MOCVD grown Metamorphic InAlAs/InGaAs HEMTs on GaAs substrates

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Abstract

We report MOCVD-grown metamorphic InAlAs/InGaAs HEMTs with good device performance, by introducing a multi-stage buffer growth scheme. Room temperature Hall mobility of the 2-DEG was over 8000 cm^2/V-s with sheet carrier densities larger than 3 x 10^{12} cm^{-2}. Transistors with 0.7µm gate length exhibited transconductance up to 427mS/mm and current gain cut off frequency (f_T) of 48GHz.

INTRODUCTION

MHEMTs by MBE have been demonstrated with huge successes [1, 2] in the past few years. Metamorphic technology by MOCVD is much lagged behind MBE and there have been very scarce reports, particularly with device results. One major difficulty has been the growth of metamorphic RF devices on GaAs substrates by MOCVD with a high resisitivity buffer. Significant buffer leakage is detrimental to the RF operation of HEMTs. We have developed a multi-stage buffer growth technique to achieve high resistivity in the buffer layer leading to good device performance. This sets the stage for potential MHEMT manufacturing by MOCVD.

MATERIAL GROWTH AND DEVICE FABRICATION

Metamorphic $In_{0.51}Al_{0.49}As/In_{0.53}Ga_{0.47}As$ HEMTs were grown on 4-inch (001) oriented semi-insulating GaAs substrates using an Aixtron AIX-200/4 MOCVD system. CBr_4 was used as C dopant source for one of the buffer layers. The epitaxial structure is shown in figure 1.

The growth temperature of the first InP metamorphic buffer layer was varied from 450 to 600℃. Another low-temperature (LT) InP: C layer (buffer 2) grown at 500℃ serves as a high resistivity buffer to isolate the active layers from the conductive buffer. This is followed by a composite LT, high resistivity InAlAs (buffer 3) and a HT (600℃) 10nm-thick InAlAs (buffer 4). The MHEMT active layers were grown at a substrate temperature of 650 ℃ . Device fabrication was started with mesa isolation by wet chemical etching down to the LT-InAlAs buffer. The source/drain ohmic contacts were formed by E-beam evaporated AuGe-Ni-Au metals and rapid thermal annealing at 360℃ for 120s.

Si-doped $In_{0.53}Ga_{0.47}As$, 150A (n= 5 x 10^{18} cm^{-3})	Contact layer
u- $In_{0.51}Al_{0.49}As$, 150A	Barrier
Si-doped $In_{0.51}Al_{0.49}As$, 150A (n= 2 x 10^{18} cm^{-3})	Carrier supply layer
u- $In_{0.51}Al_{0.49}As$, 50A	Spacer
$In_{0.53}Ga_{0.47}As$, 200A	Channel
Undoped HT- $In_{0.51}Al_{0.49}As$, 1000A	Buffer 4
Undoped LT- $In_{0.51}Al_{0.49}As$, 2500A	Buffer 3
LT-InP: C, 2000A	Buffer 2
High temperature undoped InP, 0.65µm	Buffer 1
Low temperature undoped InP, 110nm	Nucleation
Semi-insulating GaAs(100) Substrate	

Fig. 1 Cross section of MHEMT structure.

The resulting contact resistance was around 0.29Ω-mm, determined by TLM measurements. Double gate recess was achieved by selective wet-etching of the cap layer and wide recess groove etching. Finally, defining and deposition of the Ti/Pt/Au-gate electrodes were done by metal liftoff process. No passivation was used on the devices.

RESULTS AND DISCUSSION

From the Hall Effect Measurements, the electron mobilities of the MHEMT structure were 8,010 and 21,900 cm^2/V-s with sheet carrier densities of 3.30 x 10^{12} cm^{-2} and 3.16 x 10^{12} cm^{-2} at 300K and 77K, respectively. In our preliminary studies, buffer leakage problems resulted in MHEMTs that could not be pinched off, which was traced to some unintentional conductive impurities in the buffer and substrate interface. Buffer leakage was also problematic in lattice-matched HEMTs by MOCVD due to conductive impurities within the buffer and substrate interface [3]. High resistivity buffer layer is the key to good RF device performance. Effectiveness of the InP:C and InAlAs buffer grown at LT was demonstrated by step-etched Hall measurements. With removal of the active layers, the material changed to very high resisitivity and eventually exceeded measurement limit of the Hall system. In our devices, all the layers are compositional lattice matched to InP. Figure 2 shows the HR-XRD rocking curve of a MHEMT grown on a GaAs substrate. The single peak, locating at 31.67 degree with a FWHM of 340arcsec, indicates excellent lattice matching of the multi-layered buffer and the active device structure, and reasonably good crystalline quality.

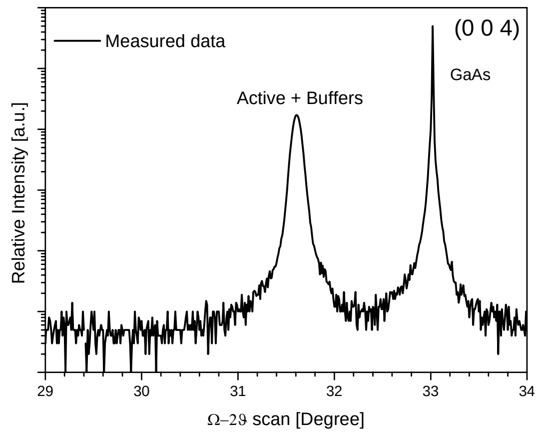

Fig. 2 HR-XRD rocking curve of a MHEMT

Shown in figure 3 is an AFM image of the MHEMT structure. The RMS value of the surface roughness was 2.3nm scanned across a 2µm x 2µm area.

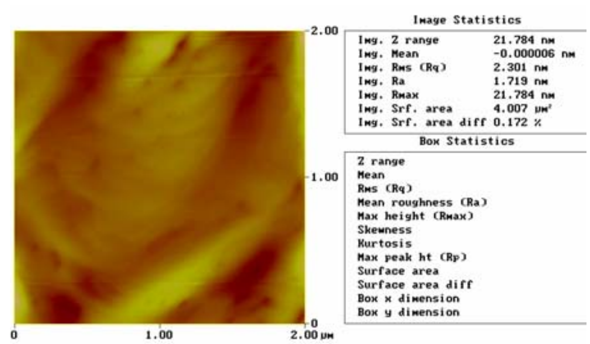

Fig. 3 AFM image of a MHEMT surface.

Encouraging device performance was obtained on the MOCVD grown MHEMT devices. Fig. 4 shows the DC result of the device, with kink-free I-V characteristics.

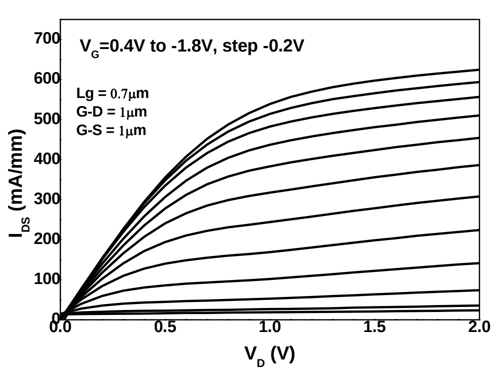

Fig. 4 Output characteristics of a MHEMT

The off-state breakdown was around 6V at Vg = -1.6V. From the DC measurement, the maximum saturation Current I_{DSmax} was determined to be 660 mA/mm at V_{DS} = 1.5V. Transistors with 0.7µm gate length exhibited transconductance up to 450mS/mm (Figure 5). The RF

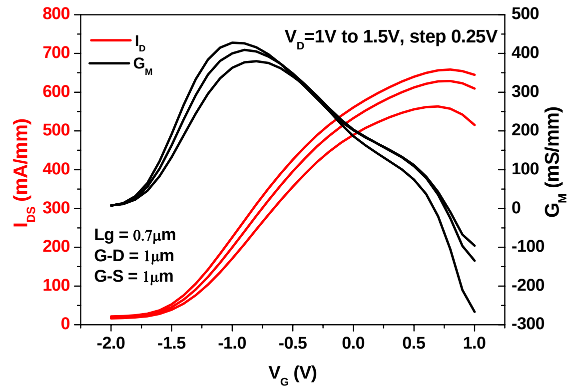

Fig. 5 Saturation current and transconductance versus gate bias

current gain cutoff frequency of 48GHz was shown in figure 6. Maximum oscillation frequency (f_{Max}) was around 56GHz.

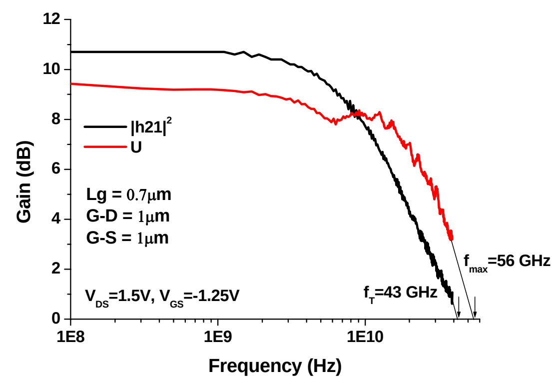

Fig. 6 RF small signal characteristics

The SEM photo shows a device with 1.5µm gate length and 50µm width on each finger.

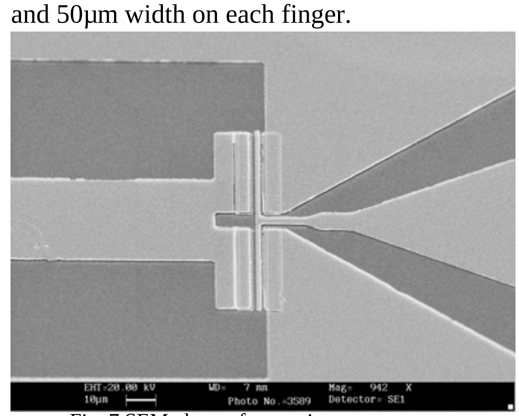

Fig. 7 SEM photo of a transistor

CONCLUSIONS

We have successfully grown metamorphic InAlAs/InGaAs HEMTs by MOCVD techniques with good device characteristics, by introducing a multi-stage buffer growth. We believe the DC and RF performance of the devices is among the best by MOCVD.

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ACRONYMS

MOCVD: Metalorganic Chemical Vapor Deposition
MHEMT: Metamorphic High Electron Mobiility Transistor
2DEG: 2 Dimensional Electron Gas
LT: Low Temperature