AlGaN/GaN-heterojunction FET with inverted 2DEG Channel

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Abstract.

Novel heterojunction AlGaN/GaN-FET with inverted device channel is investigated. FET-heterostructures were grown by MBE on sapphire substrates. Devices were fabricated with 0,25μm-T-shaped gates, using electron beam lithography. Electron density profile under the device gate has demonstrated localization of electrons in very narrow nm-region (<10nm) at the bottom GaN/AlGaN – interface, giving direct evidence of HEMT-nature of our FET's. I-V-characteristics of HEMT's demonstrated high value of drain current I_d^{max}>1A/mm, and good extrinsic transconductance $g_m^{ext}\cong$140mS/mm. DC-specific output power of HEMT was 2,0W/mm. Extrinsic cut off frequency f_τ^{ext} of HEMT, determined from transconductance g_m and gate-source capacitance C_{gs}, was 20GHz. Its intrinsic value, f_τ^{ext}, was found to be as high as 36GHz.

Introduction.

AlGaN/GaN- HEMT's have demonstrated the unquestionable advantages over the other competitive RF-semiconductor technologies in the application both for the high power devices [1] and for the robust low noise amplifiers, combining the excellent noise performance with the high breakdown voltage [2]. Both of them are of the great importance for the RF-transmit-receive modules in the military and commercial active phase antenna array radars. The most of the papers in the field of the III-nitride technology are devoted to the devices, based on the HEMT-structure with the top AlGaN layer, and there are only a few papers, devoted to HEMT's with the inverted device channel (with GaN top-layer), though the latter's are much more stable with respect to the chemical reactions in the different ambient atmospheres and also are more preferable in terms of the realization of the high quality Ohmic contacts.

The present work describes the results of the investigation of the AlGaN/GaN HEMT's with the inverted device channel and includes: MBE-growth of heterostructures, fabrication of the devices with the T-shaped gate, and investigation of the device characteristics.

1. MBE-growth.

$Al_{0,3}Ga_{0,7}N$/GaN-FET-structures were grown by RF-assisted nitrogen plasma MBE on 2in-saphire (0001) substrates. Nitrogen radicals were generated by RF ADDON plasma source at RF-power of 400W. After nitrogenization of the growth surface during 30min at N_2-flow of 1,25cm^3/min at T_{sub}=750^{0}C, the following sequence was realized: deposition of a 2μm GaN buffer layer at

T_{sub}=690^{0}C, a 50nm – $Al_{0,3}Ga_{0,7}N$ barrier layer at T_{sub}=720^{0}C, a 30nm-GaN-channel at T=720^{0}C, and, finally, deposition of very thin 4nm-confining $Al_{0,3}Ga_{0,7}N$ layer at T_{sub}=725^{0}C.

Unlike the 'standard' AlGaN/GaN-HEMT-heterostructures, in our MBE-growth AlN- nucleation layer was not formed. Such a procedure allowed us to form the n-type of the conductivity, in the case of which the vectors of the spontaneous and piezoelectrical polarizations were oriented along the growth direction. This (as will be shown) provides the localization of two dimensional electron gas (2DEG) at the bottom boundary of the GaN – channel layer. Hall measurement showed a sheet electron density n_e of $2,7 \cdot 10^{13}cm^{-2}$ and an electron mobility of 500cm^2/Vs at room temperature.

2. Device fabrication and characterization.

Devices were fabricated using optical lithography and reactive-ion etching to define Ohmic contacts configuration and the mesa regions for the inter-device isolation. Ohmic contacts were formed by the rapid thermal annealing of evaporated Ti/Al/Ti/Au (or Ti/Al/Ti) -metallization at 820^{0}C for 40 sec in N_2-ambient using on-wafer transfer length method patterns. The Ohmic contact resistance was typically measured to be <1Ω-mm. T-shaped gates with lengths L_g of 0,25μm were defined using a tri-layer PMMA/MMA/PMMA -resist system and electron beam lithography. Ni/Au metals were then evaporated for gate metallization.

Typical DC output current-voltage characteristics of 20μm-wide FET with gate length L_g=0,25μm and the gate to drain spacing L_{gd}=1μm are shown in Fig.1.

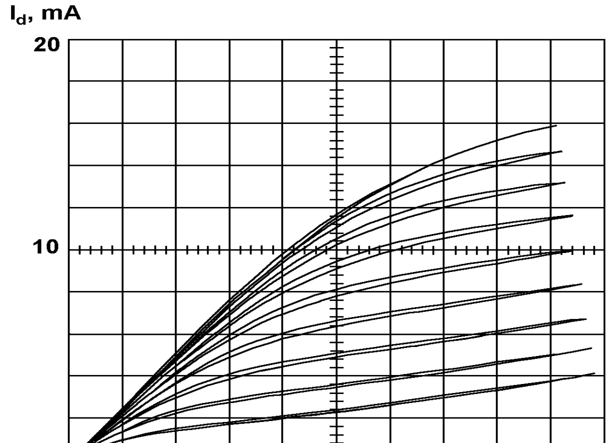

Fig.1. Output current-voltage (I-V) characteristics of 0,25μm AlGaN/GaN-FET at the different gate bias U_g(U_g-step is 1V).

According to Fig.1, the maximum saturation drain current I_d^{max}, is as high as 1A/mm at V_{gs}=O. The peak value of extrinsic transconductance, $g_m^{ext} = \frac{dI_d}{dU_g}$

(where U_g is the gate bias) is 140mS/mm. The devices have demonstrated the good values of the drain knee voltage U_d^k<2V, and the gate-drain break voltage V_{gd}^{BD} was typically 26-30V.

According to the shape of the depth profile of electrons $n_e(x)$, determined from the experimental $G_{gs}(U_{gs})$ – dependence of our FET, where C_{gs} is the gate to source capacitance and U_{gs} is the gate to source bias, the majority of the electrons in the channel layer are localized in the very thin (<10nm) bottom region of the channel at the GaN/AlGaN – interface. These results give a direct evidence of the two dimensional nature of the electron gas and, respectively, of HEMT-nature of FET's studied here. DC-specific output power of these HEMT's, calculated from I_d, U_d^k and U_d^{BD}-values, was 2W/mm. Coming from the experimental values of the extrinsic transconductance g_m=140mS/mm and the gate-to-source capacitance C_{gs}=0,9pF/mm, we have estimated the extrinsic current gain cut off frequency f_τ^{ext}:

$$f_\tau^{ext} = \frac{g_m}{2\pi C_{gs}} = 20GHz$$

Then, taking into account the parasitic source resistances R_s, we could estimate the intrinsic transconductance g_m^{int}=240mS/mm and the intrinsic current gain cut off frequency, f_τ^{int}=36GHz, both of which correspond to the best values, published for the AlGaN/GaN-HEMT's.

Conclusion.

A novel heterojunction 0,25µm-AlGaN/GaN-FET with inverted device channel on the sapphire (0001) substrate has been investigated. The voltage dependence of the gate capacitance in this FET has shown the strong localization of the majority of the electrons in the very narrow nm-region (<10nm) at the bottom GaN/AlGaN-interface, and, respectively, the HEMT-nature of the FET studied here. The output I-V characteristics of the HEMT's have demonstrated the high value of the drain current I_d>1A/mm, the good value of the extrinsic transconductance g_m^{ext}=140mS/mm, and the extrinsic cut off frequency f_t^{ext} of 20GHz. Intrinsic f_t value, f_t^{int}, was found to be as high as 36GHz. Characteristics of this inverted HEMT are among the best ones for a such type of devices.

References

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