Growth, Fabrication and Characterization of $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As/InAs_{0.3}P_{0.7}$ Composite channel HEMTs

Dongmin Liu, Mantu Hudait, Yong Lin, Hyeongnam Kim, Steven A. Ringel, Wu Lu
Department of Electrical and Computer Engineering
The Ohio State University
Columbus, OH 43210, USA

InP-based composite channel high electron mobility transistors (HEMTs) are attractive to improve the breakdown voltage and power performance of InAlAs/InGaAs HEMTs. InP and InGaAs with lower Indium concentration have been used in composite channel HEMT devices. In this work, we present our recent results on the growth, fabrication, and characterization of $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As/InAs_{0.3}P_{0.7}$ composite channel HEMTs.

The epilayer structure for this study is shown in Figure 1. The MBE grown device wafer had a two-dimensional sheet carrier density of 3 x 10^{12} cm^{-2} and a Hall electron mobility of 7300 $cm^2/V \cdot s$ at room temperature. Figure.2 shows the simulation result of depth profile of conduction band and electron concentration at equilibrium by solving Poisson and Schrodinger equation self-consistently in one dimension. Electrons are confined in InGaAs main channel at equilibrium and transfer to InAsP sub-channel under high electric field. The device fabrication started with mesa isolation by dry etching using Cl_2/Ar plasma. Ge/Au/Ni/Au Ohmic contacts were deposited and annealed at 360 °C for 1 minute in a furnace in N_2 ambient. The contact resistance is 0.03 Ω·mm. 0.25 μm long mushroom gates were patterned by electron beam lithography, followed by a two-step gate recess etching process. Finally, Ti/Pt/Au was deposited as Schottky gate contacts. The device drain to source spacing is 2 μm.

DC characteristics of InGaAs/InAsP composite channel HEMTs were measured on wafer using Agilent 4156 Semiconductor Parameter Analyzer. The I-V characteristics are shown in Fig. 3. The maximum drain current at $V_{GS} = 0.2$ V and $V_{DS} = 1$ V is 432 mA/mm. The devices pinch off well at a gate voltage of -0.5 V. Fig. 4 shows the device transfer characteristics. The maximum extrinsic transconductance (g_m) achieved is 888.3 mS/mm at $V_{GS} = -0.01$ V and $V_{DS} = 0.8$ V. The small signal microwave characteristics of the composite channel HEMT were measured using an Agilent 8510C network analyzer from 1 GHz to 40 GHz. Fig. 5 shows the dependence of intrinsic current gain ($|H_{21}|^2$) and maximum stabile/available gain (MSG/MAG) on frequency for a typical device at V_{GS}=-0.02 V and $V_{DS} = 0.8$ V. The cutoff frequency (f_T) determined to be 115 GHz by extrapolating the $|H_{21}|^2$ at -20dB/dec. The maximum frequency of oscillation (f_{max}) is 137 GHz. Fig. 6 is the dependence of f_T and f_{max} on the gate bias voltage. The drain bias is fixed to 0.8 V. f_T (f_{max}) increased from 20 GHz (44 GHz) at $V_{GS} = –0.4$ V to 115 GHz (137 GHz) at $V_{GS} = -0.02$ V.

In conclusion, we have demonstrated the first $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As/InAs_{0.3}P_{0.7}$ composite channel HEMTs. The 0.25 μm devices exhibited a peak extrinsic transconductance of 888.3mS/mm, an f_T of 115 GHz, and f_{max} of 137 GHz. To our knowledge, the f_T is the highest ever-reported in literature for composite channel HEMTs with the same gate length.

This work was supported by the NSF FRG Grant DMR-0313468.

1-4244-0084-8/05/$20.00/©2005 IEEE

Cap	InGaAs	400Å	1×10^{19} cm^{-3}
EtchingSto	InP	60Å	undoped
Barrier	InAlAs	100Å	undoped
δ-doping	Si	-	6×10^{12} cm^{-2}
Spacer	InAlAs	30Å	Undoped
Channel	InGaAs	70Å	Undoped
Channel	InAsP	40Å	Undoped
Channel	InAsP	40Å	2×10^{18} cm^{-3}
Buffer	InAlAs with supperlattice	3600 Å	Undoped
Substrate	InP	-	-

Figure 1. MBE-grown layer structure for InAlAs/InGaAs/InAsP composite channel HEMT on InP substrate.

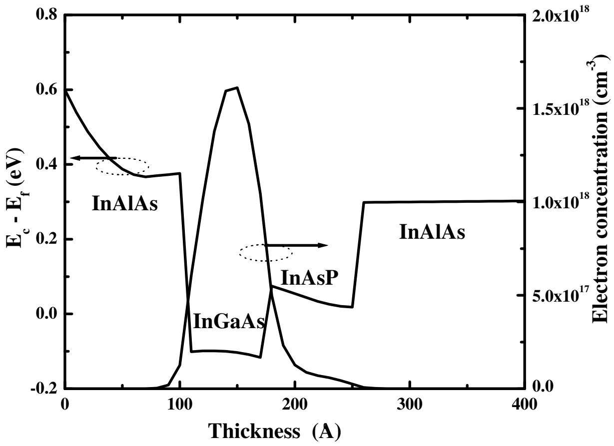

Figure 2. Simulated conduction band diagram and electron distribution in composite channel HEMTs at equilibrium (Thickness starts from barrier layer).

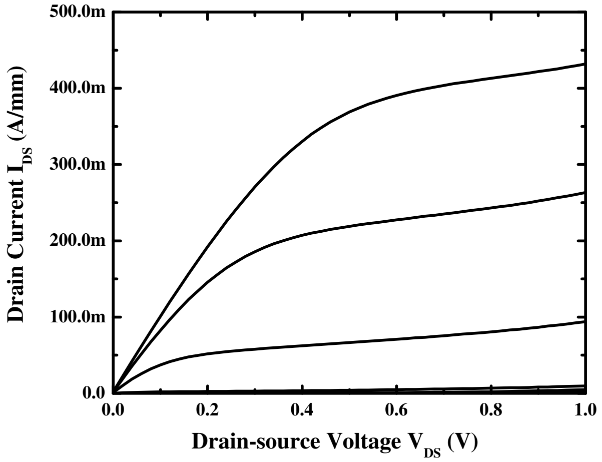

Figure 3. DC I-V characteristic of a 0.25 x 2 x 50 μm^2 composite channel HEMT. Gate was biased from –0.6 V to 0.2 V in a step of 0.2 V.

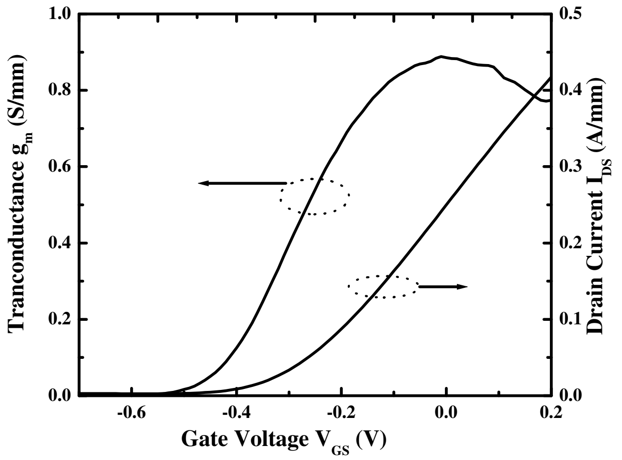

Figure 4. Transfer characteristic of a 0.25 x 2 x 50 μm^2 composite channel HEMT. The drain was biased at 0.8 V.

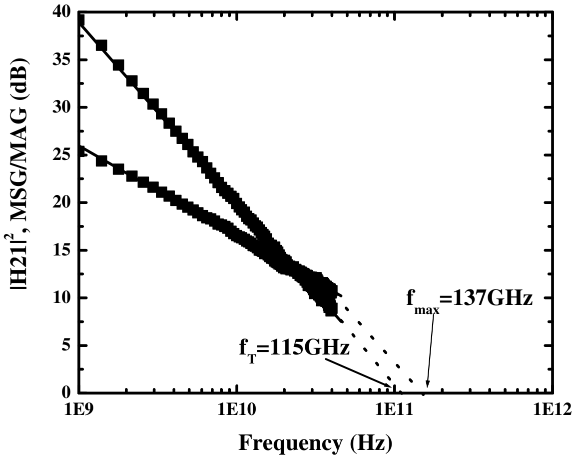

Figure 5. Current gain and maximum stable (available) gain characteristics of a typical 0.25 x 2 x 50 μm^2 composite channel HEMT.

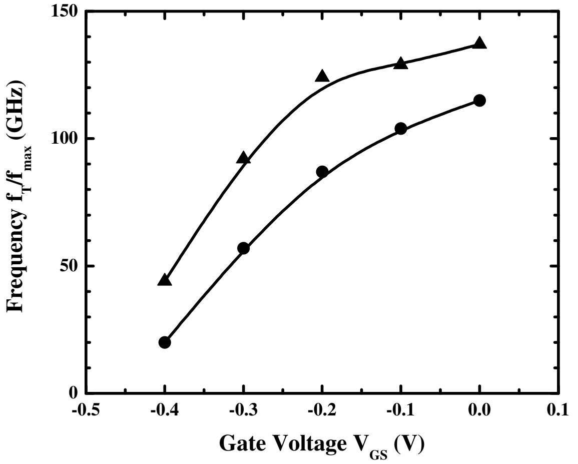

Figure 6. Dependence of f_T (circle) and f_{max} (triangle) on gate bias voltage. The drain is biased at 0.8 V.