Effect of AlN Spacer in the Layer Structure on High RF Performance GaN-based HEMTs on Low Resistivity Silicon at K-band Application.

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AlGaN/GaN High Electron Mobility Transistors (HEMTs) grown on Si substrate are emerging as an attractive devices for many RF applications. This is due to lower circuits realization cost and multifunction chips integration. In this study we investigate the effect of AlN spacer between AlGaN and GaN of a sub-micron gate (0.3 µm) AlGaN/GaN and AlGaN/AlN/GaN HEMTs on a Low Resistivity LR Si substrates on RF performance. We have observed an enhancement in RF performance f_T and f_{MAX} in the HEMT with of AlN spacer; (f_T) was increased from 47 GHz to 55 GHz and (f_{MAX}) was increased from 79 GHz to 121 GHz. This enhancement in performance is mainly due to the increase in the mobility in the channel and confinement of the carriers reducing C_{gs}, and delay τ under the gate. We believe this is the first RF study of this type as previous studies were based on the effects of the DC characteristic of the devices [1].

The GaN-based heterostructures with and without the AlN spacer layer were grown on 6-inch LR Si (111) (σ < 10 Ω.cm) substrate by MOCVD, as shown in figure 1. Both device structures were simultaneously fabricated and characterized for accurate comparison. Initially, the source/drain Ohmic contacts Ti/Al/Mo/Au (15/60/35/50 nm) were deposited and annealed at 800^0C for 30 s followed by the mesa isolation by $SiCl_4$ plasma. A minimum contact resistance (R_C) of 0.6 Ω.mm was achieved with transmission line model measurements. To form the centered T-gate between source and drain, 200nm-thick Si_3N_4 passivation layer was deposited and then the (0.3 × 100) µm footprint was opened by fully etching the Si_3N_4 layer. Ni/Au (20/200nm) bilayer was subsequently evaporated for gate metallization. Next, the Si_3N_4 in the Ohmic contact areas was etched whilst other areas were kept passivated to avoid any exposed GaN surface. Finally, NiCr/Au (50/200nm) was deposited for the 700 nm gate-head and optimized bond-pads simultaneously.

The DC *I-V* characteristics and transfer curve of the fabricated two-finger devices are shown in figures 2 and 3, respectively. It is observed that the HEMT with AlN spacer layer exhibits comparatively higher I_{DS} by 18% and lower pinch-off voltage by 0.8 V than conventional AlGaN/GaN devices. A maximum drain current density of 1.4 A/mm associated with peak extrinsic transconductance, G_M, of 400 mS/mm were obtained when the AlN spacer layer was presented. Consequently, slight degradation in the switching performance of AlGaN/AlN/GaN HEMTs occurs with R_{ON} = 2.76 Ω.mm compared to 2.24 Ω.mm for AlGaN/GaN HEMTs.

On-wafer RF measurements were carried out from 0.1-67 GHz. For precise comparison, both device structures were biased at their G_M where the highest f_T and f_{MAX} exist. The effect of the AlN interlayer on RF performance was characterized based on the bias-dependent equivalent-circuit elements values, which are indicated in table I [2]. Significant improvements in RF performance were observed when incorporating the AlN spacer in the layer structure. This improvement in performance is attributed to the decrease in device intrinsic capacitances; particularly C_{gs} as it was reduced from 145fF to 92fF. We believe this is due to the AlN interlayer as it plays a crucial rule in carriers confinement in the channel and therefore reduced access of carriers to electron traps at surfaces and crystalline defects. As a result, a maximum f_T of 55 GHz and f_{MAX} of 121 GHz were achieved for the AlGaN/AlN/GaN HEMTs in comparison to an f_T of 47 GHz and f_{MAX} of 79 GHz for the AlGaN/GaN HEMTs, as shown in figure 4.

We believe this is the highest RF performance reported to date for GaN-based HEMTs on LR Si substrates. In addition, we trust this is the first RF study on the effect of AlN interlayer on RF performance for GaN HEMTs on LR Si. The obtained GaN HEMTs on LR Si results are compatible and even better than what was reported in [3], [4] where Sapphire and High-Resistivity (HR) Si was used, respectively.

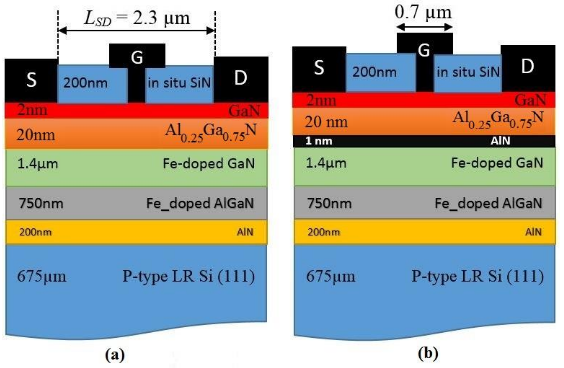

Figure 1. Schematic plot of the GaN-based HEMTs.

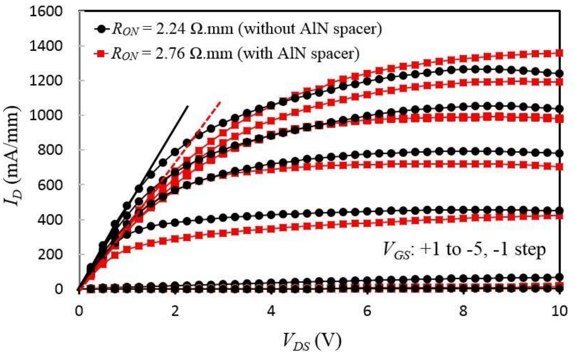

Figure 2. I_{DS}-V_{DS} characteristics for GaN-based HEMTs with Wg = (2×100) µm and Lg = 300 nm.

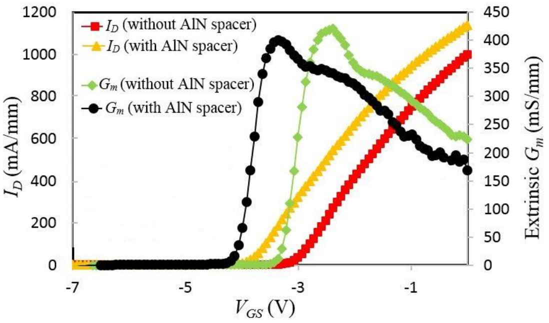

Figure 3. Transfer characteristic at V_{DS} = 10 V for the GaN HEMTs.

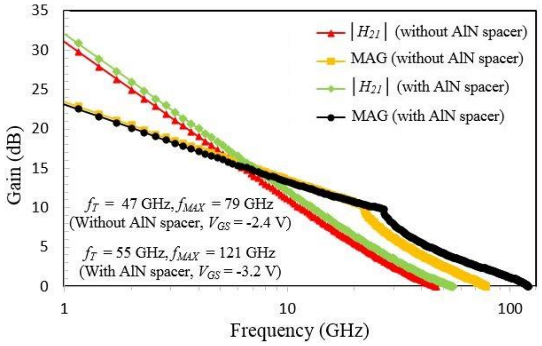

Figure 4. Microwave performance of the fabricated devices at V_{DS} = 5 V.

Table I. Extrinsic and Intrinsic Parameters for the fabricated HEMTs.

Extrinsic Parameters				**Intrinsic Parameters**			
Without AlN spacer		**With AlN spacer**		**Without AlN spacer**		**With AlN spacer**	
C_{pg} =43.9 fF	C_{pgd} = 16 fF	C_{pg} = 43.9 fF	C_{pgd} = 15 fF	C_{gd} = 9.1 fF	G_M = 602 mS/mm	C_{gd} = 10.5 fF	G_M =530 mS/mm
C_{pd} =43.1 fF	R_s = 10.5Ω	C_{pd} = 43.8 fF	R_s = 10.5Ω	C_{gs} = 145.4 fF	R_{in} = 20.3Ω	C_{gs} = 92.4 fF	R_{in} = 13.11Ω
L_s = 0.03pH	R_g = 17.9Ω	L_s = 0.03pH	R_g = 17.9Ω	C_{ds} = 15.6 fF	R_{gd} = 500Ω	C_{ds}= 11.8 fF	R_{gd} = 500Ω
L_g = 23pH	R_d = 12.3Ω	L_g = 23pH	R_d = 12.3Ω	τ = 1.5ps		τ = 1.2ps	
L_d = 25pH		L_d = 25pH					

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