MOCVD GROWTH OF GaAs-$Ga_{1-X}Al_XAs$ STRUCTURES FOR MICROWAVE MESFET's

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Abstract: MOCVD GaAs-$Ga_{1-X}Al_XAs$ epitaxial structures to fabricate MESFET's have been successfully grown in a low pressure MOCVD system. The growth parameters were optimized to obtain very high uniform epitaxial layers ($\sigma \simeq 2\%$). MESFET's were fabricated and the devices with heterobuffer layer showed good transconductance and linearity as compared to conventional GaAs buffered structures. A 7.7 dB gain was performed at $I_{DSS}/2$ at 18 GHz. However the breakdown voltage has to be improved by lowering the background doping in the $Ga_{1-X}Al_XAs$ buffer layer.

Introduction

The demand of better performing GaAs MESFET devices is driving the development of highly sophisticated technologies for device fabrication, but also new epitaxial structures suitable to improve device characteristics.
FET transconductance and output conductance are parameters affected very much by the active-buffer layer interface quality. In particular substrate conduction and poor electron confinement are the main sources for FET performance degradation.
The compensation of buffer layers by deep levels is at present a practical way to reduce the two previously mentioned effects, but the growth of a $Ga_{1-X}Al_XAs$ buffer layer (Fig.1) is expected to give significant advantages to device performances mainly due to the reduced electron velocity in the ternary buffer layer and to the improved carrier confinement given by the conduction band discontinuity of the heterostructure. [L.F. Eastman and M.S.Shur, IEEE Trans. on ED Vol.ED-17 n°5, May 1970].
Among the available growth techniques suitable to obtain device quality and reproducible GaAs-$Ga_{1-X}Al_XAs$ structures, MOCVD is becoming very attractive because of the maturity of the equipment technology and of the industrial oriented process with good layer properties with even superior morphological qualites compared to MBE layers.
However, state of the art $Ga_{1-X}Al_XAs$ epitaxial layers grown by MOCVD suffer from the difficulty of reducing the background impurity concentration down to typical GaAs values and practical applications to FET buffer layers are yet to be fully demonstrated.

Experimental and discussion

GaAs and $Ga_{1-X}Al_XAs$ epitaxial structures were grown on Semiinsulating GaAs substrates in a low pressure MOCVD horizontal reactor [AIXTRON GmbH]. Hydrogen was used as carrier gas and arsine (AsH_3), trimethygallium (TMGa) and trimethyaluminium (TMAl) were used as growth sources. N-type doping was obtained by injecting into the growth chamber a hydrogen-silane mixture. Background impurity concentration and the electrical parameter uniformity were investigated in GaAs-$Ga_{1-X}Al_XAs$ layers and structures to determine the optimum growth parameters and conditions. The Al content was varied between X=0 and X=0.5.

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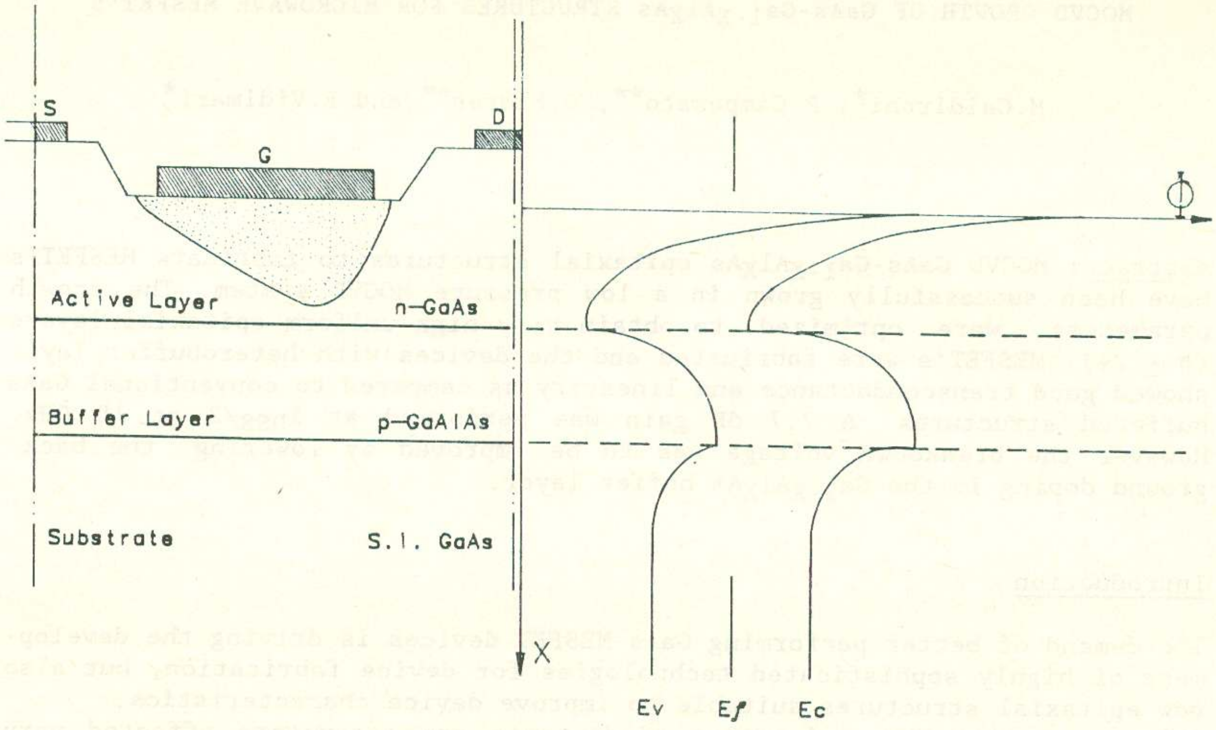

Fig.1 - $Ga_{1-X}Al_XAs$ buffered MESFET section and band structure.

Unintentionally doped GaAs layers always exhibited n-type behaviour with a typical residual doping level of about 2xE14 cm^{-3} with 77 K mobilities of 95-105.000 cm^2/v.s.

On the other hand, $Ga_{1-X}Al_XAs$ layers showed, in the range of $0.15<X<0.5$, a p-type conduction with a background doping between 2xE16 and 2xE17 cm^{-3} respectively at X=0.15 and X=0.5 Al mole fraction in the ternary layers.

The background doping levels observed in the $Ga_{1-X}Al_XAs$ layers are in good agreement with other workers [T.K.Kuech, M.A.Tischler, R.Potemski, F.Cardone and G.Scilla, Journal of crystal growth Vol.98 (1983) pp.174-187] and it is likely to be due to carbon incorporation into As sites during growth.

Even though the mechanism of carbon incorporation in $Ga_{1-X}Al_XAs$ is not yet well understood, its uptake into the growing layer can be reduced by increasing the V/III ratio [T.K.Kuech, M.A.Tischler, R.Potemski, F.Cardone and G.Scilla, Journal of crystal growth Vol.98 (1989) pp.174-187].

However in these experiments this ratio could be at maximum 100.

In the applications to heterobuffer MESFET structures, the relatively high background doping of $Ga_{1-X}Al_XAs$ layers and its increasing extent with Al mole fraction, limit the choice of layer composition range. In fact the benefit of a higher band gap discontinuity at the active-buffer layer interface could be compromised by the associated high doping level of the ternary buffer layer. An Al mole fraction of X=0.3 was a good compromise in order to minimize the background doping and to maintain the advantage of a heterostructure.

GaAs MESFET structures with a GaAs or $Ga_{1-X}Al_XAs$ buffer layers were grown on 2" <100> oriented CaAs Semiinsulating substrates. The growth conditions are reported in Table 1.

The Si doped active layer had a carrier concentration of N=2xE17 cm^{-3} and a thickness of 0.5 microns in both kinds of structures. Undoped GaAs buffer layers had a thickness of 0.5 microns while $Ga_{1-x}Al_xAs$ buffer layers were 0.2 microns thick.

Table I

Conditions	*GaAs*	*$Ga_{0.7}Al_{0.3}As$*
Growth temperature	700°C	700°C
Growth rate	2.2 micron/h	3 micron/h
Reactor pressure	20 mbar	20 mbar
V/III ratio	200	85
Flow velocity	2.1 m/s	1.7 m/s

The thickness reduction was necessary to guarantee that the whole buffer layer were completely depleted by the active layer charge in order to minimize the parasitic capacitances to final devices.

The heterostructures were grown with the compositional transition occurring in few monolayers.

Doping and thickness uniformity distribution over 2" wafers were assessed by two dimentional mapping of test patterns containing FET saturated current, carrier concentration and sheet resistance devices.

Reproducible structures with active layer sheet resistance with a standard deviation below 6% can be routinely obtained on FET structures with homo and heterobuffer layers (Fig.2). However a very careful control of the growth parameters and a rotating susceptor will help to achieve deviationsof sheet resistance in the range of 1%.

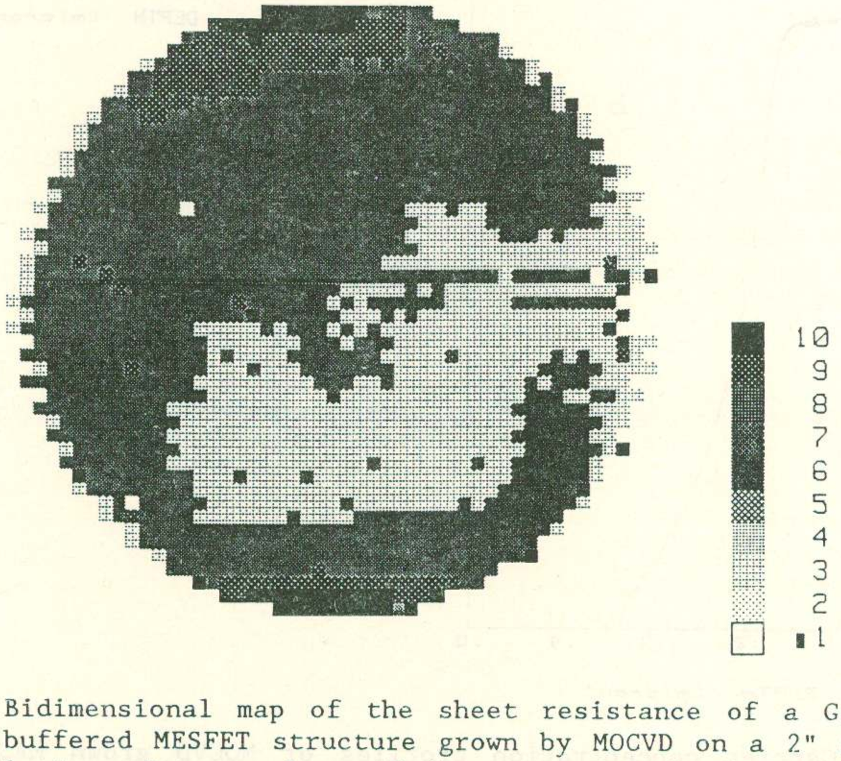

Fig.2 - Bidimensional map of the sheet resistance of a $Ga_{1-x}Al_xAs$ buffered MESFET structure grown by MOCVD on a 2" semiinsulating GaAs wafer. Each tone is 3 ohm/□ . Average sheet resistance is 185 ohm/□ and standard deviation is 3.5 ohm/□ .

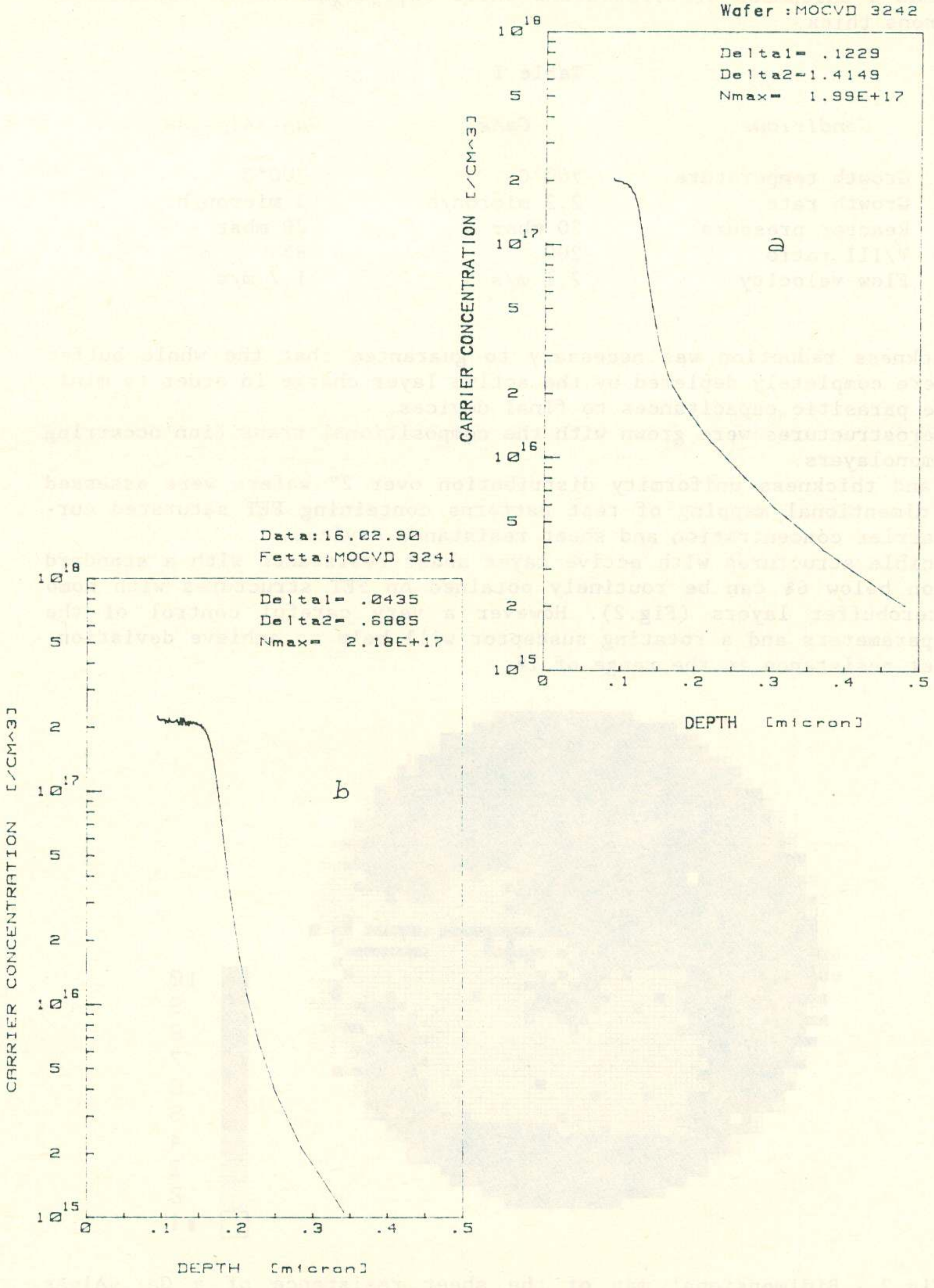

Fig.3 - Carrier concentration profiles of MOCVD grown MESFET epi-structures with a) GaAs and b) $Ga_{1-x}Al_xAs$ buffer layer.

Typical carrier concentration profiles of a homostructure and a heterostructure for FET devices are shown respectively in Fig.3a) and 3b). The carrier confinement is more effective in the structure with Ga$_{1-x}$Al$_x$As buffer layer as can be seen by comparing the sharpness of the carrier concentration transition at the active-buffer layer interface.
0.7 micron gatelength MESFET devices were fabricated on both kind of structures.

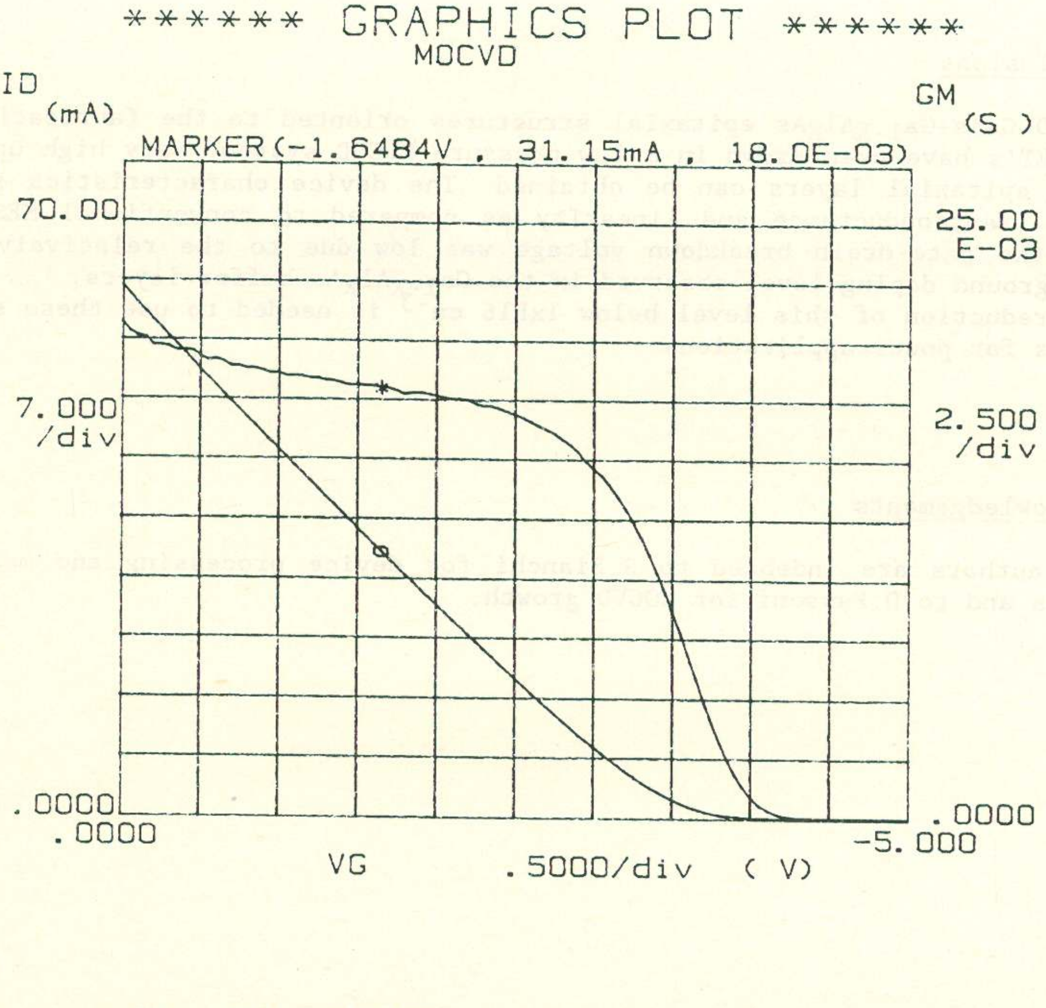

Fig.4 - DC transcharacteristics of a MESFET fabricated on a GaAs-Ga$_{1-x}$Al$_x$As epitaxial structure (V_{DS}=4 V).

The comparison of the DC characteristics shows a better linearity and a slight lower output conductance (0.54 mS) for the device fabricated on the heterostructure buffer layer. In Fig.4 the DC transcharacteristics of a 150 micron periphery MESFET fabricated on a GaAs/Ga$_{1-x}$Al$_x$As structure are shown.

Small signal S-parameters were measured on 150 micron periphery devices using Cascade Microtech Probe up to 18 GHz. MESFET's with GaAs buffer and $Ga_{1-x}Al_xAs$ buffer layer gave respectively a small signal gain of Ga=7.2 dB and Ga=7.7 dB.
However the gate-drain breakdown voltage resulted to be lower in the $Ga_{1-x}Al_xAs$ buffered devices (BV ~ 7 V) against the conventional MESFET (BV ~ 15 V).
This behaviour is likely to be due to the relatively high background doping in the $Ga_{1-x}A_1As$ layer, thus limiting at present the use of these devices for high power applications.

Conclusions

MOCVD GaAs-$Ga_{1-x}Al_xAs$ epitaxial structures oriented to the fabrication of MESFET's have been grown in a low pressure MOCVD system. Very high uniformity epitaxial layers can be obtained. The device characteristics showed good transconductance and linearity as compared to conventional MESFET's but the gate-drain breakdown voltage was low due to the relatively high background doping level observed in the $Ga_{1-x}Al_xAs$ buffer layers.
The reduction of this level below 1xE16 cm^{-3} is needed to use these structures for power applications.

Acknowledgements

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