Manufacturing Technology of InGaP HBT Power Amplifiers for Cellular Phone Applications

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Abstract: Mass production of InGaP-HBT power amplifiers for cellular phones application in GSM and CDMA standards using a simplified device structure and process procedures are reviewed. The critical processes to realize high volume InGaP HBT production include a damage free SiN passivation by catalytic CVD and a ledge thickness process control. A triple band power amplifier MMIC with the world smallest package size (3.3x4.0x0.9 mm^3) was demonstrated.

1. Introduction

InGaP based-materials show an excellent potential in GaAs based HBTs[1-5] and FETs[6-9] because of its superior surface and interfacial properties in comparison to AlGaAs based heterostructures. Especially for cellular phone applications, InGaP-emitter HBTs can deliver higher performances and higher reliability due to the favorable band alignment and stable base-emitter junction with a highly doped C-doped GaAs base layer.

Mass production of InGaP based devices needs high quality epitaxial layers and good reproducibility in the surface passivation treatment. Although InGaP material shows low surface state density, the surface potential is very sensitive to the surface treatment and passivation procedure. A manufacturing technology for InGaP HBTs using a simple HBT device structure and a simple process and passivation procedure was established at Mitsubishi. Using this simplified HBT device structure, the smallest Triple band 3-stage MMICs, power modules, and Tx modules for GSM, and 2-stage power modules for W-CDMA with excellent performance were demonstrated.

2. Process Technologies

For a non-self aligned process, the ledge structure control is the key parameter to realize a high yield and a high reliability process under high volume manufacturing. Our InGaP-HBTs are constructed by 4μm x 20μm emitter fingers with Au thermal shunt on the reliable WSin emitter electrode to reduce thermal resistance by 40%.

The thickness of the InGaP ledge layer of around 40nm was shown to be optimum for good reproducibility in the dc and RF, and reliability performance. Figure 1 shows the reduction of the InGaP layer thickness by the several process reworks as measured by nondestructive X-ray measurements[10], which provides an accurate control. InGaP thickness may be reduced by approximately 1.2nm due to rework or surface treatment. This highly accurate non-destructive in-line inspection of InGaP ledge layer thickness can provide an excellent diagnostic tool to ensure a stable production process.

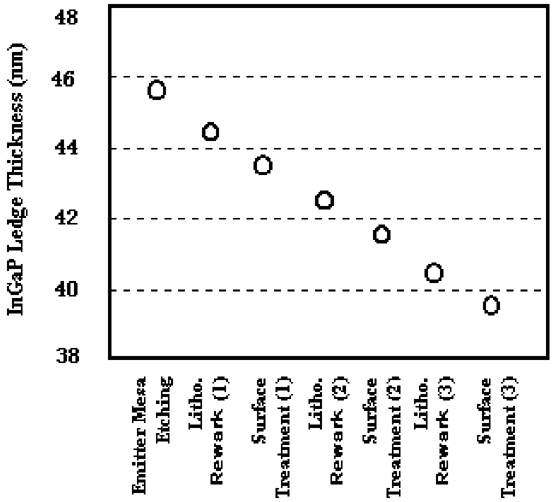
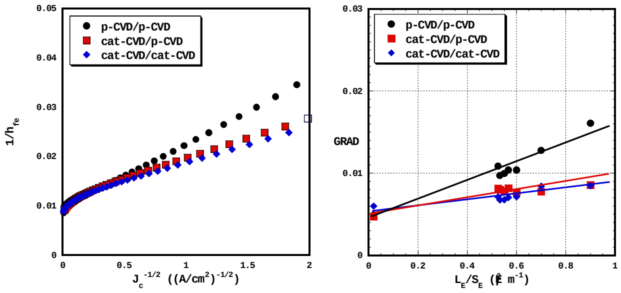


Figure 1 InGaP ledge thickness change under several reworks of the photolithography process.

The passivation of the ledge layer surface is another key issue that is critical for long-term reliability characteristics. The SiN film adhesion to the InGaP ledge layer surface and the surface recombination can be strongly improved by the Catalytic CVD (Cat-CVD) SiN passivation technology$^{11)}$ in comparison to the traditional Plasma Enhanced CVD (PE-CVD) passivation. The recombination at the ledge surface can be separated empirically from the recombination at the base layer and base-emitter junction space charge region by the following manner. Figure 2 (a) is $1/h_{FE}$ vs. $Jc^{-1/2}$ curve, where the vertical intersection corresponds to the base recombination and the gradient can be divided into the at EB junction and ledge layer recombination by the L_E/S_E dependence of the gradient as shown in Figure 2(b) (Jc: collector current density, h_{FE} :dc current gain, L_E : emitter periphery length, S_E : emitter junction area.



(a) $1/h_{FE}$ vs $Jc^{-1/2}$ curve (b) gradient (a) vs L_E/S_E

Figure 2 Base, EB-junction, and surface recombination extractions of Cat-CVD passivated and PE-CVD passivated InGaP-HBTs.

It is clearly shown that the Cat-CVD SiN passivation can effectively reduce the surface recombination in comparison to PE-CVD SiN passivation, while base and EB-junction recombination remained unchanged.

A combination of the passivation technology and accurate ledge control provides a strong foundation for high volume manufacturing.

3. GSM and W-CDMA Power amplifiers

Figure 3 is a photograph of single chip MMIC for the triple band power amplifier of GSM, DCS, and PCS application made using the simplified InGaP HBTs described above.

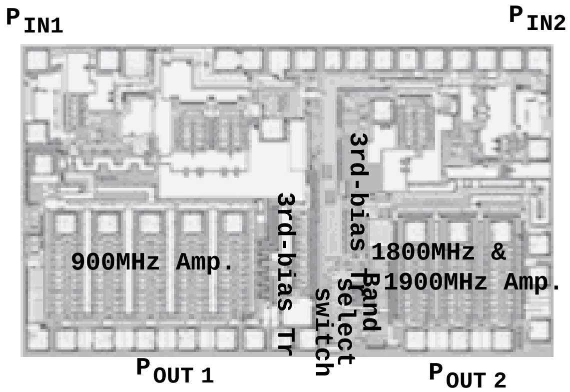


Figure 3. A photograph of a monolithic MMIC chip for a triple band GSM power amplifier is shown.

The chip size is 1.1×2.15mm^2. Figure 4 shows the circuit block diagram of this chip, which includes two separated 3-stage amplifiers and band select switch.

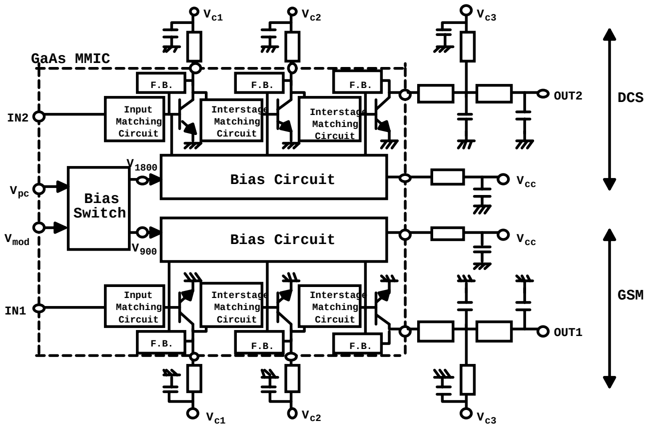


Figure 4. Circuit block diagram of Triple Band Power Amplifier chip for GSM application is shown.

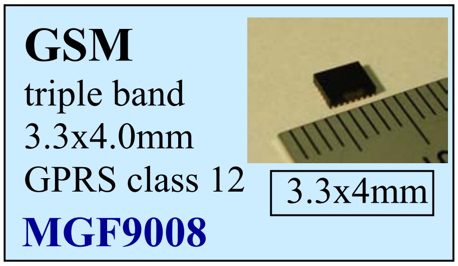


Figure 5. A photograph of the world's smallest package of a Triple Band Power Amplifier for GSM application is shown (3.3 x 4.0 x 0.9 mm^3)

The plastic package size of 3.3×4.0×0.9mm^3 is the world's smallest package to the best of our knowledge (Figure 5). RF performances are 55% PAE at 34.5dBm for 900MHz, and 50%

PAE at 32.0dBm for 1750MHz. By optimizing device structure and circuit design, our triple band power amplifier can withstand 10:1 VSWR operating conditions. Power output voltage control characteristics for 900MHz and 1750MHz are demonstrated in Figure 6. The specified power levels at 3.2V Vcc was achieved at the lower power control voltages (less than 2.5V) in comparison with the voltages used for AlGaAs based HBTs. 50-ohm module for W-CDMA application was produced in 6×6mm^2 die size.

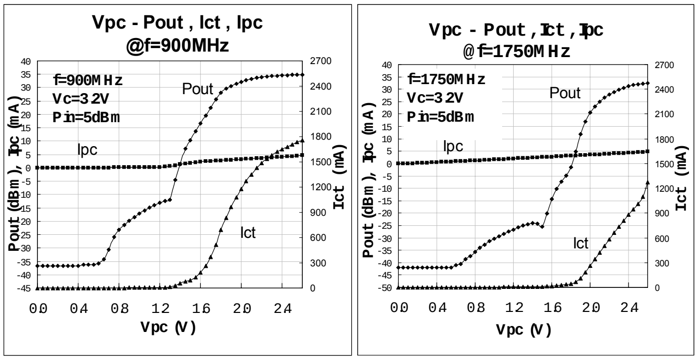


Figure 6. Power output voltage control characteristics at 900MHz and 1750MHz are shown.

In Figure 7, characteristics of Pin vs. Pout and Pout vs. PAE for W-CDMA application are demonstrated. A high efficiency of 42% and low quiescent current of 60mA are achieved at 26.5dBm output power, -41dBc ACLR(±5MHz) and -52dBc ACLR(±10MHz).

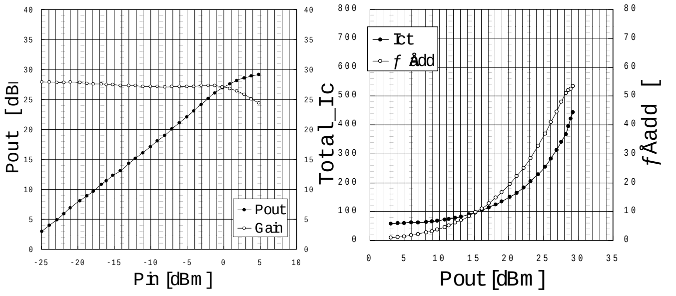


Figure 7. Pin vs. Pout and Pout vs. PAE for W-CDMA application are shown.

4. SUMMARY

InGaP HBT's can be produced at high volumes with good reproducibility using a combination of a simplified device structure and robust process to control the ledge passivation. We have demonstrated the world's smallest triple band MMICs package for GSM applications. A W-CDMA module with excellent linearity performance was realized using InGaP-HBTs.

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