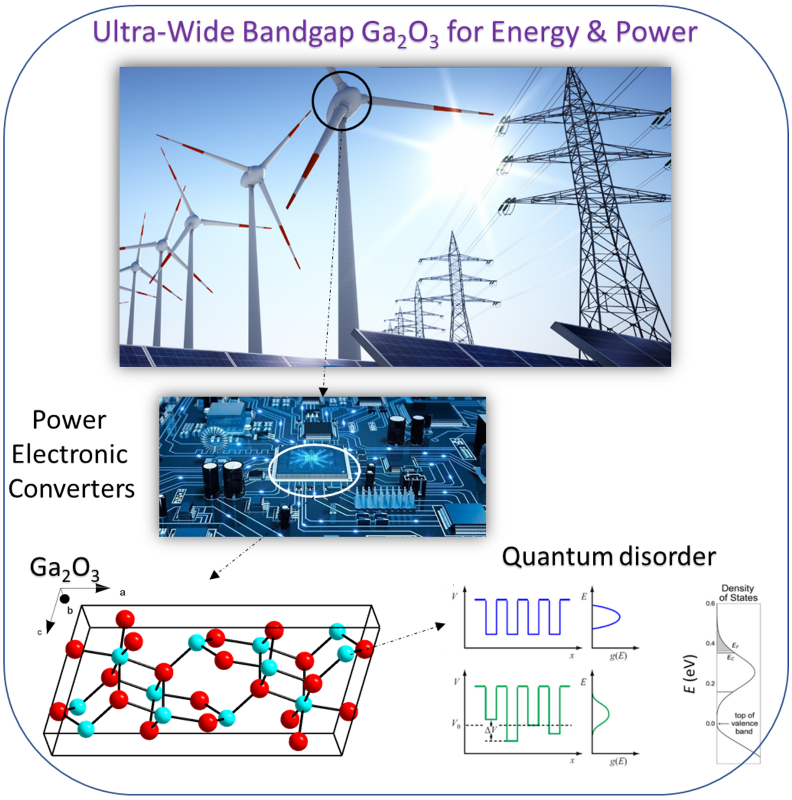
GEMaC
Groupe d’Étude
de la Matière Condensée

# PUSHING THE BOUNDARIES OF GAO TECHNOLOGY FOR ENERGY AND POWER ELECTRONICS THROUGH QUANTUM DISORDER

**A new study shows that, through phosphorus doping of -GaO, an exceptional p-type conductivity is obtained at room temperature, as well as a metal-insulator transition. These results open avenues for improving power electronics, essential to power grids and transport systems, and contributes to wider adoption of renewable energies.**

A new study explores the electrical and magneto-transport properties of -GaO through phosphorus implantation. It reveals exceptional p-type conductivity at room temperature, as well as a metal-insulator transition. These results shed light on the underlying conduction mechanisms in highly disordered systems. They also offer promising prospects for improving power electronic modules in critical applications—such as power grids and transport systems—where reliability and energy efficiency are essential.

In the long term, these advances could contribute to wider adoption of renewable energies by reducing energy losses in power conversion and management devices.



This research is set against the backdrop of reducing fossil fuel use and fighting climate change. For over a century, energy production has been mainly based on the consumption of fossil resources, which are not only finite but also major sources of pollution. As such, developing more efficient power electronics to control and convert electrical energy is crucial to reducing overall energy consumption.

In the energy chain—generation, transmission, storage, and usage—about 30% of electricity currently passes through power electronic components. This figure could rise to 80% within the next decade, given the growing power module market, projected to expand by 9.1% annually through 2025.
While silicon-based power electronics are widely used, they are limited by their low operating temperatures and breakdown voltages. In this context, the industrial development of modules based on wide-bandgap (WBG) semiconductors—such as GaN and SiC—is gaining momentum.

Beyond the typical 600 V / 1200 V applications covered by current WBG materials, other technological nodes (>3 kV) correspond to existing markets for high-voltage conversion and protection. These include power distribution, smart grids, onshore (3.3 kV) and offshore (6.5 kV) wind turbines, rail transport, and high-voltage (22 kV) electric vehicle

charging infrastructure.
To meet performance, reliability, and cost requirements, new platforms using ultra-wide bandgap (UWBG) semiconductor materials are being considered. Among these, monoclinic -GaO has recently drawn significant interest due to several advantages: the ability to grow bulk crystals, an ultra-wide bandgap (4.8 eV), and a very high critical electric field (>10 MV/cm).

To meet voltage requirements such as those of electric vehicles powered via high-voltage lines (22 kV), -GaO-based power electronics must be bipolar—i.e., support both n-type and p-type conductivity. However, achieving p-type conductivity in this material is a major challenge.

A new study led by researchers at GEMaC, in collaboration with international partners from the National Yang Ming Chiao Tung University (Taiwan), the Institute of Microelectronics of Barcelona (Spain), the Institute of Nanotechnology of Lyon, the Institute of Micro and Nanoelectronics (Georgia), Ivane Javakhishvili Tbilisi State University (Georgia), and Kwangwoon University (South Korea)—and involving three young researchers (two master's students and one postdoc)—has experimentally demonstrated effective p-type conductivity through phosphorus implantation, as well as a metal-insulator transition.
These observations were explained through theoretical simulations based on the Anderson disorder model.

The results of this study pave the way for achieving p-type conductivity in -GaO and potentially in other ultra-wide bandgap semiconductors. They also offer promising directions for improving power electronic modules in critical applications such as power infrastructure and transportation systems, where reliability and energy efficiency are key. Ultimately, these advances could facilitate a broader adoption of renewable energy by reducing energy losses in power conversion and energy management devices.

Reference :
Z. Chi et al., Anderson disorder related p-type conductivity and metal-insulator transition in -Ga2O3, Materials Today Physics **49**, 101602 (2024)