Approach to Normally-Off AlGaN/GaN MIS-HEMTs with High Drain Current using AlGaN Overgrowth Technique

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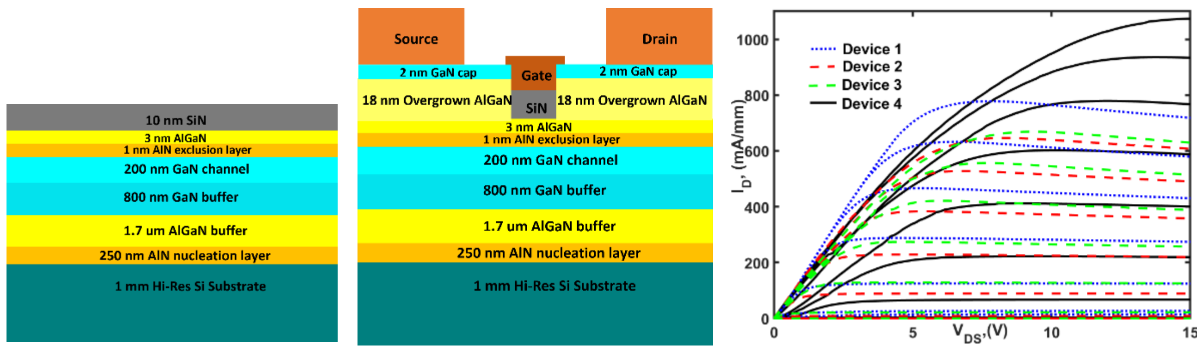
In this paper we present the processing and device characteristics of AlGaN/GaN metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) aimed at the realisation of uniform and reproducible normally-off characteristics with high threshold voltage (V_{TH}). The new approach utilizes the overgrowth of the AlGaN barrier layer to thicken it to 21 nm thickness from a basic structure having only a 3 nm thin barrier layer. This way, an equivalent recessed gate normally-off AlGaN/GaN MIS-HEMT can be realised with expected uniform V_{TH} across the sample since the barrier layer thickness is epitaxially grown. Initially, the epitaxial HEMT structure consists of a 10 nm SiN_X layer on only a 3 nm AlGaN barrier, with a 1 nm AlN exclusion layer between this and the GaN channel grown on high-resistivity (HR) silicon substrate, see Figure 1(a). Here, the area for overgrowth was defined by the selective removal of the SiN_x layer using SF_6-based plasma. The overgrowth of 18 nm AlGaN barrier layer along with 2 nm GaN cap layer was done using metal organic chemical vapour deposition (MOCVD) at 1075˚C. A second standard sample with 21 nm AlGaN barrier layer and 2 nm GaN cap was also grown for benchmarking purposes.

Four different device structures were fabricated: Device #1, as illustrated in Figure 1(b) where the Ohmic contacts are placed on the overgrown AlGaN layer, devices #2 and #3, where the Ohmic contacts are placed on the SiN_x cap layer and 3 nm AlGaN layer respectively and for reference, depletion mode device, device #4 where 10 nm SiN_x is completely removed including in the gate and access regions before AlGaN overgrowth. The device dimensions were L_G and L_{GS} of 4 µm, L_{GD} of 5 µm and W_G of 75 µm. Measured output characteristics show high drain current density of 1074 mA/mm for the depletion mode device #4 at -1 V V_{GS} as seen in Figure 1(c) which is comparable to conventional depletion mode AlGaN/GaN HEMT devices. The highest drain current for the selective area overgrown devices was 760 mA/mm for device #1 at 5 V gate bias. For device #4, the standard structure realised through the overgrowth of AlGaN barrier layer, V_{TH} was -15 V which might indicate a thicker final AlGaN layer. Further investigation using TEM analysis is planned to determine this. For all the selective area overgrown devices, a positive shift in the threshold voltage is observed when compared to the standard depletion mode device, up to -0.44 V for device #2, with no significant differences between these 3 devices. The 1-nm AlN exclusion layer prevents realisation of higher turn-on voltages in this case. Bi-directional C-V sweep at 1 MHz (not shown here) shows low hysteresis indicating reduced charge trapping effects which shows good quality SiN_X grown using MOCVD. The advantage of this approach is it avoids the use Cl-based plasma etch on the AlGaN barrier which considerably influences the device characteristics, and which is difficulty to control precisely [1]. These preliminary results show high drain current density can be achieved by maintaining a good interface for AlGaN regrowth. Through improved processing of the gate region and overgrowth conditions, we believe that the approach can be used to realise high V_{TH} (>3 V) normally-off high performance AlGaN/GaN MIS-HEMTs for use in power electronics.



(a) (b) (c)

Figure 1. (a) Initially grown wafer structure, (b) Cross-section of fabricated device #1, (b) Measured output characteristics of devices 1 to 3 with V_{GS} steps of 1 V and for device 4, V_{GS} steps of 2 V.

References

[1] J. T. Asubar, S. Kawabata, H. Tokuda, A. Yamamoto and M. Kuzuhara, "Enhancement-Mode AlGaN/GaN MIS-HEMTs With High V_{TH} and High I_{Dmax} Using Recessed-Structure with Regrown AlGaN Barrier," in *IEEE Electron Device Letters*, vol. 41, no. 5, pp. 693-696, May 2020.