AlN/GaN HEMTs with thin GaN/AlN buffer layers on sapphire (0001) substrates

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High Electron Mobility Transistors (HEMTs) should combine high electron mobility channels and high resistivity buffer layers on insulating substrates. The efficient confinement of the carriers in the channel can be enhanced by the presence of a barrier underneath the channel. The thinnest possible epitaxial structure may be important for specific applications, but also satisfies the condition for reduced manufacturing cost.

With the above motivation, in this work we have studied the performance capabilities of AlN/HEMT structures with narrow GaN buffer layer (300nm) on a thin AlN back barrier (200 nm) grown directly on insulating sapphire substrates. The double barrier AlN/GaN/AlN HEMT structure can enhance the channel confinement, decrease electron spill-over effects and suppress the buffer leakage, as needed for high frequency performance and high breakdown fields.

Spontaneous and strain induced polarization, which are two determinant factors in nitride semiconductors research, lead to a high positive polarization in the AlN, resulting in a 2DEG induced at the AlN/GaN interface. Since our structures contain GaN layers, grown on AlN buffer layer, it also follows a negative polarization charge which can cause an accumulation of holes. The AlN/GaN heterojunction offers the highest polarization discontinuity for GaN channel transistors and HEMT devices can be realized with ultra-shallow channels and very high current density. Enhancement-mode AlN/GaN HEMTs have also received great attention recently, especially for high power switching applications. A particular subject of interest was to assess the possibility of realizing normally-off HEMT devices, only by scaling of the AlN top barrier thickness without any other surface or gate treatment (gate recess, plasma treatment).

Material and device characterization, as well as two-dimensional electron gas density calculations, produced very consistent results for the scaling of material and device properties with the AlN top barrier thickness. It is shown that the transistor threshold voltage could be scaled linearly from +0.2 V to -2.7 V by varying the AlN barrier thickness from 1.5 nm to 4.5 nm, respectively. The maximum drain current was 1.1 A/mm for intermediate AlN barrier thicknesses. The results demonstrate the strong performance capabilities of thin AlN/GaN/AlN heterostructures and their potential use for normally-off devices.

Fig. 2 shows the variation of the 300K 2DEG mobility, as well as the theoretical and experimental results of N_S for different AlN barrier thicknesses. For AlN thickness between 1.5 nm and 3nm, the electron mobility increases rapidly from 46 to 900 cm^2/Vs. A small reduction was observed for higher AlN barrier thicknesses, reaching the value of 703 cm^2/Vs for 4.5 nm AlN. The theoretical and experimental N_S values of 2DEG densities are in a very good agreement, with the highest value being $2.2x10^{13}$ cm^{-2} for the HEMT structure with 4.5 nm AlN barrier thickness.

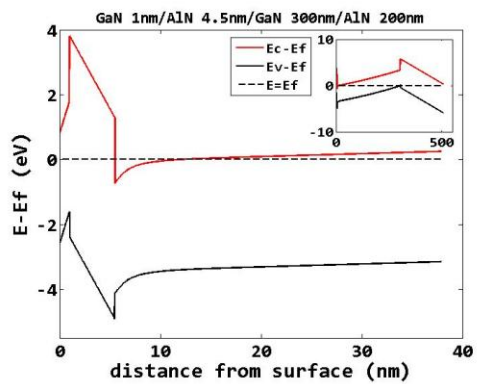

Fig. 1. Simulated band diagram of the GaN/AlN double heterostructure for AlN thickness at 4.5nm. The insert diagram presents the band profile for the whole structure.

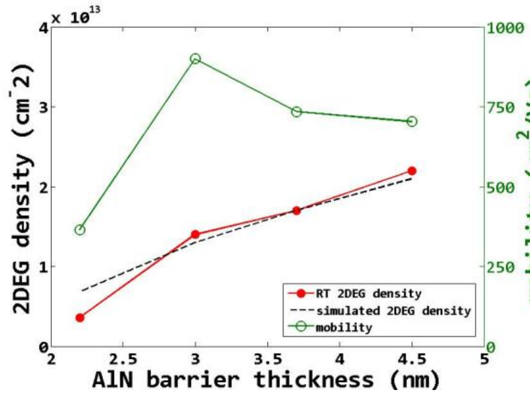

Fig. 2. Theoretical and experimental 2DEG sheet density (N_S) and electron mobility, as functions of AlN barrier thickness.