Optically-induced 2DEGs in GaN/AlGaN Heterostructures

S. Schmult,[1] **S. Wirth**[2], **V.V. Solovyev**[3], **R. Hentschel**[4], **A. Wachowiak**[4], **T. Scheinert**,[1] **A. Großer**[4], **I.V. Kukushkin**[3], **and T. Mikolajick**[1,4]

[1] *TU Dresden, Electrical and Computer Engineering, Institute of Semiconductors and Microsystems, Nöthnitzer Str. 64, 01187 Dresden, Germany*

[2] *Max-Planck-Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany*

[3] *Institute of Solid State Physics RAS, 142432 Chernogolovka, Moscow district, Russia*

[4] *Namlab gGmbH, Nöthnitzer Str. 64 a, 01187 Dresden, Germany*

In our MBE-grown ultra-pure GaN/$Al_{0.06}Ga_{0.94}N$ heterostructures with barrier thickness of 16 nm, a 2-dimensional electron gas (2DEG) is absent in dark environment and at room temperature. However, illumination with ultra-violet light (UV, photon energies larger than the GaN band-gap) generates a conductive 2D channel at the GaN/AlGaN interface. An immediate consequence for lateral field-effect transistors (FETs) is their normally-off switching characteristics in the dark (Fig. 1).

Upon UV illumination below 100 K the 2DEG persists after switching off the illumination, with a charge carrier density depending only weakly on the excitation power (Fig. 2). Shubnikov-de Haas-oscillations and Zeroes in the longitudinal resistance recorded from Hall bars at T = 0.5 K clearly point at the 2D channel character with no parasitic current paths. The respective electron densities are extracted from Landau level filling factors (e.g. $\nu = 10$, dashed line, Fig. 2).

Band diagram simulations point at the significance of the GaN surface potential value for the existence of a 2DEG in the dark. Two factors, namely the residual impurity background in the GaN/AlGaN layer stack as well as impinging UV radiation, appear to influence the surface potential, resulting in the difference between normally-on or -off FET operation. The reported characteristics demonstrate the technical feasibility of next-generation normally-off as well as light-sensitive GaN-based device concepts.

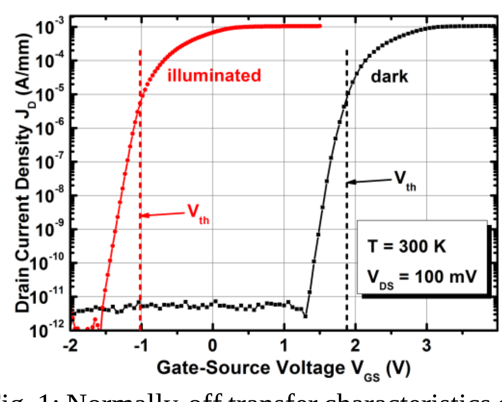

Fig. 1: Normally-off transfer characteristics of an FET fabricated form a GaN/AlGaN heterostructure without a conductive channel at 300 K in the dark. A channel is formed under UV exposure, which results in normally-on FET operation.

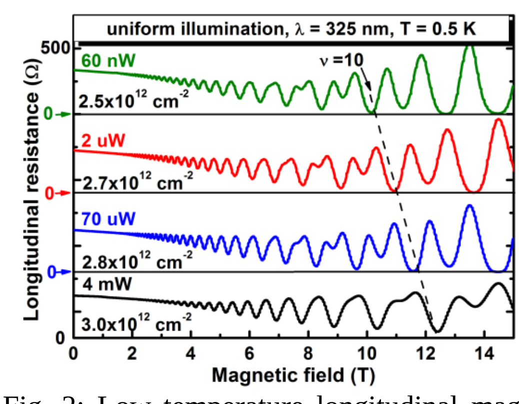

Fig. 2: Low temperature longitudinal magneto-resistance of a Hall bar device under steady UV excitation at different power. An increase in the illumination power of almost 5 orders in magnitude only raises the channel density by 20 %.

+ Author for correspondence: stefan.schmult@tu-dresden.de

Supplementary Page (Optional)

The following figures and captions deliver further confidential information on the optical and transport properties of the GaN/AlGaN heterostructure described above.

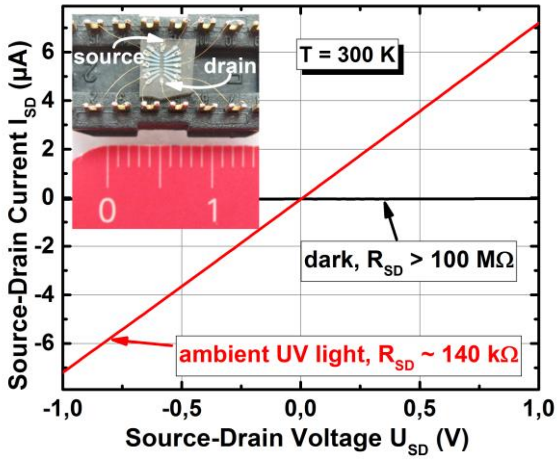

Fig. 3: Two-terminal current vs. voltage characteristics of a Hall bar (inset top left, reference is a centimeter ruler) fabricated from the ultra-pure GaN/AlGaN layer stack illustrated in Fig. 4, but without the Al_2O_3 dielectric layer and gate contact. At room temperature and in the dark practically no conductivity is observed. Illumination with UV light however generates a conductive channel at the GaN/AlGaN interface. The exact position of the channel is verified in capacitance vs. voltage measurements (Fig. 5).

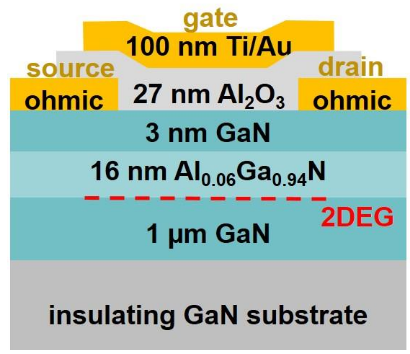

Fig. 4: Cross-sectional illustration of a lateral FET fabricated from a GaN/AlGaN heterostructure with no 2DEG present in the dark. The overlap of gate and source/drain contacts is essential for FET operation, since only underneath the gate electrode a 2DEG can be generated electrostatically. Gate and source/drain contacts are separated by a highly insulating dielectric layer.

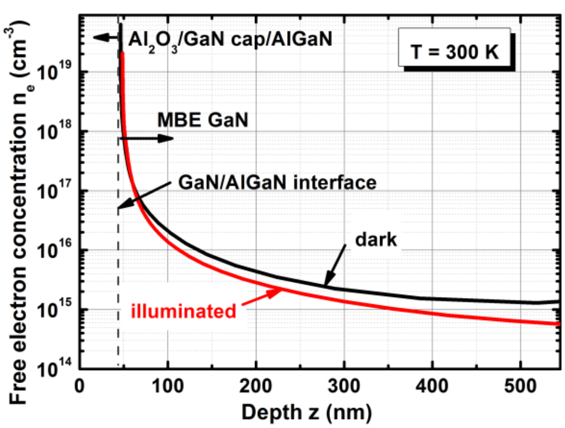

Fig. 5: Vertical free electron density profiles extracted from capacitance vs. voltage measurements. For both cases of optical and electrostatic generation, the conductive 2D channel is located at the GaN/AlGaN interface.