Studies of MIMIC Power amplifier for millimeter-waves

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Abstracts

In this paper, we have designed and fabricated power PHEMT's with an unit gate width of 80㎛ and 4 fingers, and MIMIC power amplifiers using the PHEMT's as well. The PHEMT's have a 0.2㎛ gate length and source to drain spacing of 3㎛. The characteristics of the fabricated PHEMT's are 4.08dB of S_{21} gain at the 35GHz and 317mS/mm of gm, and 62GHz of f_T and 120GHz of f_{max}. The designed and fabricated MIMIC's power amplifiers with 6 PHEMT's and MIM capacitors were fully passivated by 1000Å of Si_3N_4 film for higher performance and surface protects. The chips were processed using the MINT processes [1], and size was 3.25 x 1.8mm^2.

The fabricated MIMIC power amplifiers have RF characteristics such as 11.25dB of S_{21} gain, 11.37dB of input return-loss and 12.69dB of output return-loss at the 34.55GHz.

I. Introduction

Recently, Millimeter-wave devices and MIMIC power amplifiers are required for commercial and military applications, which include a high-speed and wide-band wireless system, a wireless LAN, an anti-collision system and so on Furthermore, in order to overcome limitations of operating frequencies and bandwidths, millimeter-wave devices must be developed [2]. For these applications, higher power, higher power-added efficiency, high reliability and lower power consumption have to be significantly considered.

To achieve high power and gain, both design and processes such as T-gate for shorter gate-lengths, low resistance ohmic contacts, crossover air-bridges, source-vias, backside lapping, and surface passivation must be optimized. In this paper, studies of design and fabrication processes PHEMT's and MIMIC chips for millimeter-waves applications are mainly emphasized.

II. Design of PHEMT and MIMIC

In order to elevated the performance, PHEMT's were designed using AlGaAs/InGaAs/GaAs wafer structures with a n+ GaAs cap, donor, channel and buffer layers, and used for the MIMIC's power amplifiers [3]. The PHEMT's have 4-fingers and an unit T-gate length of 0.2㎛ and source to drain spacing of 3㎛ as shown in Fig. 1.

In order to achieve the design goals, which are 22dBm of high output power and 10dB of S_{21} gain at 35GHz, the MIMIC power amplifiers were designed with 2-stages using 6 PHEMT's, MIM capacitors, and distributed devices for repeatable processes [4].

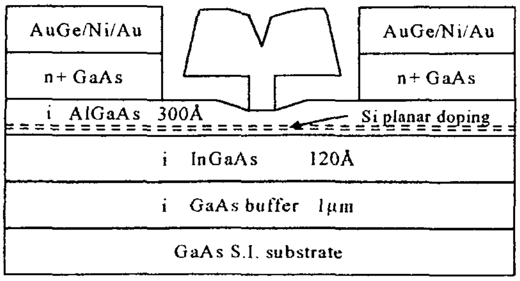

Fig. 1. A PHEMT structure

From the simulation of MIMIC's, we have obtained 10.9dB of S_{21} gain, -19.4dB of S_{11} (input return-loss), -15.8dB of S_{22} (output return-loss) and 4.9 of stability factor.

Ⅲ. Fabrication of PHEMT and MIMIC

The MIMIC epi-wafer was grown by a MBE system. Main processes were T-gate formation, air-bridge, ohmic contact and back- side processes. As shown in Fig.2, the T-gate formation of 0.2㎛ gate-foot and 1.4㎛ gate-head was processed using Electron-beam lithography for 3-layer resist(PMMA/P(MAA-M MA)/PMMA)[5]. Source to source was connected by air-bridge process [6] as shown in Fig. 3. The chips were fully passivated with 1000Å of silicon nitride by PECVD. In order to achieve high performance, the processed MIMIC chips thinned down to a nominal thickness of 100㎛, and the backside of chips was dry-etched for source-vias of 35㎛-diameter.

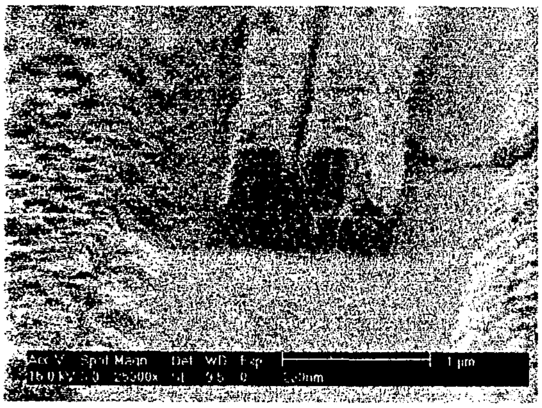

Fig. 2. A SEM photo of T-gate

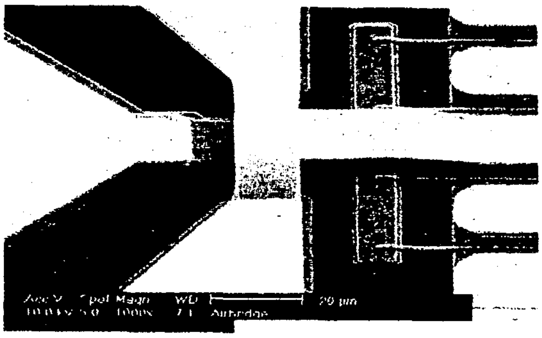

Fig. 3. A SEM photo of air-bridge

Also, 100x100㎛^{2} MIM capacitors were processed with a silicon nitride interlayer of 1000Å. A SEM photo of the fabricated MIMIC power amplifier chip is shown in Fig. 4.

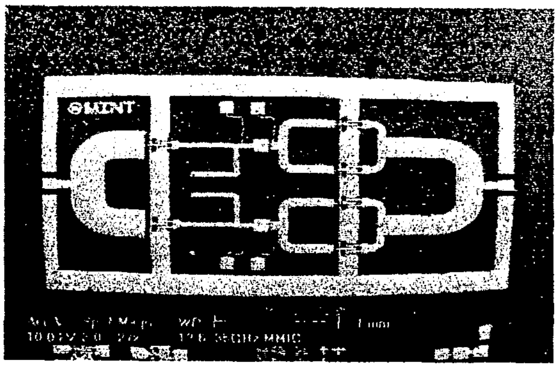

Fig. 4. A SEM photo of MIMIC chip

Ⅳ. Measurements

PHEMT devices were tested on-wafer at the completion of processing for the DC and RF characterizations. I-V and gm characteristic of the fabricated PHEMT's were measured as a fabrications of thickness of passivation and a gate vias condition are shown in Figs. 5, and 6. From the measurements for the 1000Å of silicon nitride passivation, we obtained that saturated drain current (Idss) was 137mA (428mA/mm), knee voltage(Vk) 0.95V, pinch-off voltage(Vp) -2.5V, and maximum transconductance(gm) 317mS/mm at -1.5V of Vgs and 3.0V of Vds.

The characterizations of small signal RF tests were performed using HP8510C-Vector Network

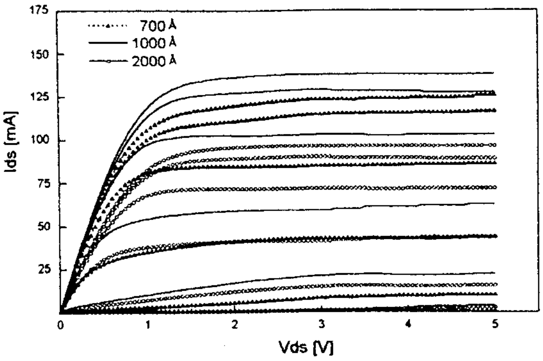

Fig. 5. I-V characteristics of PHEMT's as a function of silicon nitride thickness (Vgs=−0.5V/div)

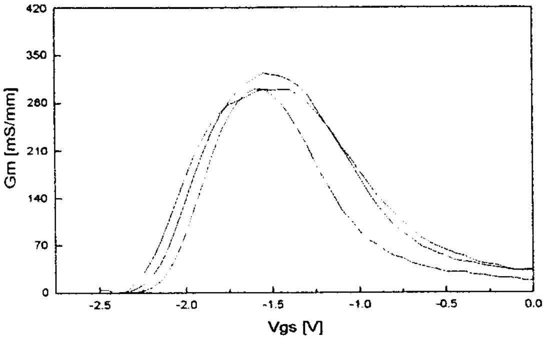

Fig. 6. Transconductance of PHEMT's as a function of gate vias condition

Analyzer. They are shown in Figs. 7 and 8. From the Figs. 7 and 8, we obtained that an unity current gain frequency (f_T) and a maximum oscillation frequency (f_{max}) were 62GHz and 120GHz, respectively.

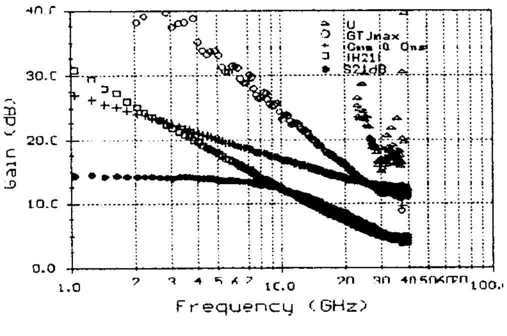

Fig.7. Gain characteristics of PHEMT's

Idss was obtained 137mA, 120mA, 97mA for the passivation thickness of 1000Å, 700Å and 2000Å, respectively. In other words, Idss was increased by 14% for 1000Å and unchanged for passivation thickness of 700Å. However, Idss was decreased by 19% for passivation thickness of 2000Å.

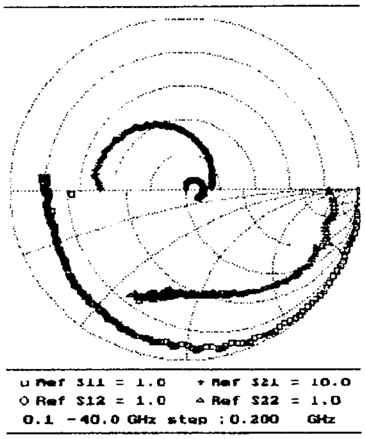

Fig. 8. S-parameters of PHEMT's

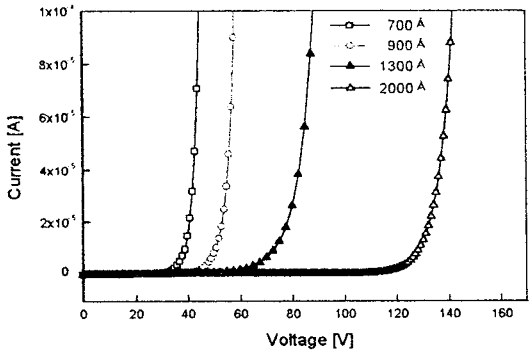

Fig. 9. Breakdown Voltage characteristics as a function of silicon nitride thickness.

The reflected index of silicon nitride interlayer used in a MIM capacitor was 1.95. And breakdown voltages for the various thickness are shown in Fig. 9. Breakdown voltages measured at 20μA were 43V (6.1MV/cm), 58V(6.4MV/cm), 83V(6.38MV/ cm), 137V(6.9MV /cm) for 700Å, 1000Å, 1300Å and 2000Å of silicon nitride interlayers, respectively.

Fig. 10 illustrates that small signal RF characteristics of MIMIC's were tested DC~40GHz frequencies at the 3.0V of Vds and −1.5V of Vgs conditions. From the measurements, S_{21} gain and input/output return-loss S_{11}, S_{22} at the 34.55GHz were 11.25dB, 11.37dB and 12.69dB, respectively.

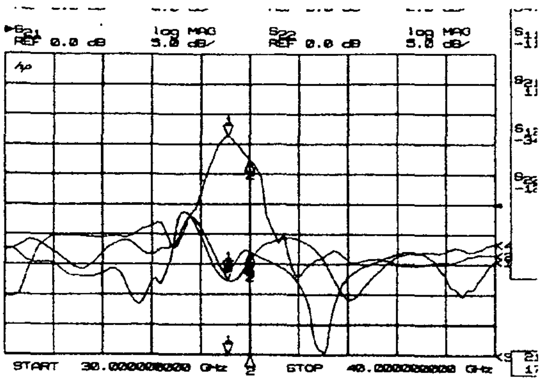

Fig. 10. Small signal RF characteristics of MIMIC power amplifiers

V. Conclusion

The PHEMT's and MIMIC power amplifiers chip were designed and fabricated with a AlGaAs/InGaAs/GaAs wafer. PHEMT's have 4.08dB of S_{21} gain at 35GHz, 317mS/mm of gm. And, f_T and f_{max} were 62GHz and 120GHz, respectively.

Passivation process conditions were optimized with Idss maximum which is increased by 14% for 1000Å of silicon nitride. Also, backside lapping and source-vias were be able to minimize the inductance of source and parasitics of ground. In order to satisfy the design goals such as 22dBm of P1dB and 10dB of S_{21} Gain, the 2-stages MIMIC power amplifiers using Conjugate-matching methods and, then, fabricated by MINT processes. The chip size was 3.25 x 1.8mm^2.

Small signal RF characteristics of MIMIC's was 11.25dB of S_{21} gain at the 34.55GHz. Also, input return-loss and output return-loss were 11.37dB and 12.69dB, respectively. From the measurements results, it was able to observe that frequency with maximum S_{21} gain was shifted by 450MHz, even though, S_{21} gain was increased by 0.35dB than the design goal.

In this paper, we have established design technologies and fabrication processes conditions for the power PHEMT's and MIMIC power amplifiers. It is believed that the results may be useful in design and fabrication for millimeter-wave PHEMT's and MIMIC power amplifiers.

Acknowledgments

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