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Normally-off GaN Transistors for Power Applications

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Normally-off high voltage AlGaN/GaN-HFETs for switching applications are presented. AlGaN/GaN HFETs are considered as a competitive device technology for efficient power switching up to approximately 1200 V due to their low area-specific on-state resistance and the particularly low gate charge required for switching. The resulting low switching losses are beneficial for high-frequency converter operation with increased power density. Three challenges have to be mastered to adopt AlGaN/GaN HFETs for power-switching applications. The intrinsic normally-on device characteristic has to be converted into normally-off, off-state leakage paths have to be eliminated for the required high-voltage blocking and the increased dynamic on-state resistance after switching from high-bias off-state has to be reduced.

Normally-off devices with threshold voltages between 1 V and 2 V have been obtained by using a MOCVD-grown p-type GaN layer as gate (Fig. 1). Higher threshold voltages can be realized at the cost of higher on-state resistance. Introducing an AlGaN buffer beneath the GaN channel reduces the on-state resistance for a fixed threshold voltage [1]. The resulting high-barrier pin-type diode between the two-dimensional electron gas in the transistor channel and the p-type gate enables a wide gate swing for the on-state operation. With 5 V gate bias, the gate current is still limited to 10^{-5} of the maximum drain-source current.

AlGaN/GaN HEMTs with a non-doped GaN buffer often show electron spill over from the channel into the buffer, resulting in a limited device blocking strength. An improved electron confinement is thus required to suppress off-state leakage currents under high drain bias. Using an AlGaN buffer beneath the GaN channel creates an efficient back-barrier for improved electron confinement [2]. An alternative, iron or carbon doping of the GaN buffer also induces a back-barrier to the non-doped GaN channel due to the introduced acceptor states. When properly designed, the device blocking strength scales with the gate-drain separation and values of 40 V/µm for AlGaN buffer devices, 50 V/µm for iron-doped GaN buffer devices and of 100 V/µm for carbon-doped devices have been obtained. The very strong blocking capability of the carbon-doped buffer resulted in device breakdown strengths > 1000 V [3]. The superior blocking capability of the carbon-doped GaN buffer is attributed to deep electron trapping.

But these traps are also considered as root cause for the particular strong increase in dynamic on-state resistance (dyn. R_{ON}) that was observed in some devices with carbon-doped buffer [3]. An increased dyn. R_{ON} immediately after switching from high-bias off-state condition is characteristic for most GaN-HFETs. Trap states in the (Al)GaN-based semiconductor stack or on the semiconductor surface that deplete the electrons in the transistor channel are considered as root cause. AlGaN-buffer and iron-doped GaN buffer based devices showed a 2-3 times increased dyn. R_{ON} for 250 V switching, while dyn. R_{ON} was found to be 100 times higher for carbon-doped buffer based devices. However, an only 2.6 times increased dyn. R_{ON} for 500 V switching was demonstrated for an improved semiconductor stack based on a carbon-doped buffer (Fig. 2).

[1] O. Hilt, A. Knauer, F. Brunner, E. Bahat-Treidel and J. Würfl “Normally-off AlGaN/GaN HFET with p-type GaN Gate and AlGaN Buffer”, Proc. ISPSD 2010, Hiroshima, pp. 347-350, 2010.

[2] E. Bahat-Treidel, O. Hilt, F. Brunner, J. Würfl, and G. Tränkle "Punchthrough-voltage enhancement of AlGaN/GaN HEMTs using AlGaN double-heterojunction confinement" IEEE Trans. on Electron Devices, vol. 55, no. 12, pp. 3354-3359, 2008.

[3] O. Hilt, E. Bahat-Treidel, E. Cho, S. Singwald and J. Würfl, "Impact of Buffer Composition on the Dynamic On-State Resistance of High-Voltage AlGaN/GaN HFETs", Proc. ISPSD 2012, Bruges, pp. 345-348, 2012.

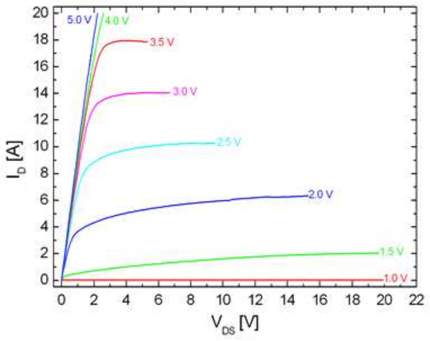

Figure 1: Output characteristic of a normally-off, 300 V / 85 mΩ AlGaN/GaN HFET in p-GaN gate technology

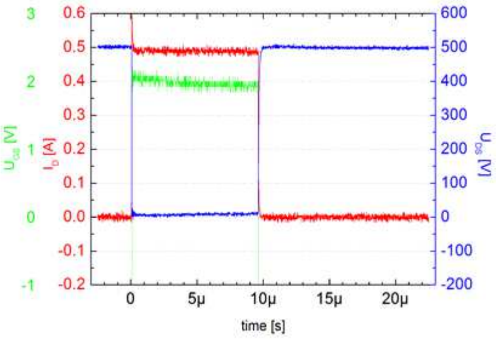

Figure 2: 500 V / 0.5 A switching transient of an AlGaN/GAN HFET with 12.9 Ω static R_{ON} and showing 33.5 Ω dynamic R_{ON} in switching.