PERFORMANCES OF LASER-PROCESSED HEMTs WITH AlAs-nGaAs SUPERLATTICE DONOR LAYERS

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ABSTRACT

In-site laser desorption of GaAs semi-insulating substrate surfaces prior to MBE growth and laser processing of ohmic contacts have been used for the fabrication of X-band HEMTs with superlattice donor layers. The improvements made lead to high performance devices.

INTRODUCTION

Molecular Beam Epitaxy (MBE) is the standard technique presently available for the fabrication of high electron mobility transistors (HEMTs). However, the inherent defects present in MBE epitaxial layers at interfaces and surfaces (oval defects, DX centers, dislocations) introduce a number of problems related both to device fabrication and performance. These problems result, for example, in poor transconductance values and a large dispersion of the threshold voltage.

In-site laser desorption of GaAs semi-insulating substrate surfaces, prior to MBE growth, has been developped as a method for attaining low temperature growth of buffer layers [1]. This technique has improved the interface properties between the GaAs substrate and the GaAs buffer layer and has resulted in minimizing the fixed charge which may be present at such interfaces. Buffer layers were grown using the technique of laser assisted MBE at temperatures as low as 400°C. Laser processing has also been used for the formation of low contact resistivity ohmic contacts on HEMTs and has been reported previously [2]. These two processing innovations have been systematically studied and optimized on MBE grown HEMT structures ; and then transferred for the fabrication on X-band HEMTs with superlattice donor layers.

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DEVICE FABRICATION

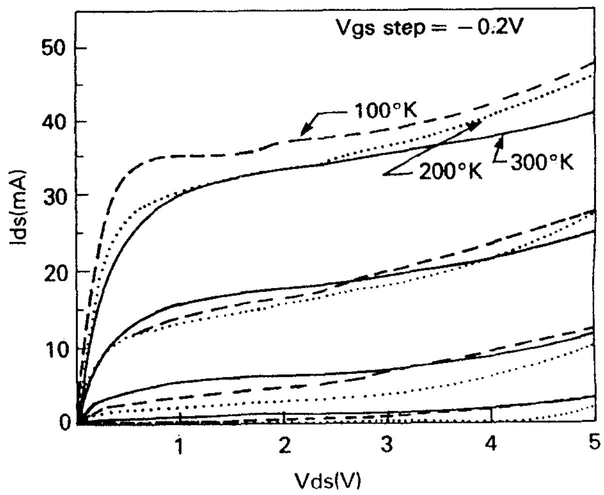
Laser desorption of undoped semi-insulating LEC GaAs substrates was accomplished by utilizing an excimer laser beam at 248 nm. The desorbed species were detected by a mass spectrometer and the optimum energy density for desorption was determined to be 90 mJ. cm^{-2} using 1pps for 1.5 min. The desorption was accomplished while the substrate was maintained at the growth temperature of 580°C for the GaAs buffer layer. The substrate temperature was then decreased to 400°C in order to complete the buffer layer growth. The laser was continuously pulsed for the first two minutes of MBE growth and then terminated when the RHEED 2x4 As stabilized pattern becomes sharp and excessively bright. A 4 µm thick undoped GaAs buffer layer was grown. The spacer consists of 100 Å of undoped $Al_{.27}Ga_{.73}As$. The donor layer is made with 7 periods of AlAs (40 Å) - GaAs (40 Å). The GaAs is spiked doped with Si at $2.10^{18} cm^{-3}$. The top layer consists of 40 Å of undoped GaAs of the superlattice buffer layer.

AuGeNi ohmic contacts were initially sintered at 450°C for one minute and then laser annealed at 60 mJ. cm^{-2} at 1 pps, 15 pulses. The resulting effect was to significantly lower the source resistance from 0.7-0.8 Ω/mm to less than 0.5 Ω/mm. The laser processing of the ohmic contacts resulted in a uniform, planar-like contact with the 2-DEG channel thereby lowering the contact resistivity. A 0.75 µm length X 200 µm width recessed TiPtAu gate is used. The chips were finally mounted in 70 mils hermetically sealed packages.

ELECTRICAL CHARACTERIZATIONS

Static Measurements and Physical investigations

We observed practically no collapse with the temperature (down to 90°K) on the I_{ds} (V_{ds}, V_{gs}) characteristics as illustrated Fig. 1, and the threshold voltage shift remained lower than 0.2 V.



. Fig. 1 : Ids(Vds, Vgs) characteristics as a function of the temperature.

The lack of threshold voltage shift was expected due to the presence of the AlAs-n.GaAs superlattice which eliminates DX centers [3]. However, the other traps (deep acceptors) contributing to this degradation [4] have also been eliminated.
The very low trap densities in the HEMT layers have been confirmed by means of Deep Level Transient Spectroscopy investigations (Fig. 2) and isothermal relaxation experiments (Fig. 3).

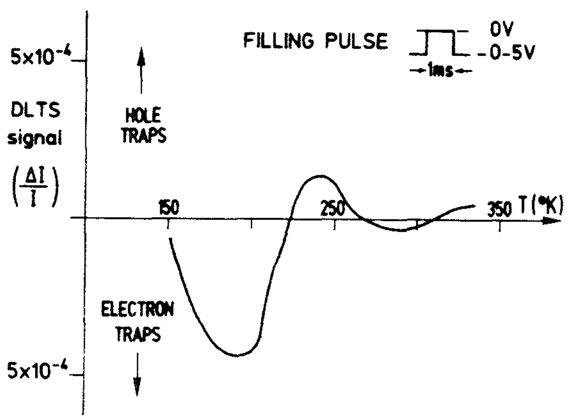


Fig. 2 : Typical DLTS spectrum. All three signals correspond to very low trap densities.

The level of traps were, as a first order estimate, in the range n_t = 1 to $5x10^{-4}$ N_D (as N_D= $2.10^{18}cm^{-3}$ $\Longrightarrow$ n_t = 2.10^{14} to $10^{15}cm^{-3}$). Typical values for n_t (DX centers) for GaAs/AlGaAs (x = .3) conventional HEMTs are in the range 10^{-2} to 1 N_D.

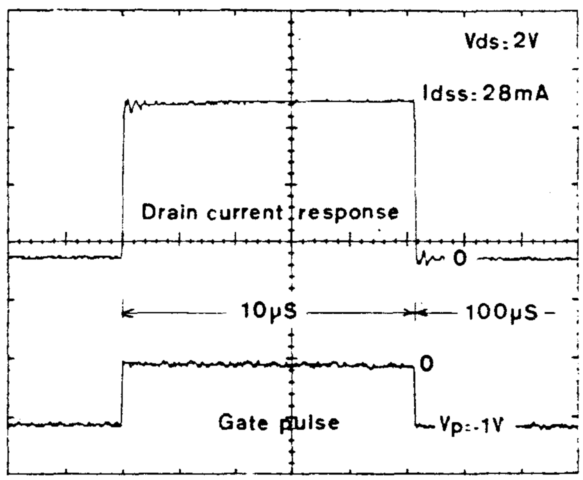


Fig. 3 : Isothermal relaxation : there are obviously no capture time by DX centers as observed on conventional HEMTs [5].

High transconductance (gm) values have been attained, ranging from 350 to 400 mS/mm of gate width. The gm versus V_{gs} characteristics do not exhibit the parasitic MESFET conduction generally observed with normal HEMT structures (Fig. 4). The pinch-off voltage (V_{gs}.off) dispersion stays within the margin of error (0.01 V). The total gate current (I_{gs}) measured at the DC operating point is about 300 nA and remains lower than 1 μA when measured near pinch-off (I_{gs}.off), as illustrated Fig. 5.

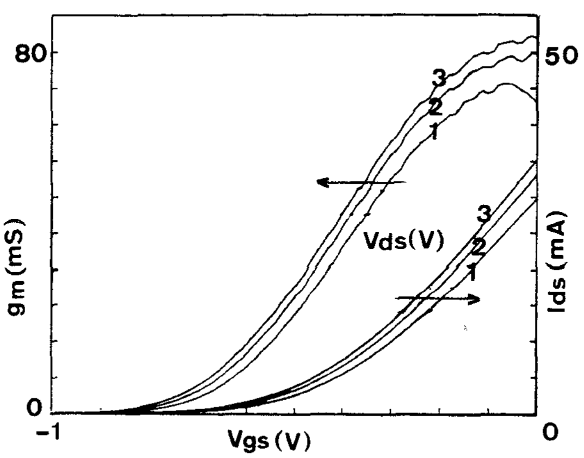


Fig. 4 : gm (Vgs, Vds) together with Ids (Vgs, Vds) characteristics. The pinch off voltage is ≃ 0.8 V.

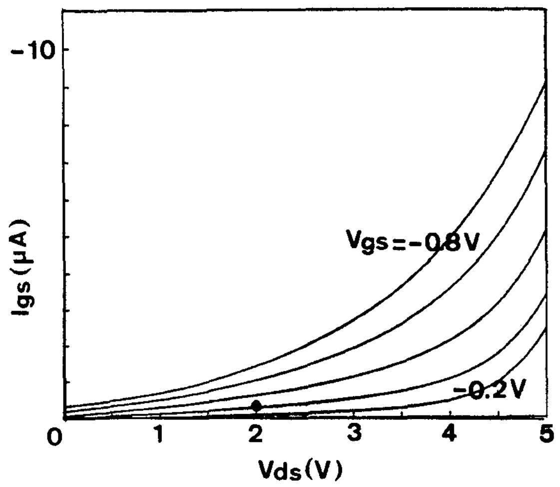


Fig. 5 : Igs (Vds, Vgs) characteristics.
• represents the static bias point for a low noise operation

The low trap densities together with the optimized values of device parameters such as gm, V_{gs}.off and I_{gs}.off, which strongly depend on the substrate preparation, the epilayer growth conditions and the interface quality, indicate the improvements achieved by laser processing of HEMTs.
Furthermore, to further assess these improvements, a characterization of the bulk parasitic effects limiting the operation of HEMT-based IC's has been carried-out. We report that the kink effect (detrimental to the gate switching because the threshold voltage becomes frequency-dependent) which is closely related to the buffer layer quality (residual doping) is drastically reduced, as reported in Fig. 6.

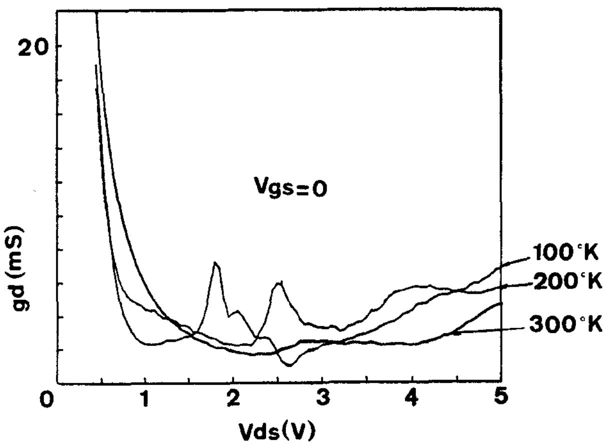


Fig. 6 : Outpout conductance gd vs Vds measured on Idss (i.e. Vgs = 0)as a function of the temperature. The abrupt increase on gd easily visualizes the kink effect.

The positive temperature coefficient indicates that the impact ionization mechanism is responsible for the kink effect. However, the observed increases on gd are in the range 2 to 5 ms. They are lower than values usually measured on conventional HEMTs : 10 to 15 mS [2].

Microwave measurements

Microwave parameters has been investigated from 8 to 12 GHz (see Fig. 7). The optimum DC bias point has been determined to be V_{ds} = 2 V and I_{ds} = 10-12 mA. At 10 GHz, the optimum Noise Figure (NF) is 0.9 dB with an Associated Gain (Ga) $\simeq$ 11 dB. At 12 GHz : NF = 1.2 dB with Ga $\simeq$ 10 dB were measured.

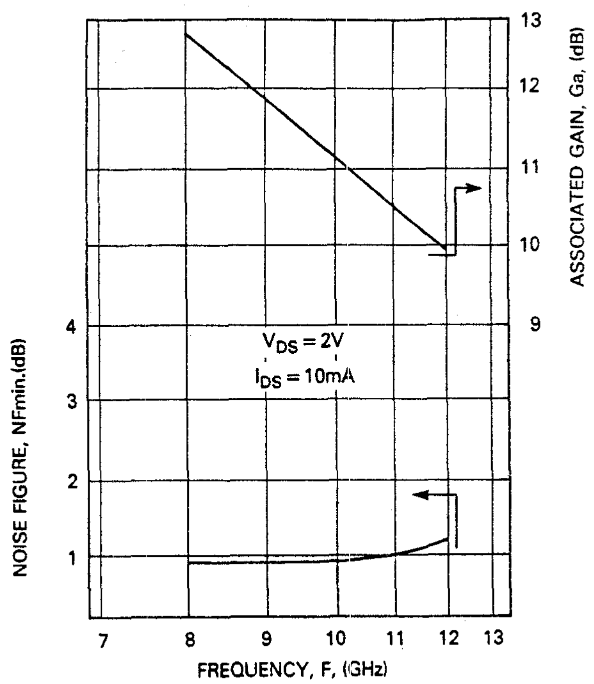


Fig. 7 : Noise figure (lower part) and Associated Gain (upper part) in the band 8-12 GHz. The optimum static bias point has been determined to be Vds = 2V and Ids = 10 mA .

One can note that the performances of these 0.75 μm gate length devices are clearly comparable to the "State-of-Art" values reported for 0.3 to 0.5 μm gate length conventional HEMTs. The lowering of the source resistance by laser processing may explain, in addition to several other parameters, the present optimized noise figure value for 0.75 μm gate length HEMTs.

RELIABILITY INVESTIGATION

Similar to any other type of device, screening can eliminate most of the infant mortality problems.
Life testing has also been carried-out on these devices. The advanced HEMTs were biased at the static bias point (V_{ds} = 2V, I_{ds} = 10 mA) for low noise operation and with accelerated channel-to-ambiant temperatures of 180 and 210°C. At the same time, conventional commercially available HEMTs (both MBE and MOCVD grown layers) have been driven into ageing under the same conditions. Parameters are automatically scanned. Failure criteria are computerized in order to switch-off the power supply when they are reached, thus preventing any burn-out.
1000 hours have been reached with only one failure which gradually developped between 200 and 500 H, at 180°C, on a superlattice HEMT. This is a classical gate defect inducing a high gate leakage current. It seems that the stability of the AlAs-n.GaAs superlattice (Al and/or Si diffusion) is not affected. These results indicate that reliability levels comparable to these of GaAs MESFETs are reached.

CONCLUSION

As a conclusion, we have reported that laser processing, by improving substrate preparation, MBE growth and ohmic contact fabrication, leads to high performance and reliable HEMTs.

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