Energy Focus

Gallium nitride goes vertical

Although familiar to most as the workhorse material underpinning blue light-emitting diodes (LEDs), gallium nitride plays a critical role in many technologies beyond lighting. In particular, GaN-based transistors are well suited for high power applications, as these devices can function at much higher temperatures and voltages than other semiconductors.

However, commercial GaN-based power transistors are currently limited in application because the average electric field in these devices—typically planar high-electron-mobility transistors that exploit two-dimensional (2D) electron gas channels—is much lower than the critical field of GaN at the breakdown voltage. Ideally, the average field should be closer to the critical field, yielding higher power densities. This discrepancy prevents currently available GaN transistors from providing a performance advantage large enough to change the basis of power conversion from silicon-based devices to GaN-based devices.

Now, a team of researchers led by Umesh Mishra at the University of California–Santa Barbara (UCSB) has developed a new vertical GaN-based transistor design that enables high breakdown voltages with high current. This scheme allows for transistors with high power densities, which could lead to low-loss switches for power-conversion applications such as hybrid vehicles.

This transistor is called the current aperture vertical electron transistor, or CAVET. The CAVET structure combines a 2D electron gas with a vertical design that moves the peak electric field away from the surface (see Figure).

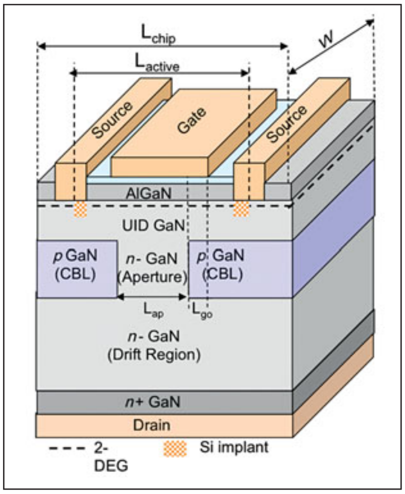
This design innovation allows the device to operate at higher average electric fields, closer to the critical field of the material. In addition, the breakdown voltage scales with the device thickness, resulting in higher power density. By marrying the best aspects of vertical and 2D design parameters, the CAVET structure increases the overall performance of GaN transistors.

In an article published in the May 5 online edition of *Applied Physics Letters* (DOI: 10.1063/1.4919866), Ramya Yeluri at UCSB, Mishra, and co-authors from UCSB and Arizona State University established the critical role the current blocking layer plays in device performance. The researchers demonstrate that planar regrowth of *p*-type GaN layers on *n*-type GaN layers resulted in high-quality junctions with high breakdown field strength. In particular, ammonia-based molecular beam epitaxy was used to grow over *p*-type areas while keeping these regions active.

The team also investigated the impact of two different growth techniques on breakdown voltages in CAVETs. When the material was grown selectively by molecular beam epitaxy, the edges adjacent to the mask were rough, causing low breakdown voltages. Metal–organic chemical vapor deposition, on the other hand, yielded smooth profiles at mask edges, but this smoothness likely resulted from redistribution of materials at the step edge. This resulted in low breakdown voltages, which could be improved from tens of volts to more than 500 V using various regrowth temperatures. Moving forward, the researchers say using an optimized regrowth temperature of *p*-type current blocking layers will yield high-voltage, low-loss CAVETs with good switching characteristics.

“When optimized, these devices will ultimately replace silicon-based devices primarily in applications from 5 kW and higher. The final target application is in the drive in electric vehicles and hybrid electric vehicles at the 50 kW to 100 kW levels,” said Mishra. “The ultimate goal is to reduce the losses to levels that allow a complete change in system design from water-cooled drives to ones that just require convection cooling.”

Aditi Risbud



Schematic showing the structure of the current aperture vertical electron transistor, or CAVET, consisting of the AlGaN/GaN heterojunction channel, the *p*-GaN current blocking layer (CBL) and aperture layer, and *n*-GaN drift region. Reprinted with permission from *Appl. Phys. Lett.* **106**, 183502 (2015), DOI: 10.1063/1.4919866. © 2015 AIP Publishing LLC.

Bio Focus

Electronic devices engineered to dissolve and disintegrate by thermal triggering

What if rigid and solid electronics could vanish before your eyes? An emerging class of electronic devices that could physically disappear or hydrolyze has been given the name of *transient electronics*. The rate of dissolution depends on the material used and properties such as film thickness, polymer crystallinity, and environmental conditions. All of these parameters could be engineered to enable programmable degradation of electronic devices.

In the May issue of *Advanced Materials* (DOI: 10.1002/adma.201501180), a team led by Scott R. White and John A. Rogers from the University of Illinois at Urbana-Champaign report thermal-triggered degradation of electronic devices based on temperature-sensitive wax coatings that release encapsulated acid microdroplets. These lead to the disintegration of both the circuit and substrate. “The wax encapsulation provides a simple and versatile approach for thermally triggered device destruction, and the destruction

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condition is controllable by tuning wax encapsulations," says Chan Woo Park, the lead author of this work. Above the wax melting temperature, the methanesulfonic acid that is encapsulated is released to rapidly degrade the magnesium electrodes and produce hydrogen gas. The hydrogen with methanesulfonic acid then initiates acidic depolymerization of the cyclic poly(phthalaldehyde) substrate and finally destroys the entire device.

By tuning the acid concentration, the trigger temperature, and the thickness of pure silicone wax, the researchers could adjust the transient time of simple magnesium resistors, arrays of silicon *p*-i-*n* diodes, and parallel light-emitting diode circuits with magnesium interconnect traces. Lower acid concentrations, lower trigger temperatures, and thicker wax layers all contribute to the delay of transient time. Silicone wax with different melting temperatures could also be used to tailor the trigger temperature threshold, providing another factor that gave researchers control over the structure. In addition, on-demand destruction is possible through wireless induction coupling. A self-destructive device with a Mg/SiO_2 /Mg resistive heater can be powered wirelessly using a magnesium inductive coil receiver to melt the wax coating and eventually lead to full device degradation.

"The activation of transience can be made by various stimuli like bio-fluid, UV, heat, or other chemical reactions," says Seung-Kyun Kang, an expert researcher in the field of transient electronics; "This kind of control could be useful to destroy the device on our demand to protect personal or military information. It is very closely related to hardware security applications. Also, this kind of trigger concept is very useful in the view of [a] drug release vehicle with bio-resorbable electronics as well."

YuHao Liu

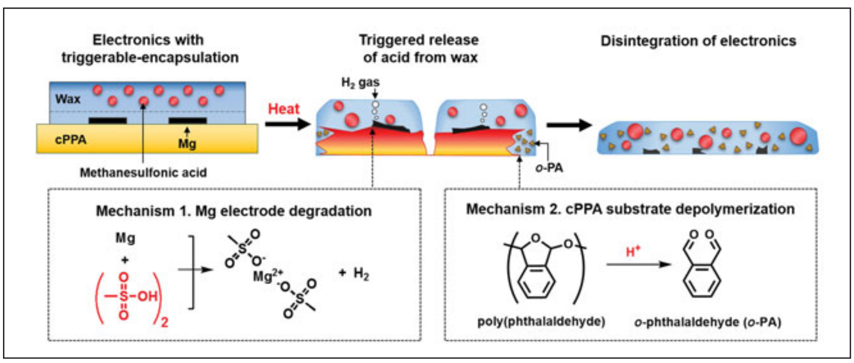

Illustration of thermally triggered degradation of electronic devices with encapsulated acid microdroplets. Mechanisms 1 and 2 show the key degradation and depolymerization process of the magnesium electrode and substrate to achieve full disintegration. Credit: Chan Woo Park.

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