Surface capping of AlInN/GaN HEMT structures

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We have recently shown that AlInN/GaN heterostructure could be an attractive alternative to AlGaN/GaN power devices or even be the next generation of such devices. Indeed, first experiments have demonstrated the capabilities of this structure to deliver higher sheet carrier densities and maximum DC output currents [1,2,3]. However they are also nitride heterostructures using their polarized nature. AlGaN/GaN structures suffer from the instability mostly related to the spontaneous and piezo polarization and the properties of the polarization induced surface donor at a pinned surface potential of approx. 1.5 eV [4]. The question addressed here is whether these instabilities are also dominating this new heterostructure, where the AlGaN surface is substituted by InAlN. The AlInN/GaN heterostructure used here is lattice matched and therefore without piezo polarization. Three different ways to terminate the surface have been investigated by pulse experiments. These were the free InAlN surface (Fig. 1.a), the surface capped (Fig. 2.a) with 2 nm of GaN (which is normally used to prevent oxidation of Al at the surface) and the surface passivated with Si_3N_4 (Fig. 3.a).
AIXTRON Metalorganic Vapor Phase Epitaxy system has been used to grow AlInN/GaN on 2 inch diameter (0001) sapphire substrate [5]. The studied structures (described in Fig. 1) consist of 2 µm thick GaN buffer, 1 nm thick AlN spacer layer, 13 nm thick AlInN barrier layer with 81% Al content (structure 1), an additional 2 nm GaN cap layer for the structure 2 and a 200 nm Si_3N_4 passivation for the structure 3. Hall Effect measurements at room temperature give a sheet carrier density $N_S = 2.6\times10^{13}$ cm^{-2}, a sheet resistance of 260 Ω/□ and a mobility of 1160 cm^2/Vs. MESA isolation has been performed by dry etching in Argon plasma. For the ohmic contacts, we used Ti/Al/Ni/Au metal sequence annealed at 890°C for 60 sec. We obtained by TLM measurements contact resistances R_C = 0.7 Ω.mm for the structures 1 and 3 and R_C = 2.2 Ω.mm for the structure 2. The Drain-Source distance is 2.5 µm. Ni/Au Schottky gates have been realized by e-beam lithography with length and width of 0.25 / 50 µm respectively. We reached a maximum saturated DC output current I_{DSS} = 2 A/mm at V_{GS} = +1 V with a breakdown voltage at pinch-off of about 40V and a peak transconductance G_m = 250 mS/mm. We obtained cut-off and maximum oscillation frequencies F_t of 31 GHz and F_{max} of 52 GHz extrapolated from the current gain H_{21} and the maximum available gain (MAG) at V_{GS} = -7V and V_{DS} = 10V.
Pulse experiments were performed in a routine as used to assess the stability of AlGaN/GaN devices (described with more details elsewhere [6]) with 500 ns pulses. All quiescent bias points (V_{DS0}, V_{GS0}) are chosen in order to simultaneously eliminate the thermal effect (cold polarization) and to reveal the gate and drain lag effects: (V_{DS0} = 0 V, V_{GS0} = 0 V), (V_{DS0} = 0 V, V_{GS0} = pinch-off voltage) and (V_{DS0} = 10 V, V_{GS0} = pinch-off voltage). The first quiescent bias point is used as the reference to compare with the other bias conditions. For the structure 1, a drop of 13 % (gate lag) and 38 % (drain lag) regarding the maximum drain current density is observed at V_{DS} = 10 V. Compared to the typical unpassivated AlGaN/GaN structures on sapphire, those slumps are much lower, which indicate a more stable surface in the case of AlInN material. For the structure 2, a decrease of 20 % (gate lag) and 31 % (drain lag) regarding the maximum drain current density is noted at V_{DS} = 10 V. No significant improvement appears with the introduction of the GaN cap layer which confirms again the relatively stable AlInN surface. Finally, the SiN passivation (structure 3) involves a drop of only 8% (gate lag) and 26 % (drain lag) regarding the maximum drain current density at V_{DS} = 10 V. Consequently, the passivation of the AlInN surface seems efficient to reduce the parasitic gate and drain lag effects. No GaN intermediate layer is needed, preventing Al-oxydation.

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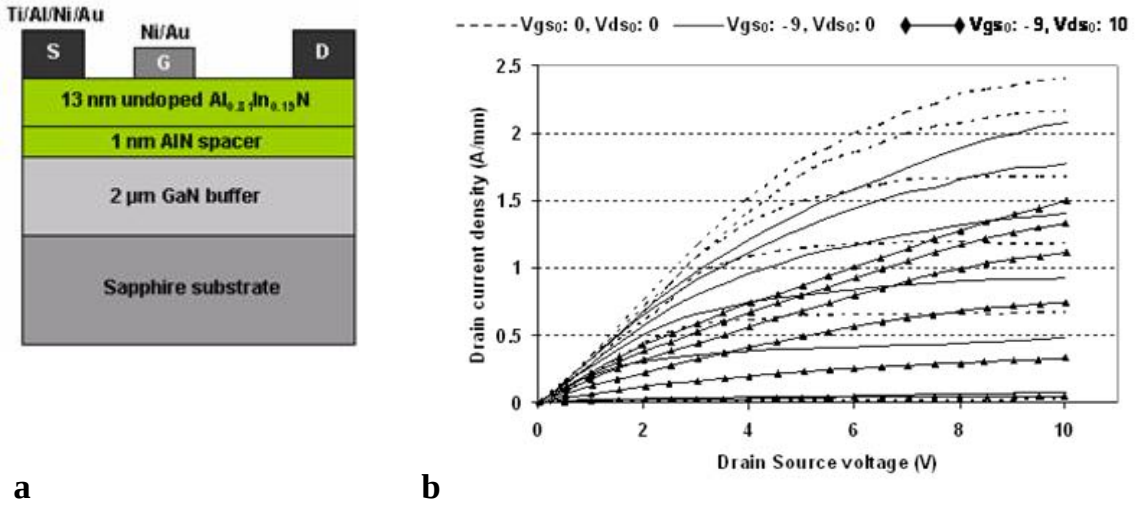

Figure 1: a) Schematic cross section of surface free AlInN/GaN HEMT (structure 1) b) Pulsed I_D-V_{DS} characteristics of the structure 1 with three different quiescent bias points. V_{GS} swept from -9 to 1 V by step of -2 V.

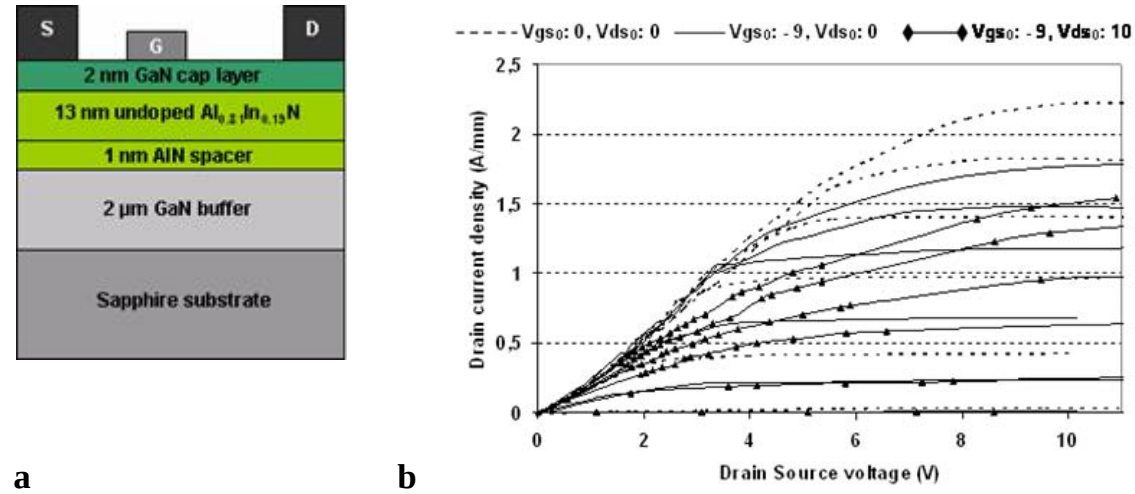

Figure 2: a) Schematic cross section of GaN capped AlInN/GaN HEMT (structure 2) b) Pulsed I_D-V_{DS} characteristics of the structure 2 with three different quiescent bias points. V_{GS} swept from -9 to 1 V by step of -2 V.

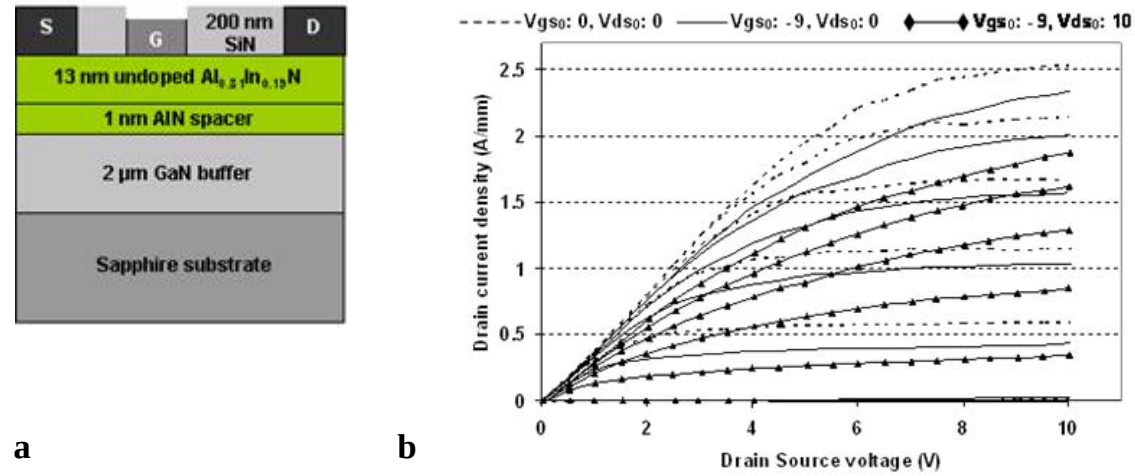

Figure 3: a) Schematic cross section of SiN passivated AlInN/GaN HEMT (structure 3) b) Pulsed I_D-V_{DS} characteristics of the structure 3 with three different quiescent bias points. V_{GS} swept from -9 to 1 V by step of -2 V.