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High-Performance $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ Power Metamorphic HEMT for Ka-Band Applications

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Abstract **· A 70-nm $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ power MHEMT with double δ-doping was fabricated and evaluated. The device has a high transconductance of 827 mS/mm. The saturated drain-source current of the device is 890 mA/mm. A current gain cutoff frequency (f_T) of 200 GHz and a maximum oscillation frequency (f_{max}) of 300 GHz were achieved due to the nanometer gate length and the high Indium content in the channel. When measured at 32 GHz, the 4 × 40 μm device demonstrates a maximum output power of 14.5 dBm with P1dB of 11.1 dBm and the power gain is 9.5 dB. The excellent DC and RF performance of the 70-nm MHEMT shows a great potential for Ka-band power applications.**

I. INTRODUCTION

FOR High frequency communication system applications such as communication satellites, radar, mobile millimeter-wave communication, and smart munitions, high-performance power amplifiers are required in the emission part. Due to superior low noise and power performances in the millimeter-wave range, InAlAs/InGaAs metamorphic HEMT (MHEMT) is a good alternative to pseudomorphic HEMT (PHEMT) on GaAs or lattice-matched HEMT on InP [1]. Although, PHEMT grown on GaAs substrate has demonstrated excellent output power density at 60 and 94 GHz in the previous work [2]. The power gain and power added efficiency (PAE) were limited by the low Indium content of the pseudomorphic InGaAs channel. On the contrary, InP-based HEMTs have shown excellent high frequency characteristics by reducing the gate length (L_g) to sub-100nm range [3], [4]. However, the advantages of InP-based HEMTs, such as higher electron saturation velocity, higher conduction band discontinuity and lower access resistance, also can be achieved with MHEMT that can be grown on less expensive and larger size GaAs substrate [5]–[7]. In this work, a 70-nm $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ power MHEMT with double δ-doping structure was processed and evaluated. The device demonstrates excellent DC and RF performances at Ka-band and shows great potential for the millimeter-wave power applications.

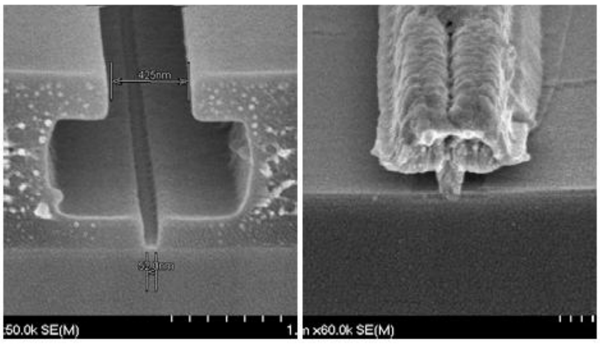

Fig. 1 Cross-sectional SEM images of the (a) resist profile and the (b) 70-nm T-gate of the MHEMT.

II. EXPERIMENT

The epitaxial structure of the MHEMT was grown by molecular beam epitaxy (MBE) on 3-inch semi-insulating GaAs substrate. The structure from bottom to top consists of an InAlAs buffer layer, a Si δ-doping layer, an $In_{0.52}Al_{0.48}As$ spacer, an $In_{0.6}Ga_{0.4}As$ channel layer, an $In_{0.52}Al_{0.48}As$ spacer, a Si δ-doping layer, an $In_{0.52}Al_{0.48}As$ barrier layer, and a Si-doped $In_{0.53}Ga_{0.47}As$ cap. The double δ-doping structure and the $In_{0.6}Ga_{0.4}As$ channel layer of the MHEMT are designed to provide higher carrier concentration and superior electron transport properties.

The mesa isolation was done by wet

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chemical etch. Source and drain Ohmic metals were formed with Au/Ge/Ni/Au. The T-shaped gate was carried out in the 50-KeV JEOL electron beam lithography system (E-beam) using conventional tri-layer E-beam resist with two steps exposure. The tri-layer resist system of ZEP-520/PMGI/ZEP520 was used for the E-Beam lithography and shown in Fig. 1(a). The Ti/Pt/Au was evaporated as gate metal. The gate length of the T-shaped gate was 70nm as shown in Fig. 1(b). Finally, a 100-nm-thick silicon nitride was deposited as passivation layer using PECVD method.

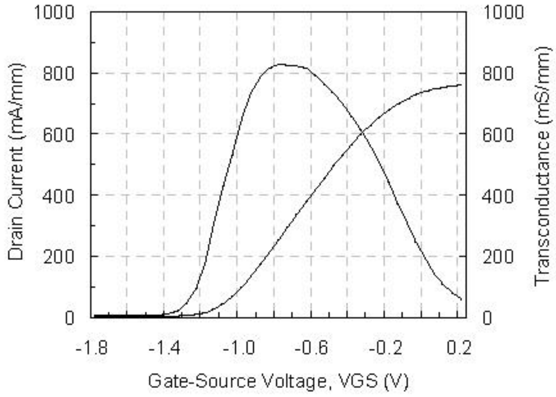

Fig. 2 Current-voltage characteristics of the 2 × 40 μm MHEMT.

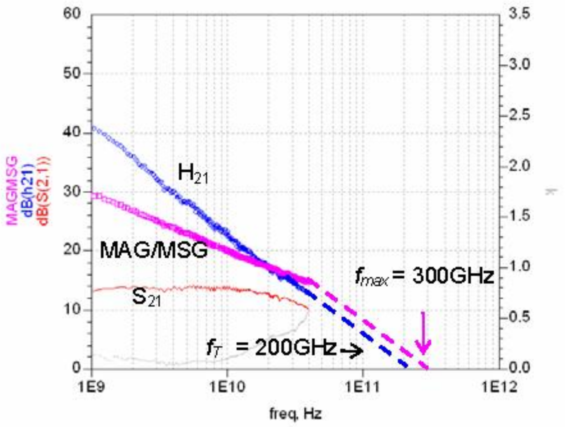

Fig. 3 Frequency dependence of the current gain (H_{21}) and *MAG/MSG* of the power MHEMT.

III. RESULTS AND DISCUSSION

Fig.2 shows the current-voltage characteristics of the 2 × 40 μm MHEMT. The fabricated $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ MHEMT shows a maximum drain-source current of 890 mA/mm and transconductance of 827 mS/mm. The high current density was due to the double δ-doping structure which provided higher carrier concentration and superior electron transport properties in the $In_{0.6}Ga_{0.4}As$ channel.

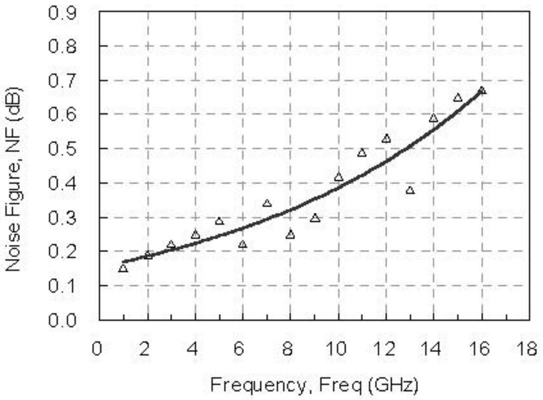

Fig. 4 Noise Figure (NF) of the 2 × 40 μm MHEMT measured from 1 to 16 GHz.

S-parameter measurement was done from 1 – 40 GHz by using a vector network analyzer with an on-wafer configuration. Fig. 3 shows the frequency dependence of the current gain (H_{21}) and power gain (MAG/MSG) for the 2 × 40 μm MHEMT with gate and drain bias of – 0.6 V and 1.5 V. The f_T and f_{max} of the MHEMT are 200 GHz and 300 GHz, respectively, by extrapolating H_{21} and MAG/MSG using least-squares fitting with a –20 dB/decade slop. The H_{21} is 13 dB at 40 GHz and the MAG/MSG is 15 dB at 40 GHz. Fig. 4 shows the noise figure (NF) of the MHEMT from 1 to 16GHz. The minimum NF was below 0.67 dB up to 16 GHz. This superior behavior is attributed to the low access resistance, larger drain current and high transconductance across a wide range of gate Bias.

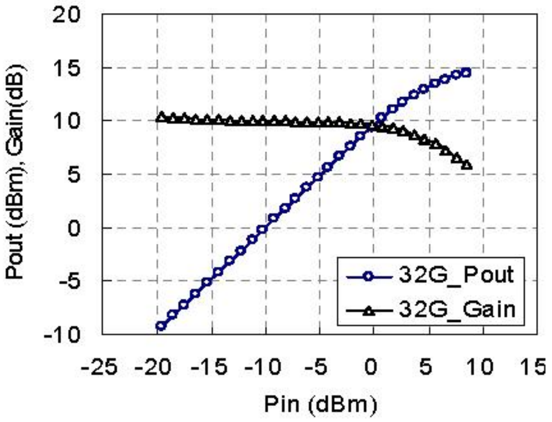

Fig. 5 Measured 32-GHz power performance of the 4 × 40 μm power MHEMT at drain bias of 2.5 V.

Further, the power performance of a 4 × 40 μm gate width device was measured at 32 GHz by load-pull systems for Ka-band application. The measured result is shown in Fig. 5, at drain bias of 2.5 V. With the tuner impedance matched for maximum power, the device showed the maximum output power of 14.5 dBm and P1dB of 11.1 dBm with 9.5 dB power gain at 32 GHz. This high power gain is attributed to the high Indium content at the channel and the short gate length. Overall, the MHEMT exhibits comparable RF performances to the InP-based HEMT due to the appropriate epi-structure design and the short gate length.

IV. CONCLUSION

The $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ power MHEMT with double δ-doping structure and 70nm T-gate has been designed and fabricated. The MHEMT developed showed excellent DC and RF performances and demonstrated great potential for power applications at Ka-band and millimeter-wave range.

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