

Diamond transistor achieves 1530V breakdown voltage

Researchers in Japan have more than doubled the breakdown voltages previously achieved for diamond-based transistors.

Japan's National Institute of Advanced Industrial Science and Technology (NAIST) has claimed the highest breakdown voltage to date for a diamond metal-semiconductor field-effect transistor (MESFET) [Hitoshi Umezawa et al, IEEE Electron Device Letters, published online 25 September 2014].

In principle, diamond transistors should benefit from high breakdown electric field, high thermal conductivity, low dielectric constant and high bulk carrier mobility. Such material properties could lead to high performance in terms of high-power and low-loss or high-power and high-frequency electronics.

High-temperature operation was also explored with a view to reducing or eliminating the need for complex and expensive thermal management.

The MESFETs were fabricated from microwave plasma-assisted chemical vapor deposition (MWCVD) p-type epitaxial material on semi-insulating Ib (001) synthetic diamond substrate (Figure 1). The carbon source was methane and the light p-type dopant was boron.

The researchers describe the boron doping as 'unintentional' at the level of $\sim 10^{15}$ atoms per cubic centimeter. The low doping level was aimed at preventing degradation of film quality and the Schottky contact.

The transistors were formed in circular 'Corbino type' configurations, with the ohmic drain contact in the center, the source contact on the outside, and the Schottky gate as a thin annulus between the source and drain. The ohmic metals were titanium gold.

The Schottky gate metal stack consisted of platinum/gold multi-layers. The gate region was exposed to ultraviolet light in ozone before the gate metal deposition. The pre-treatment was designed to give a stable oxygen termination of the surface bonds of the epitaxial layer.

The source-gate distance was fixed at $5\mu\text{m}$. The gate length and gate-drain distance were varied to allow optimization of various performance characteristics.

The maximum drain current and peak transconductance of $20\mu\text{m}$ -gate-length devices (gate-drain $30\mu\text{m}$) both increased as the temperature was raised from room temperature to 300°C . The drain currents were $-0.06\text{mA}/\text{mm}$ and $-1.23\text{mA}/\text{mm}$, respectively. The corresponding transconductances were $9.7\mu\text{S}/\text{mm}$ and $61\mu\text{S}/\text{mm}$. The increase in current is attributed to greater thermal activation of holes from the boron acceptor levels at 0.36eV ($360\text{meV} \gg 26\text{meV}$ gives low carrier density at room temperature). Another factor boosting the drive current, suggest the

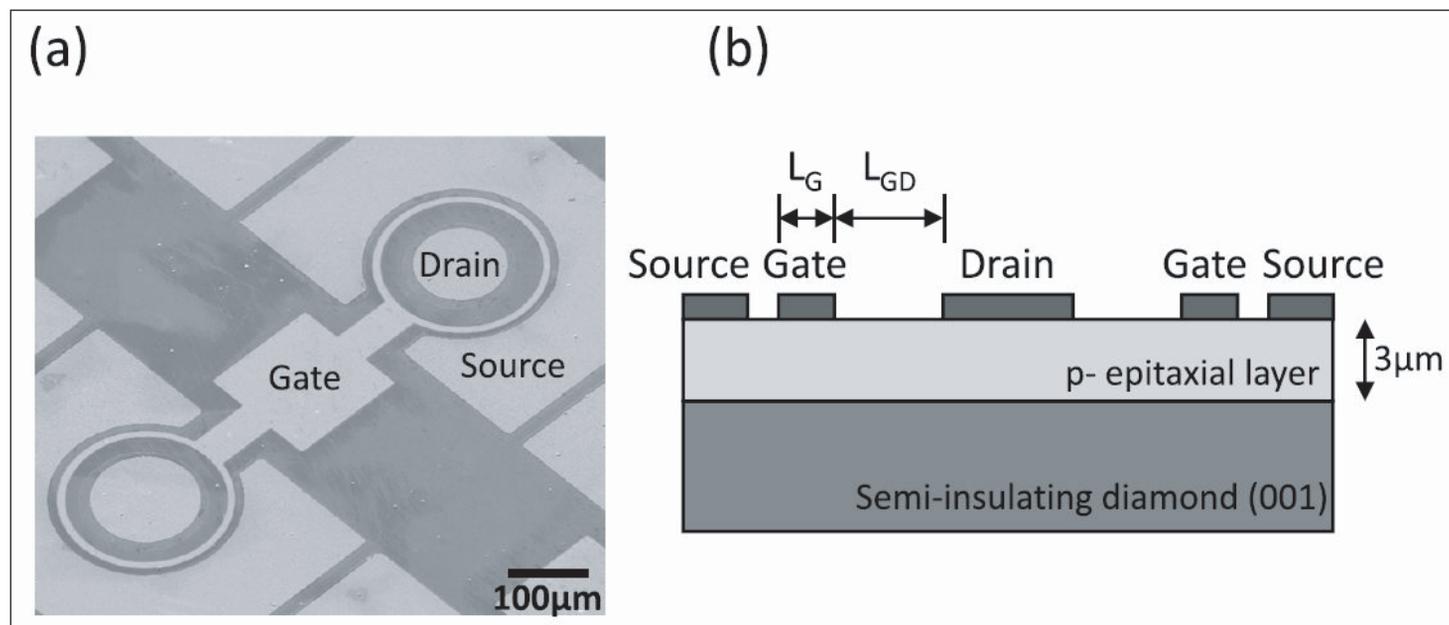


Figure 1. (a) Top view showing two linked diamond MESFETs with Corbino geometry and (b) cross-sectional schematic.

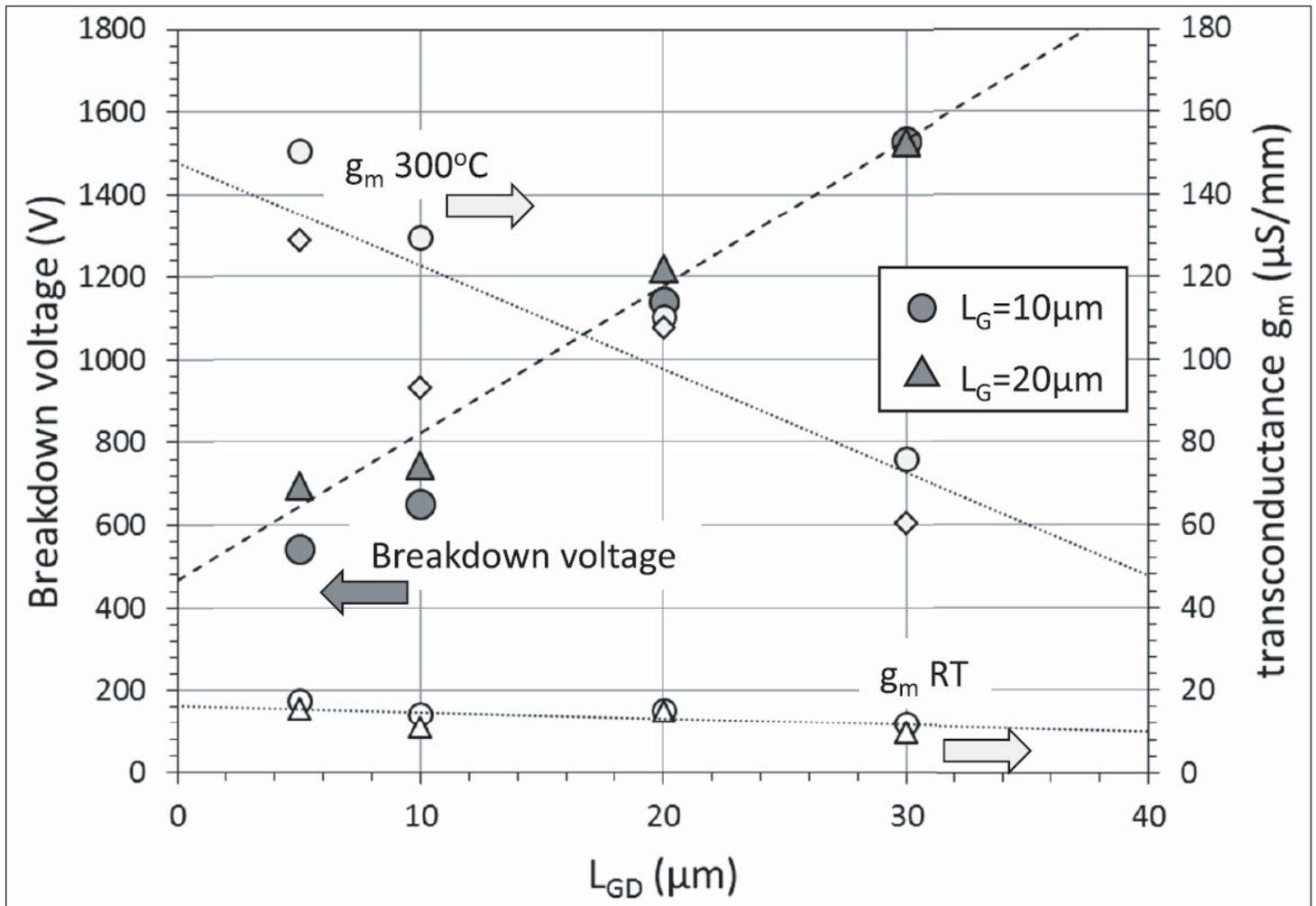


Figure 2. Breakdown voltage and transconductance of diamond MESFETs as a function of gate-drain distance (L_{GD}) for gate lengths (L_G) of 10 μm and 20 μm .

researchers, is lower ohmic contact resistance at high temperature.

Analyzing the parasitic resistances, the researchers extracted intrinsic values for the transconductance of 143 $\mu\text{S/mm}$ at 300°C (4.9x the value of 29 $\mu\text{S/mm}$ at room temperature).

The researchers say that improved current response would require reduced gate lengths, parasitic resistance in the source-gate gap, and ohmic contact resistance.

The threshold voltage of the device was 2.7V. The on/off current ratio was $\sim 10^7$ at room temperature, reducing to $\sim 10^3$ at 300°C. The much poorer ratio at 300°C was attributed to increased gate leakage (even under reverse bias) of the Schottky junction.

The 1530V breakdown voltage is "the highest for a diamond FET reported to date". Previously, breakdown voltages in diamond transistors have been limited to less than 700V. The 1530V breakdown performance is almost comparable to that achieved in GaN-based devices

The breakdown was assessed with a 50V gate potential to reduce leakage currents. A number of 20 μm -gate-length devices were tested. With a 30 μm gate-drain distance, breakdown occurred at 1530V (2.5x higher than for a device reported in February 2014). The researchers claim that the 1530V breakdown voltage is "the highest for a diamond FET reported to date". Previously, breakdown voltages in diamond transistors have been limited to less than 700V. The 1530V breakdown performance is almost comparable to that achieved in gallium nitride (GaN)-based devices.

After breakdown had occurred once, subsequent testing showed more than 30% degradation in breakdown voltage due to critical damage. Estimates of the critical electric field for breakdown were higher than the critical field for silicon, but were also 5–10x lower than the ideal value for diamond, suggesting room for improvement. One way to improve field profiles — reducing spikes and thus increase breakdown voltages — is to use field plates. ■

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Author: Mike Cooke