

# Simultaneous achievement of high performance and high reliability in a 38/77 GHz InGaAs/AlGaAs PHEMT MMIC

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**Abstract:** In order to meet the demand for mass production of 77 GHz automotive radar systems, a low cost and high performance 38/77 GHz AlGaAs/InGaAs PHEMT MMIC transmit amplifier with a multiplier has been realized. The chip is packaged in an inexpensive conventional non-hermetic package. Excellent power performance is demonstrated with a 15 dBm output power and 7 dB maximum conversion gain from 38 to 76.5 GHz. Also, highly reliable RF operation of a bare MMIC chip is obtained with less than 0.7 dB reduction in output power during 10<sup>6</sup> hr at  $V_d = 4$  V and  $T_a = 25^\circ\text{C}$  in air.

**Keywords:** PHEMT, reliability, MMIC, humidity, automotive radar systems, non-hermetic package

**Classification:** Electron devices, circuits, and systems

## References

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## 1 Introduction

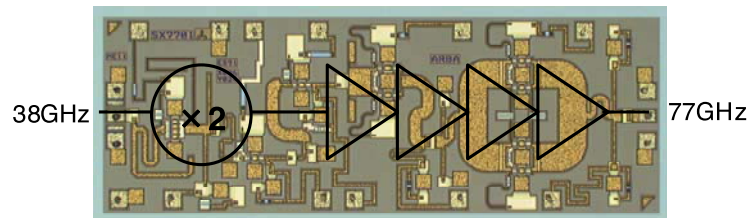
One of the most promising commercial applications for millimeter-wave systems is automotive radar to provide active safety for driving. Recently, the demand for low cost AlGaAs/InGaAs pseudomorphic HEMT (PHEMT) MMICs that are suitable for this application is emerging. In order to reduce the cost of the devices, there has been wide interest in the last few years in the use of non-hermetic packages [1]. To survive in non-hermetic packages, GaAs devices must have resistance to humidity. Thicker passivation films or other polymer coatings on the devices without hermetic sealing have been widely used to protect the device surface [2]. These films and coatings degrade the high-frequency characteristics due to their parasitic capacitance. In order to simultaneously meet the demand for high performance and low cost, there is a need for a highly reliable high-power AlGaAs/InGaAs PHEMT technology that withstands high humidity conditions.

We have previously reported a comprehensive study of degradation of AlGaAs/InGaAs PHEMTs during operation under high humidity conditions [3, 4]. We have concluded that PHEMT degradation is caused by an electrochemical corrosion reaction between the semiconductor and H<sub>2</sub>O that takes place at the SiN<sub>x</sub>/semiconductor interface on the drain side of the device. We also demonstrated that a special surface treatment to reduce oxygen at the semiconductor surface can effectively suppress the degradation without any loss of RF performance [3]. In the present work, we have adopted the surface treatment in the fabrication of 38/77 GHz MMICs transmit amplifier using AlGaAs/InGaAs PHEMTs for automotive radar. In this paper, we demonstrate the high reliable and high performance of 38/77 GHz bare-chip MMICs without a hermetic package.

## 2 Experimental

Double heterostructure AlGaAs/InGaAs PHEMTs [3] with around 0.2 μm gate length were fabricated for this study. The gate region was wet-chemically recessed to a desired drain current and metalized with Ti/Al for the gate electrode. These devices were passivated with a silicon nitride film by plasma-enhanced chemical vapor deposition (PECVD). Just prior to the deposition of the passivation film, a surface treatment that consists of dipping the wafer in a benzenoid-aromatic-compound-based organic solvent was performed. The treatment effectively reduces the amount of As-oxide at the semiconductor surface as reported previously [3].

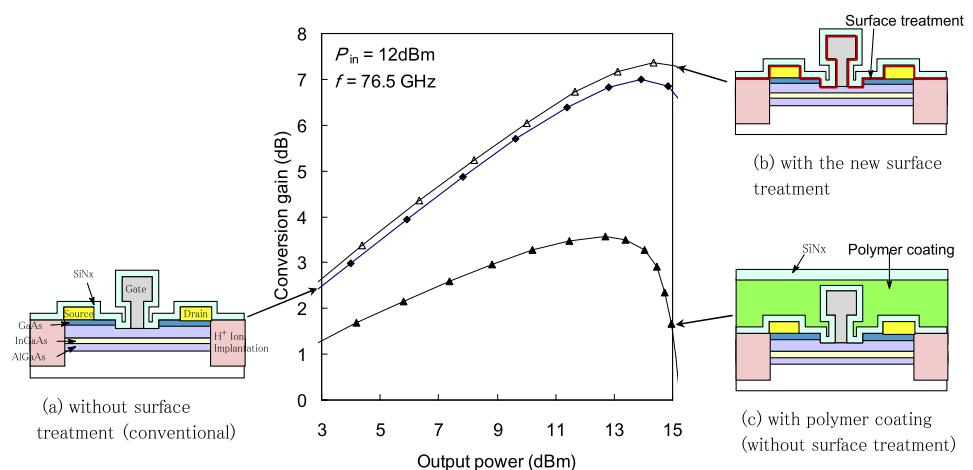
Fig. 1 shows the chip photograph of a 38/77 GHz transmit amplifier fabricated in this study. The MMIC consists of a frequency doubler and a 4-stage 77 GHz amplifier. The chip area is  $3.17 \times 1.17 \text{ mm}^2$ . The PHEMT MMICs were fabricated with 3 different processes that are: (a) without the surface treatment (b) with surface treatment, (c) with polymer coating. The relative permittivity ( $k$ ) of the polymer is 2.5. The polymer coating was formed after the  $\text{SiN}_x$  passivation film deposition [2].



**Fig. 1.** Photograph of a top of view of 38/77 GHz transmit amplifier with multiplier. The chip area is  $3.17 \times 1.17 \text{ mm}^2$ .

### 3 Results and discussions

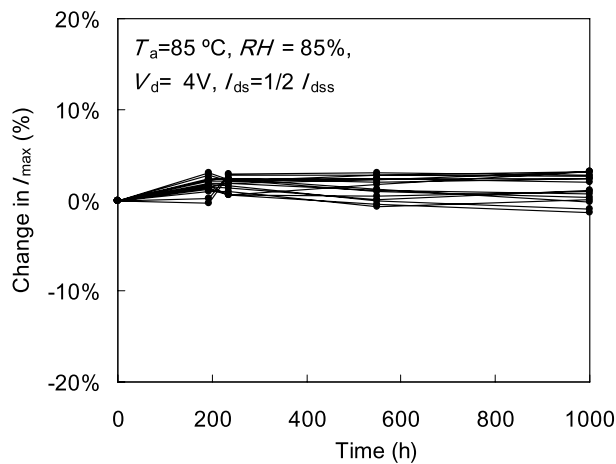
Fig. 2 shows on-wafer measurement results of the conversion gain ( $G_c$ ) as a function of output power ( $P_{\text{out}}$ ) at  $f_{\text{in}} = 38 \text{ GHz}$  and  $f_{\text{out}} = 76.5 \text{ GHz}$  of MMICs chips fabricated with the three different processes. The schematic cross sections of the three device structures are also shown in Fig. 2. Sample (c) with a polymer coating shows a 3.5 dB decrease in maximum  $G_c$  compared with the sample without surface treatment. This is caused by an increase of the parasitic capacitance. On the other hand, sample (b) with surface



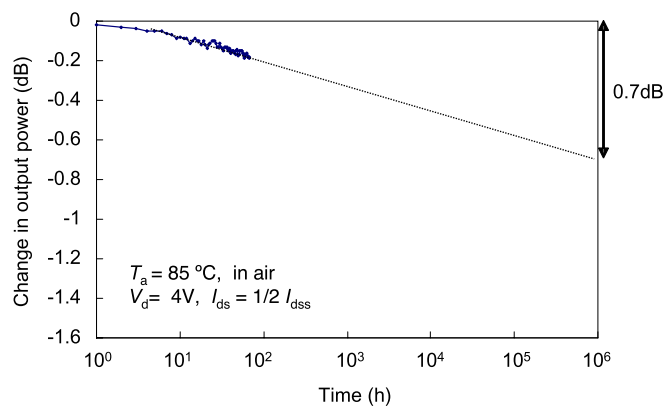
**Fig. 2.** Comparison of on-wafer measured output power ( $P_{\text{out}}$ ) at  $P_{\text{in}} = 12 \text{ dBm}$ ,  $f = 76.5 \text{ GHz}$  of 38/77 GHz transmit amplifier MMIC with 3 different processes: (a) without any surface treatment, (b) with the new surface treatment, and (c) with polymer coating.

treatment shows almost the same  $P_{out}$  and  $G_c$  as sample (a) without surface treatment. This result shows that the surface treatment is more effective especially for high frequency devices compared with the widely used polymer coating. A  $P_{out}$  of 15 dBm and maximum  $G_c$  of 7 dB were obtained for sample (a) with surface treatment. These results show an excellent performance for 77 GHz automotive applications that is comparable to that of state of the art devices [5, 6].

Fig. 3 (a) shows the change in  $I_{max}$  ( $\Delta I_{max}$ ) as a function of stress time during DC bias humidity test (relative humidity ( $RH$ ) = 85%, ambient temperature ( $T_a$ ) = 85°C,  $V_{ds}$  = 4 V,  $I_{ds}$  =  $1/2 I_{dss}$ ) of bare-chip MMICs.  $I_{max}$  is the drain current measured at  $V_g$  = +0.6 V and  $V_{ds}$  = 1 V.  $I_{max}$  changes less than 5% after 1000 hr. Other DC characteristics also do not show any



(a)  $I_{max}$  change during humidity test



(b)  $P_{out}$  change during RF life test in air

**Fig. 3.** Highly reliable results of 38/77 GHz transmit amplifier bare-chip MMICs with a new surface treatment. (a)  $I_{max}$  change during humidity test.  $RH = 85\%$ ,  $T_a = 85^\circ\text{C}$ ,  $V_{ds} = 4\text{ V}$ ,  $I_{ds} = 1/2 I_{dss}$ . (b)  $P_{out}$  change during RF life test in air.  $T_a = \text{R.T.}$ ,  $V_{ds} = 4\text{ V}$ ,  $f_{in} = 38\text{ GHz}$ ,  $f_{out} = 77\text{ GHz}$ ,  $P_{in} = 15\text{ dBm}$ .

significant change.

Fig. 3 (b) shows the change in  $P_{\text{out}}$  ( $\Delta P_{\text{out}}$ ) of bare-chip MMICs during RF life test ( $T_a = 25^\circ\text{C}$ ,  $V_{\text{ds}} = 4\text{ V}$ ,  $f_{\text{out}} = 77\text{ GHz}$ ,  $P_{\text{in}} = 15\text{ dBm}$ ), exposed in air during the test. The extrapolated  $\Delta P_{\text{out}}$  to  $10^6$  hr operation is less than  $-0.7\text{ dB}$ . These results show that the transmit MMICs with the new surface treatment simultaneously deliver the required RF performance and a high reliability even when exposed to air. This is very attractive for low-cost MMICs for automotive applications that do not use expensive conventional hermetic packages.

#### 4 Conclusion

We have developed high performance and highly reliable AlGaAs/InGaAs PHEMT MMICs for 77 GHz automotive radar systems by means of a new surface treatment. The 38/77 GHz transmit MMIC achieves an output power of 15 dBm and a conversion gain of 7 dB at 76.5 GHz. We demonstrate highly reliable RF operation of a bare chip MMIC exhibiting less than 0.7 dB reduction in output power during  $10^6$  hr at  $V_{\text{ds}} = 4\text{ V}$ ,  $T_a = 25^\circ\text{C}$  in air. We believe that these results are promising for low cost and high performance 77 GHz AlGaAs/InGaAs PHEMT MMICs for automotive applications without using conventional hermetic packages.

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