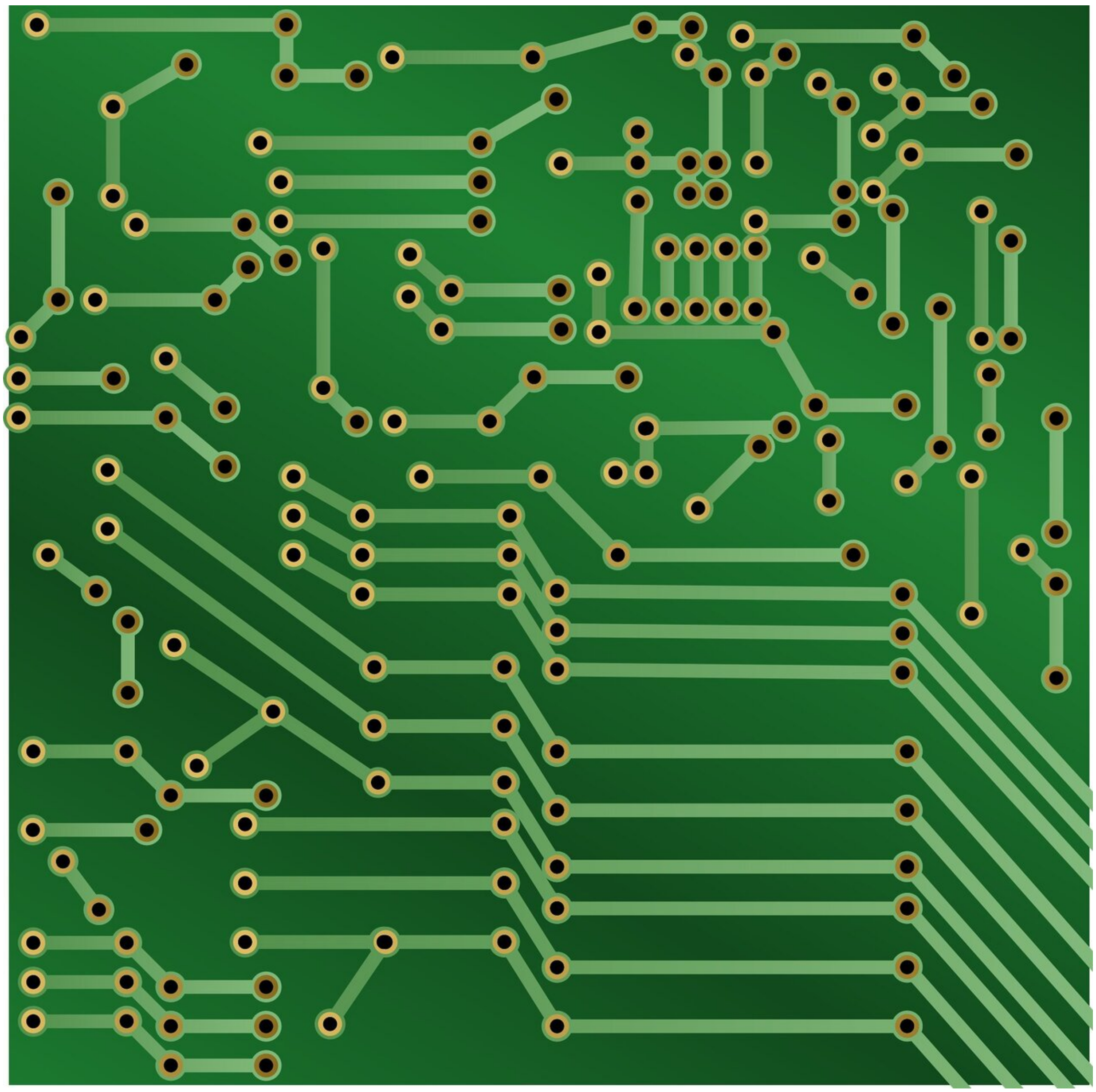

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Gallium nitride, a semiconductor that revolutionized energy-efficient LED lighting, could also transform electronics and wireless communication, thanks to a discovery made by Cornell researchers.

Their paper, "A Polarization-Induced 2-D Hole Gas in Undoped Gallium Nitride Quantum Wells," was published Sept. 26 in *Science*.

Silicon has long been the king of semiconductors, but it has had a little help. The pure material is often augmented, or "doped," with impurities like phosphorus or boron to enhance current flow by providing negative charges (electrons) or positive charges ("holes," the absence of electrons) as needed.

In recent years, a newer, sturdier family of lab-grown compound semiconductor materials has emerged: group III-nitrides. Gallium nitride (GaN) and aluminum nitride (AlN) and their alloys have a wider bandgap, allowing them to withstand greater voltages and higher frequencies for faster, more efficient energy transmission.

"Silicon is very good at switching off and on and controlling electrical energy flow, but when you take it to high voltages it doesn't operate very well because silicon has a weak electric strength, whereas GaN can sustain much higher electric fields," said co-senior author Debdeep Jena, professor of electrical and computer engineering and of materials science and engineering "If you're doing very large amounts of energy conversion, then wide-bandgap semiconductors such as GaN and silicon carbide are the solutions."

Rather than using impurities, Ph.D. student Reet Chaudhuri, the paper's lead author, stacked a thin GaN crystal layer—called a quantum well—atop an AlN crystal, and the difference in their crystal structures was found to generate a high density of mobile holes. Compared with magnesium-doping, the researchers discovered that the resulting 2-D hole gas makes the GaN structures almost 10 times more conductive.

Using the new material structure created by Chaudhuri, co-author and Ph.D. student Samuel James Bader recently demonstrated some of the most efficient p-type GaN transistors in a collaborative project with Intel. Now that the team has the capability to make hole-channel transistors—which are called p-type—they plan to pair them with n-type transistors to form more complex circuits, opening up new possibilities in high-power switching, 5G cellular technology and energy efficient electronics, including phone and laptop chargers.

"It's very difficult to simultaneously achieve n-type and p-type in a wide bandgap semiconductor. Right now, silicon carbide is the only other one that has both besides GaN. But the mobile electrons in silicon carbide are more sluggish than those in GaN," said co-senior author Huili Grace Xing, professor of electrical and computer engineering and of materials science and engineering. "Using these complementary operations enabled by both n-type and p-type devices, much more energy efficient architecture can be built."

Another advantage of the 2-D hole gas is that its conductivity improves as the temperature is lowered, meaning that researchers will now be able to study fundamental GaN properties in ways that haven't been previously possible. Equally important is its ability to retain energy that would otherwise be lost in less efficient power systems.

A patent application has been filed through the Center for Technology Licensing for the discovery.

More information: "A polarization-induced 2D hole gas in undoped gallium nitride quantum wells" *Science* (2019). science.sciencemag.org/cgi/doi … 1126/science.aau8623

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