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High Fmax AlGaAs/GaAs HBTs for 40 Gbps ICs with Ultra-Low Resistance Base Ohmic Contacts

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Ohmic contacts to 50 nm p-$Al_{0.1}Ga_{0.9}As$ formed with a Pt/Ti/Pt/Au metal system were investigated. An extremely low contact resistivity of 4.2×10^{-7} Ω cm^2 was obtained. And this metal scheme was thermally stable at 350 °C. A high fmax of 130 GHz was obtained for AlGaAs/GaAs HBTs using Pt/Ti/Pt/Au base electrodes. A MUX IC implemented with these high fmax HBTs properly operated up to 40 Gbps, the highest speed ever reported.

1. Introduction

AlGaAs/GaAs heterojunction bipolar transistors (HBTs) have promising ultra high-speed digital and microwave analog circuit applications. However, it is necessary to improve high frequency performance to operate 40 Gbps ICs. The reduction of the base resistance, especially the contact resistance to a very thin AlGaAs graded base, enhances AlGaAs/GaAs HBT high frequency performance significantly.

This paper reports on the results of investigating a low contact resistance base metal system, Pt/Ti/Pt/Au. In order to demonstrate the tremendous features of this metal system, the fmax of fabricated HBTs with this metal were investigated. Moreover a 2:1 MUX IC using these high fmax HBTs operating up to 40 GHz was fabricated.

2. Pt/Ti/Pt/Au system

The formation of low resistivity ohmic contacts to AlGaAs in conventional HBT processing is more difficult than to GaAs owing to AlGaAs surface oxidation. Pt/Ti/Pt/Au should be a suitable ohmic metal system to the AlGaAs base since Pt has a small potential barrier height to a p-type semiconductor[1] and forms a stable intermetallic compound with AlGaAs at a relatively low temperature such as 350 °C. It is necessary to control the Pt penetration depth to introduce this metal system into a thin base HBT, because the deep penetration of Pt causes a high base contact resistance. The intermetallic thicknesses with Pt and AlGaAs are approximately equal to twice the Pt thickness[2]. Therefore, the first Pt layer thickness fixes the Pt penetration depth. The dependence of contact resistivity on the first Pt layer thickness for a 50 nm p^+-AlGaAs layer ($N_{Be}=5\times10^{19}$ cm^{-3}) was investigated. These metals were annealed at 350 °C in a nitrogen atmosphere for 20 min. (5, 10 nm Pt thickness), and 40 min. (35 nm Pt thickness). Figure 1 shows the superiority of this metal system to conventional Cr/Pt/Au. The lowest contact resistivity of 4.2×10^{-7} Ω cm^2 was obtained with 5 nm Pt. The contact resist-

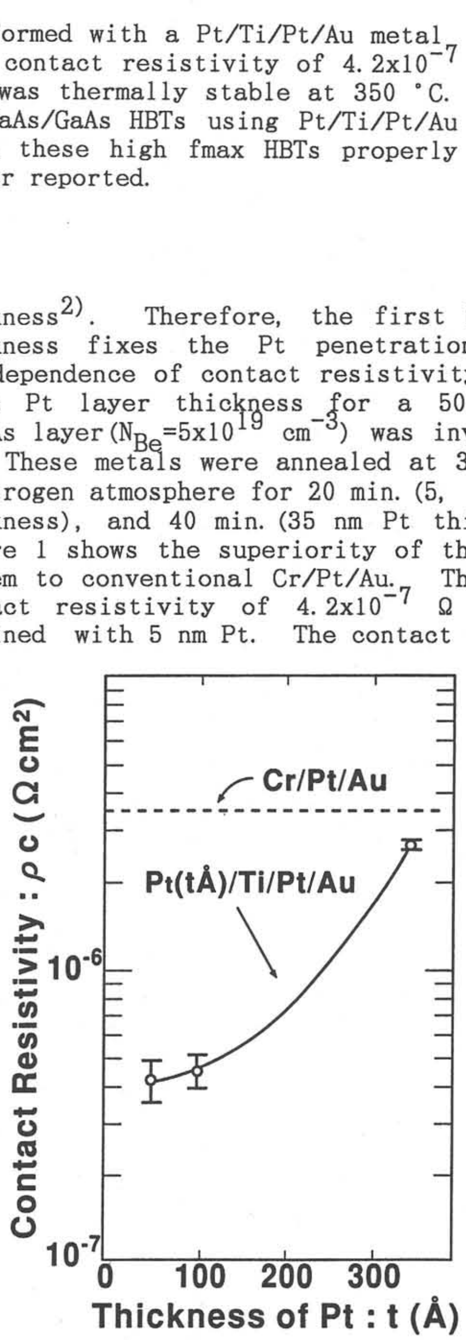

Fig. 1 Dependence of contact resistivity on Pt thickness

ance increased with increments of the Pt thickness, because the thicker the intermetallic the thinner becomes AlGaAs beneath it, which leads to a higher contact resistance. The optimum Pt thickness should be around 5 nm, since thinner than 5 nm Pt could not eliminate AlGaAs surface oxidation. Figure 2 shows the thermal stability of this metal system. No degradation was observed even after 12-hour 350 °C annealing.

Layer	Material	Doping(cm^{-3})	Thickness(nm)
Contact	n^+ InGaAs (InAs:0-0.5)	3E19	100
Emitter	n AlGaAs (AlAs:0.1-0.3-0)	5E17	150
Base	p^+ AlGaAs (AlAs:0-0.1)	5E19	100
Collector	n GaAs	6E16	600
	n^+ GaAs	5E18	500

Table 1 Layer structure of MBE-grown HBT wafer

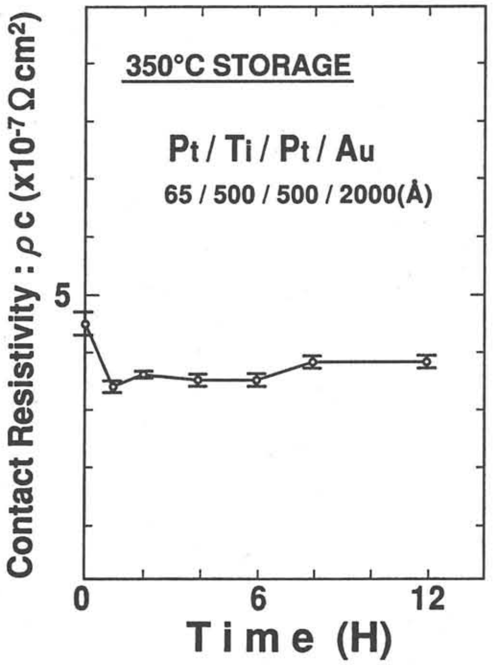

Fig. 2 Thermal stability of Pt/Ti/Pt/Au

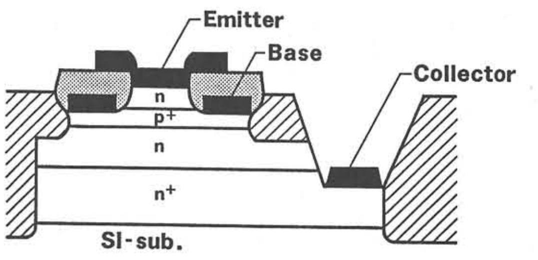

Fig. 3 Schematic cross section of fabricated HBT

3. Device performance

1) Fabrication

HBTs were fabricated on a MBE-grown wafer using the self-alignment process with polyimide walling[3]. The layer structure is shown in Table 1. And Figure 3 shows a schematic cross section of the fabricated HBTs. The ohmic contacts for the emitter and collector were formed by Ti/Pt/Au, and AuGe/Ni/Ti/Pt/Au. A low base contact resistivity was successfully obtained through the use of a Pt(6.5 nm)/Ti(50 nm)/Pt(50 nm)/Au(60 nm) alloy as described above. And this metal was alloyed at 350 °C for 20 min. The base-collector capacitance was further reduced by implanting protons into the collector in the extrinsic base region.

2) RF performance

The microwave performance of these HBTs was investigated by on-wafer S-parameter measurements at 1-26 GHz. The s-parameters were measured at a bias condition of 1.5 V Vce and 5 mA Ic for an emitter size of 1.2x4 μm^2. Figure 4 shows frequency versus current gain, h21, Mason's unilateral gain, U, maximum available gain, MAG, and maximum stable gain, MSG, of the HBTs with the Pt/Ti/Pt/Au base electrode and with the Cr/Pt/Au base electrode. The ft values of both HBTs were about 50 GHz. The fmax of Pt/Ti/Pt/Au base HBT was 130 GHz, and was superior to the fmax, 100 GHz, of a Cr/Pt/Au base HBT. The base resistance of 32 Ω with Pt/Ti/Pt/Au , and of 57 Ω with Cr/Pt/Au were obtained by using the transmission line model(TLM) measurements on the same processed wafer. This result shows the effect of a low base contact resistance to the increment of fmax.

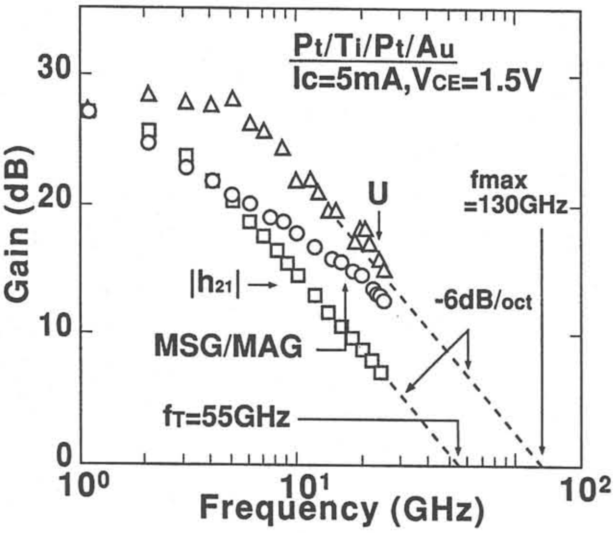

Fig. 4 a) Small-signal characteristics of HBT with Pt/Ti/Pt/Au

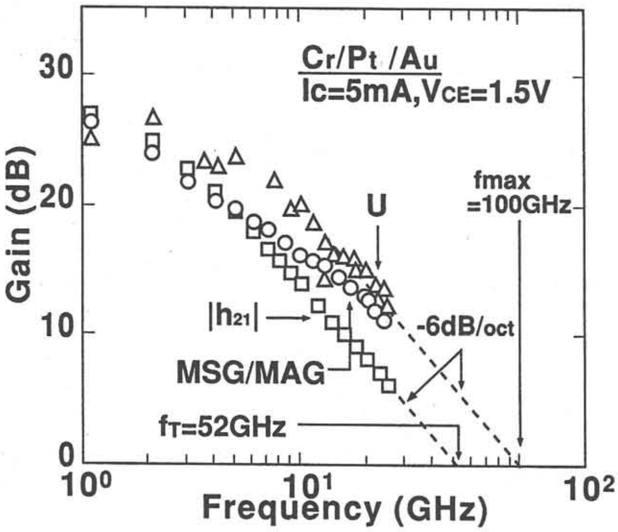

Fig. 4 b) Small-signal characteristics of HBT with Cr/Pt/Au

4. 40 Gbps MUX IC

A MUX IC was fabricated with these high fmax HBTs. The circuit design of 2:1 MUX is shown in Fig. 5. It consisted of data and clock input emitter followers, and the MUX core. On chip 50 Ω terminations were prepared for the input signals. The power supply voltage and the power consumption were -7 V and 0.7 W.

The MUX was on wafer tested using a RF probe head. The data up to 20 Gbps from the hybrid MUX module were used as the input signal. The output eye-pattern (800 mVpp into 50 Ω) of the 40 Gbps is shown in Fig. 6. This maximum operation speed was limited by measurement instrument capability.

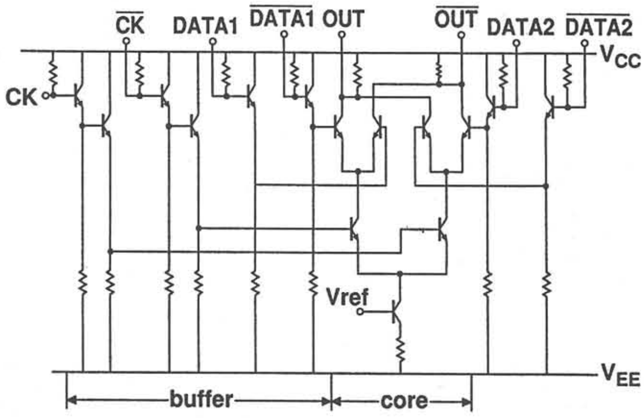

Fig. 5 Circuit design of 2:1 MUX

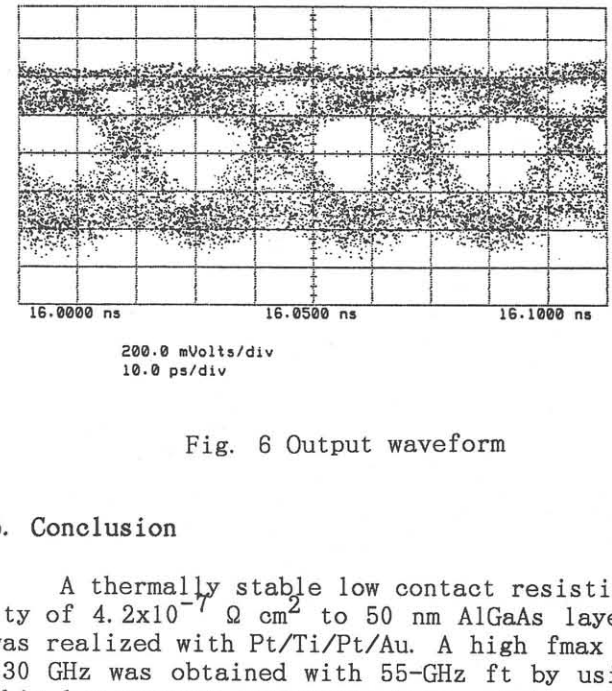

Fig. 6 Output waveform

5. Conclusion

A thermally stable low contact resistivity of 4.2×10^{-7} Ω cm^2 to 50 nm AlGaAs layers was realized with Pt/Ti/Pt/Au. A high fmax of 130 GHz was obtained with 55-GHz ft by using this low contact resistance base metal and by reducing the parasitic collector capacitance with proton implantation. A 40 Gbps MUX IC was successfully fabricated with these high fmax HBTs.

Reference

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2) V. Kumar, J. Phys. Chem. Solids 36 (1975) 535 .
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