Ohio State uses modulation doping to demonstrate high electron mobility in gallium oxide

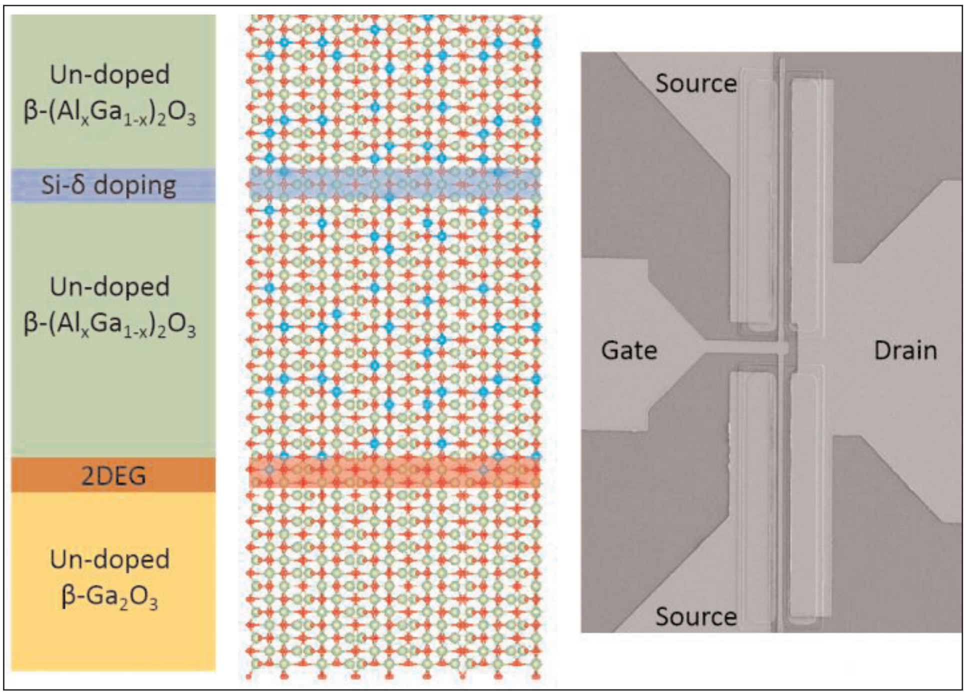
New β-$(Al_xGa_{1-x})_2O_3/Ga_2O_3$ quantum structures and electronics could yield high-frequency communication systems and energy-efficient power electronics

Ohio State University has shown that the wide-bandgap semiconductor gallium oxide (Ga_2O_3) can be engineered into nanometer-scale structures that allow increased mobility of electrons within the crystal structure (Yuewei Zhang et al, 'Demonstration of high mobility and quantum transport in modulation-doped β-$(Al_xGa_{1-x})_2O_3/Ga_2O_3$ heterostructures', Applied Physics Letters, vol112 (2018) 173502). Ga_2O_3 could hence be a promising material for applications such as high-frequency communication systems and energy-efficient power electronics, it is reckoned. "Gallium oxide has the potential to enable transistors that would surpass current technology," says Siddharth Rajan, who led the research.

Because Ga_2O_3 has one of the largest bandgaps of the wide-bandgap materials being developed as alternatives to silicon, it is especially useful for high-power and high-frequency devices. It is also unique among wide-bandgap semiconductors in that it can be produced directly from its molten form, which enables large-scale manufacturing of high-quality crystals.

For use in electronic devices, it is desirable a material to enable for high electron mobility under an electric field. Normally, to populate a semiconductor with electrons, the material is doped with other elements. However, the problem is that the dopants also scatter electrons, limiting electron mobility in the material.

To solve this problem, the researchers used modulation doping. The approach was first developed in 1979 by Takashi Mimura to create a gallium arsenide high-electron-mobility transistor (HEMT), which won the Kyoto Prize in 2017. While it is now a commonly used technique to achieve high mobility, its application to Ga_2O_3 is new.



Schematic stack and scanning electron microscopic image of β-$(Al_xGa_{1-x})_2O_3/Ga_2O_3$ modulation-doped field-effect transistor. Credit: Choong Hee Lee and Yuewei Zhang.

In their work, the researchers created a heterostructure interface between gallium oxide and its alloy aluminum gallium oxide, which has the same crystal structure but a different energy gap. A few nanometers away from the interface, embedded inside the aluminum gallium oxide is a sheet of electron-donating impurities only a few atoms thick. The donated electrons transfer into the Ga_2O_3, forming a two-dimensional electron gas (2DEG). However, because the electrons are now also separated from the dopants (hence the term modulation doping) in the aluminum gallium oxide by a few nanometers, the electrons scatter much less and remain highly mobile.

Using this technique, the researchers reached record mobilities. They were also able to observe Shubnikov–de Haas oscillations, a quantum phenomenon in which increasing the strength of an external magnetic field causes the resistance of the material to oscillate. These oscillations confirm the formation of the high-mobility 2D electron gas and allow the researchers to measure critical material properties.

Rajan says that such modulation-doped structures could lead to a new class of quantum structures and electronics that harnesses the potential of Ga_2O_3.

http://aip.scitation.org/doi/full/10.1063/1.5025704
https://nano.osu.edu