GaN/InAlN/AlN/GaN normally-off HEMT with etched access region

M. Jurkovič[1*], D. Gregušová[1], Š. Haščík[1], M. Blaho[1], M. Molnár[2,3], V. Palankovski[2], D. Donoval[3], J.-F. Carlin[4], N. Grandjean[4], and J. Kuzmík[1,2]
[1]*Institute of Electrical Engineering SAS, Bratislava, Slovakia*
[2]*Advanced Materials and Device Analysis Group, TU Vienna, Austria*
[3]*Institute of Electronics and Photonics, FEI STU Bratislava, Slovakia*
[4]*Institute of Quantum Electronics and Photonics, EPFL Lausanne, Switzerland.*
[*] E-mail: Michal.Jurkovic@savba.sk

ABSTRACT

We present a normally-off InAlN-based HEMT where we use a concept of a polarization engineering. MOCVD-grown 0.5 nm AlN/ 1 nm InAlN barrier stack is capped with a 4 nm thick undoped GaN creating a negative polarization charge at a GaN/InAlN heterojunction. Consequently, the transistor channel is depleted from carriers. On the other hand after the GaN cap is removed at access regions, the extrinsic channel becomes populated by carriers. 2 μm gate length transistors with a source-to-drain distance 8 μm showed a positive threshold voltage and a source drain current up-to 80 mA/mm. An off-state breakdown is close to 100 V.

1. INTRODUCTION AND DEVICE CONCEPT

There is a substantial interest in developing normally off GaN-based high electron mobility transistors (HEMTs) for high-power [1] and logic [2] applications. n^{++} GaN/ InAlN/AlN/GaN HEMT with a recessed gate has been described recently [3]. In the present study, we propose a normally-off GaN/InAlN/AlN/GaN HEMT with 1 nm thick InAlN barrier but with the undoped GaN cap and etched (recessed) access regions. The negative polarization charge at GaN/InAlN junction is effective to deplete the channel below the gate, similarly as shown in Fig. 1 for access regions before etching the GaN cap. On the other hand, after removing the GaN cap at access regions, electrons populate the channel, see Fig. 1. Principle of the concept is verified also by a two-dimensional numerical device simulator Minimos-NT [4].

2. EXPERIMENT

GaN (4 nm)/$In_{0.17}Al_{0.83}N$ (1 nm)/AlN (0.5 nm)/GaN has been grown by MOCVD. 2 μm gate length transistors with a source to drain distance 8 μm were prepared, GaN cap has been removed by using a CCl_2F_2-based selective dry etching while an Ir/Au gate served as a mask. The devices are unpassivated. A TLM test pattern indicated that the channel sheet resistance drops from ~ MΩ/□ to ~1 kΩ/□ after removing the GaN cap. Fig. 2 shows the HEMT input characteristic with I_{GS} = 3 μA/mm at V_{GS} = –1 V. The HEMT output characteristics before etching the GaN cap are in a range of μA/mm, see Fig. 3, and typically about 50 mA/mm at V_{GS} = 3 V, see Fig. 4, after the GaN cap was removed. Few devices exceeded 80 mA/mm (not shown), while threshold voltage always remained positive. This may indicate variation in a surface potential value. Surface potential has been shown to depend on the presence of the oxide layer which can develop on an unprotected InAlN surface [5]. Fig. 5 includes results of the device simulations. In agreement with the experiment, negligible output current was calculated for the HEMT before the GaN etching. After

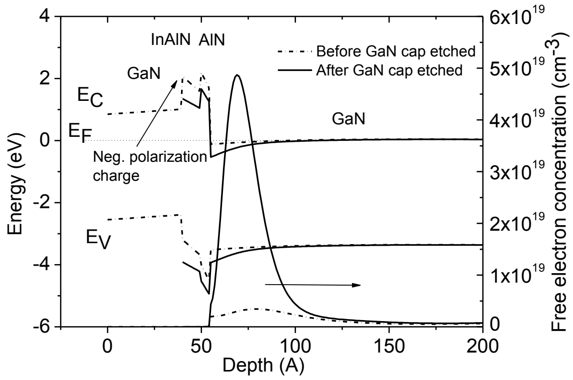

Fig.1. Calculated energy band and electron concentration profiles at (GaN)/InAlN/AlN/GaN HEMT access regions before and after etching the GaN cap. Value of a surface potential is 0.85 eV for GaN and 1.35 eV for InAlN.

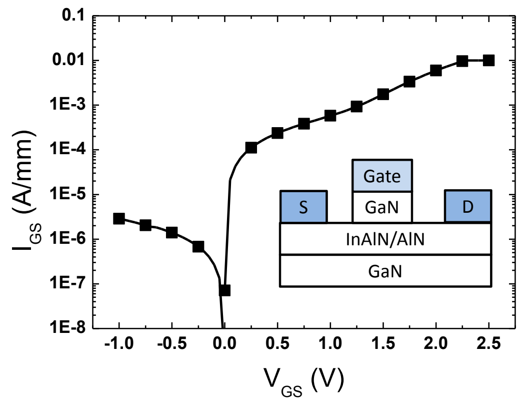

Fig. 2. Two-terminal gate characteristic after etching the GaN cap. Inset shows sketch of the HEMT.

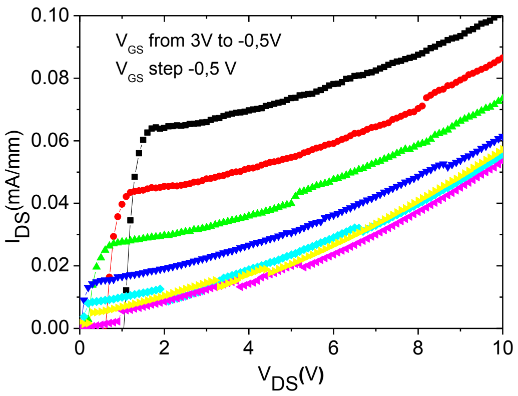

Fig. 3. GaN/InAlN/AlN/GaN HEMT output characteristics before etching the GaN cap.

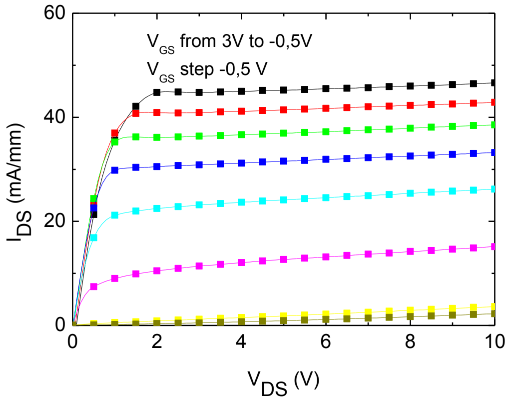

Fig. 4. GaN/InAlN/AlN/GaN HEMT output characteristics after etching the GaN cap.

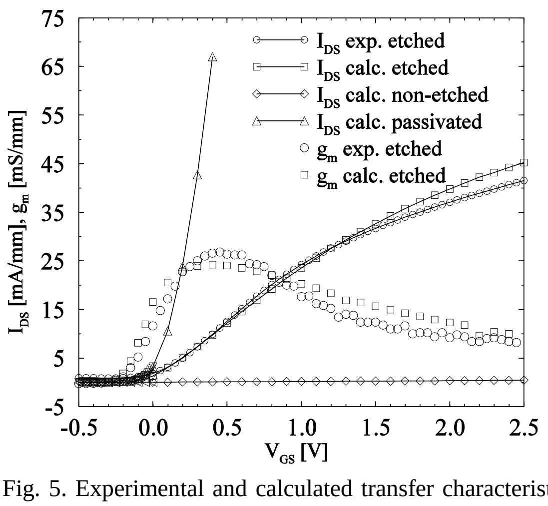

Fig. 5. Experimental and calculated transfer characteristics and transconductance g_m of GaN/InAlN/AlN/GaN HEMTs before and after etching the GaN cap. Calculation shows also expected characteristics after passivation. InAlN surface potential is 1.35 eV after etching and 0.4 eV with passivation.

the etching, the best fit is obtained for the InAlN surface potential of 1.35 eV. Further strong I_{DS} increase is calculated for a hypothetical passivated device assuming

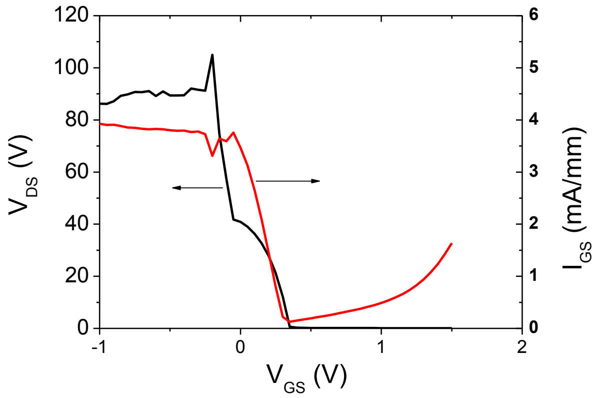

Fig. 6. GaN/InAlN/AlN/GaN HEMT off-state breakdown characteristics measured by a drain injection technique at I_{DS} = 4 mA/mm.

surface potential of 0.4 eV. An off-state breakdown voltage reached a value close to 100 V, see Fig. 6, which is a record for InAlN/GaN normally-off HEMTs.

3. CONCLUSION

Concept of GaN/InAlN/AlN/GaN HEMTs with etched access region is demonstrated as a viable approach for achieving a high-voltage normally-off operation. For 2 µm gate length unpassivated HEMTs with 8 µm source to drain distance we obtain the maximal drain current up to 80 mA/mm at the gate bias 3 V. Determined off-state breakdown is close to 100 V. As indicated by the two-dimensional modeling, significant increase of the maximal drain can be expected after device passivation.

4. ACKNOWLEDGMENT

This work was supported by the the European project MORGAN under FP7 NMP IP 214610, Slovak Research and Development Agency contract No. APVV-0104010, and by the Austrian Science Funds FWF, START Project No.Y247-N13.

5. REFERENCES

[1] S. Maroldt, Ch. Haupt, W. Pletschen, S. Müller, R. Quay, O. Ambacher, Ch. Schippel and F. Schwierz, *Jpn. J. Appl. Phys.* **48**, 04C083 (2009).

[2] R. Wang, Y. Cai, W. C. W. Tang, K. M. Lau, and K. J. Chen, *Jpn. J. Appl. Phys.* **46**, 2330 (2007).

[3] J. Kuzmik, C. Ostermaier, G. Pozzovivo, B. Basnar, W. Schrenk, J.-F. Carlin, M. Gonschorek, E. Feltin, N. Grandjean, Y. Douvry, Ch. Gaquière, J.-C. De Jaeger, K. Čičo, K. Fröhlich, J. Škriniarová, J. Kováč, G. Strasser, D. Pogany, and E. Gornik, *IEEE Trans. El. Dev.* **57**, 2144 (2010).

[4] S. Vitanov and V. Palankovski, *Solid-State Electronics* **52**, 1791 (2008).

[5] T. Hasan, H. Tokuda, and M. Kuzuhara, *Appl. Phys. Lett.* **99,** 132102 (2011).