

# Fluorinated graphene passivation for AlGaN transistors

**Technique improves performance under direct current and pulsed operation, reducing current collapse.**

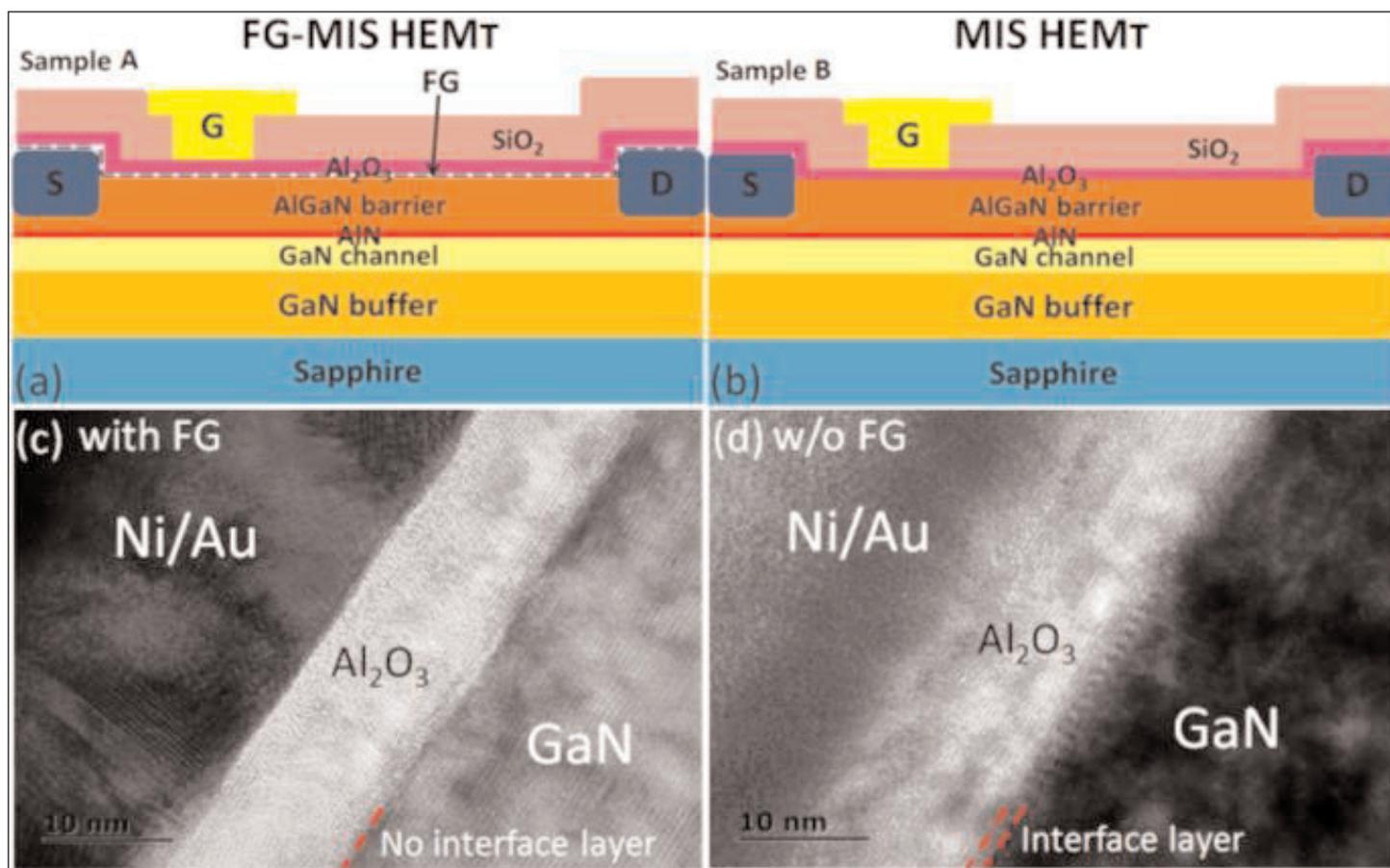
**S**hanghai Institute of Microsystem and Information Technology and Shanghai Normal University in China have used fluorinated graphene (FG) to improve the performance of aluminium gallium nitride (AlGaN) metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) [Lingyan Shen et al, IEEE Electron Device Letters, vol38, issue 5, pp596–599]. The FG was inserted as passivation between the epitaxial semiconductor and the gate-insulator dielectric. The researchers claim that their work is the first use of FG for passivation of AlGaN/GaN HEMTs.

The performance was improved both in terms of DC testing but also under pulsed conditions, where current

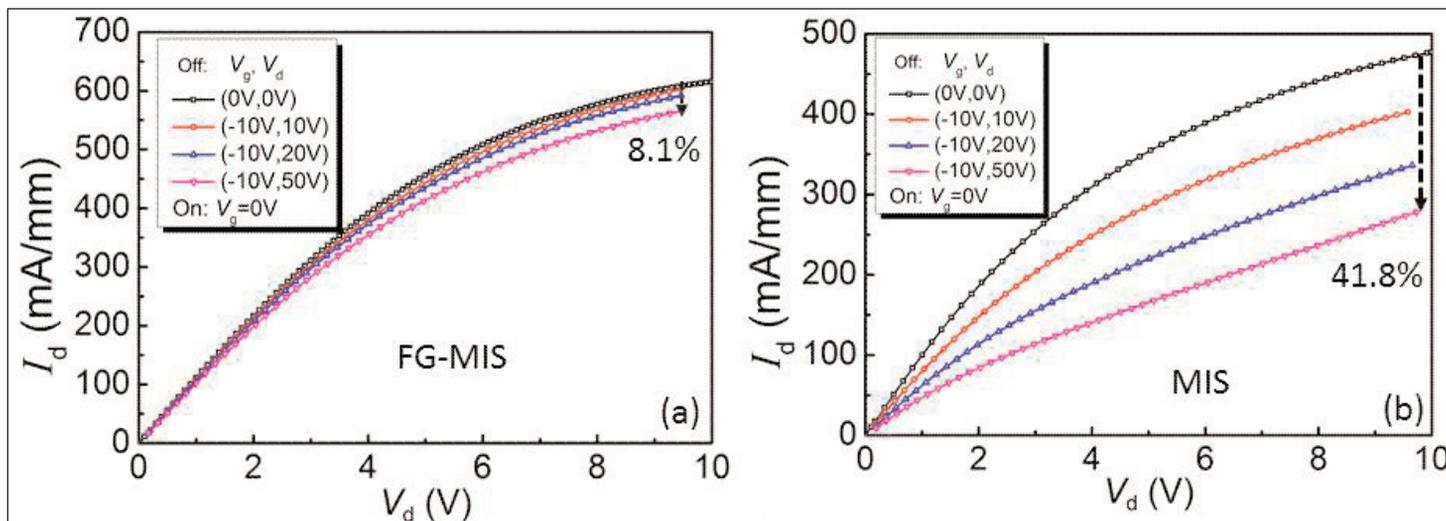
collapse is a continuing problem for III-nitride transistors. III-nitride devices are being developed for power and microwave applications.

The HEMT material was grown on sapphire with a layer sequence of 3.9 $\mu\text{m}$  carbon-doped GaN buffer, 300nm GaN channel, 1nm AlN spacer, 20nm AlGaN barrier, and 2nm GaN cap.

Device fabrication consisted of a 400nm mesa etch, annealed titanium/aluminium/nickel/gold ohmic contacts, graphene transfer and fluoridation, 14nm of atomic layer deposition (ALD) aluminium oxide, 200nm plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide, and annealed nickel/gold gate formation



**Figure 1. Schematic cross sections of (a) FG-MIS HEMT and (b) traditional MIS HEMT. HRTEM image in gate region of (c) FG-MIS HEMT and (d) traditional MIS HEMT.**



**Figure 2. Output characteristics of (a) FG-MIS HEMT and (b) MIS HEMT with various off-state bias conditions, measured at 0V gate potential.**

on the aluminium oxide dielectric.

The graphene was grown by chemical vapor deposition (CVD) on copper foil. The graphene was then separated by electrochemical delamination and transferred to the HEMT. Fluoridation was achieved by exposure to sulfur hexafluoride plasma.

The HEMT parameters were 3 $\mu$ m gate length, 15 $\mu$ m gate-to-drain spacing, and 3 $\mu$ m gate-to-source spacing.

The fluorinated graphene increased the peak transconductance by 14%, compared with a conventional MIS-HEMT. The threshold voltage of the FG devices was also 0.6V more positive (see Table 1). However, the threshold was still negative, meaning that at 0V gate potential the device was 'on' — i.e. 'normally-on'. Another improvement in the FG device was two-orders reduced leakage current in the 'off' state (as low as 10<sup>-8</sup>mA/mm).

The researchers attribute the improved performance to a clear and sharp interface between the GaN cap and aluminium oxide gate dielectric in the FG MIS-HEMTs, as revealed by high-resolution transmission electron microscopy (HRTEM). The interface in the conventional MIS-HEMT without FG was blurred with a 2nm transition region.

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**Table 1. Extracted parameters from DC characteristics.**

Parameter	Unit	FG-MIS	MIS
Threshold	V	-6.7	-7.3
Peak transconductance	mS/mm	44.6	39.0
On-resistance	$\Omega$ -mm	7.40	9.44
Saturation drain current	mA/mm	618	460
Off current leakage	mA/mm	$\sim 10^{-8}$	$\sim 10^{-6}$
Gate leakage	mA/mm	$\sim 10^{-6}$	$\sim 10^{-4}$

Capacitance–voltage analysis found that interface fixed charges were reduced to 2.5 $\times 10^{11}$ /cm<sup>2</sup> from 1.0 $\times 10^{12}$ /cm<sup>2</sup> by the use of FG. The researchers see the fixed charges as being related to the ability of nitrogen and oxygen to exchange between the GaN and aluminium oxide layers when there is no FG barrier.

Fixed charges adversely impact channel mobility and are a factor in current collapse under pulsed operation (Figure 2). The off state was for a -10V gate potential and the on state was 0V. The off-state stress was varied up to a 50V drain bias. The devices were toggled on and off at 20-second intervals.

The on-state current with 10V drain bias was reduced by 41.8% with a 50V off-state stress in the conventional MIS-HEMT. The effect was reduced to 8.1% with the FG device. The researchers see the fixed interface charge of the non-FG transistor as trapping electrons that act as a 'dummy gate' and are slow to be released when the device is turned on.

The FG MIS-HEMT turned on faster than the conventional device and the on-state current was only slightly impacted by off-state drain bias as it increased to 100V. In addition to slower turn-on, the conventional MIS-HEMT saw a reduction of more than 2x in current as the off-state drain bias increased from 10V to 100V. ■

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