A Gold Free Fully Copper Metallized InGaP/GaAs HBT

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ABSTRACT — **A gold-free, fully Cu metallized InGaP/GaAs HBT using platinum as the diffusion barrier has been successfully fabricated. The HBT uses Pd/Ge for n-type, Pt/Ti/Pt/Cu for p+type ohmic contacts, and Ti/Pt/Cu for interconnect metals with platinum as the diffusion barrier. The Ti/Pt/Cu structure was stable up to 350 ℃ annealing as judged from the data of XRD and sheet resistance. Current accelerated stress test was conducted on the device with current density J_C=140 kA/cm^2 for 24 hours, the current gain showed no degradation. The devices were also thermally annealed at 250℃ for 24 hours and showed little changes. We have successfully demonstrated that Au-free, fully Cu metallized HBT can be achieved by using Pt as the diffusion barrier and Pd/Ge and Pt/Ti/Pt/Cu as the ohmic contacts.**

I. INTRODUCTION

Copper metallization has extensively used in the silicon integrated circuit technology since IBM announced its success in silicon very large scale integration process[1]-[3]. The advantages of copper metallization for Si technology include lower resistivity and higher electromigrtion resistance. Even though the use of copper as metallization metal has become very popular in Si devices, there were very few reports of copper metallization of GaAs devices published in the literature[4]-[6]. Use copper as the metallization metal instead of gold has several advantages such as lower resistivity, higher thermal conductivity, and lower cost. However, copper diffuses very fast into Si when it is in contact with Si substrate without any diffusion barrier[7]-[9]. As in the silicon case, copper also diffuses very fast into GaAs when copper is in direct contact with the GaAs substrate without any diffusion barrier[10]. If Cu diffuse into ohmic contact, SiN and device active region, it will cause the degradation of the electrical properties of the devices. Traditionally, the n-type AuGe/Ni/Au, p-type Pt/Ti/Pt/Au ohmic contacts, and the interconnect Ti/Au metals are the most widely used metallization structures for the fabrication of the GaAs based heterojunction bipolar transistors (HBTs). If Cu replaces Au as the metallization metal for the HBTs, then the resulting improvement in the electrical conductivity can increase the transmission speed of the circuits and the heat will be dissipated as well. In our previous studies, we have demonstrated backside copper metallization on GaAs metal semiconductor field-effect transistors (MESFETs) using TaN as the diffusion barrier[6] and copper air-bridge on low noise GaAs high electron mobility transistors (HEMTs) using WN_X as the diffusion barrier[11]. On the other hand, copper is difficult to dry etch due to the lack of volatile compounds. In this study, we use Pd/Ge for n-type, Pt/Ti/Pt/Cu for p+type ohmic contacts, and Ti/Pt/Cu for interconnect metals with platinum as the diffusion barrier to fabricate the Au-free, fully Cu metallized HBTs using lift-off technology. Platinum has high melting point, and it is a good diffusion barrier to prevent Au from diffusing into the traditional GaAs Schottky (Ti/Pt/Au) and ohmic (Pt/Ti/Pt/Au) structures. In this study, the thermal stabilities of the Ti/Pt/Cu structures were investigated. Furthermore this material system was used to fabricate the InGaP/GaAs HBTs. We are reporting for the first time the fabrication and electrical performance of the gold free, fully copper metallized InGaP/GaAs HBTs with platinum as the diffusion barrier.

II. EXPERIMENTAL

The InGaP/GaAs HBTs used in this work were grown by metal organic chemical vapor deposition (MOCVD) on semi-insulating (100) GaAs substrates. The layer structure consists of (from bottom to top) a n^+-GaAs subcollector (600 nm, 5×10^{18} cm^{-3}), a n^--GaAs collector (650 nm, 4×10^{16} cm^{-3}), a p^+-GaAs base (120 nm, 2×10^{19} cm^{-3}), an n-InGaP emitter (85 nm, 2×10^{17} cm^{-3}), and an n^+-GaAs cap (100 nm, 5×10^{18} cm^{-3}). The HBT devices were fabricated using a standard triple mesa process. The InGaP and GaAs layers were etched by HCl/H_3PO_4 and $H_3PO_4/H_2O_2/H_2O$ solutions respectively. Alloyed PdGe, non-alloyed Pt/Ti/Pt/Cu, and alloyed PdGe gold-free ohmic metal systems were used for the emitter, base, and collector contacts, respectively. Device passivation was realized with PECVD silicon nitride. After opening the connecting via on the nitride film, the adhesion layer Ti (30 nm), diffusion barrier Pt (60 nm), and interconnect Cu (400 nm) metal were sequentially deposited by e-gun evaporator over patterned resist. The bulk of the resist and metal were then removed by a wet solvent lift-off process, followed by a high pressure DI water rinse to remove the residues. Finally, silicon nitride (10 nm) was deposited as a protective layer on the top of the device to prevent Cu film oxidation. The dimension of the emitter area of the HBT was 4 μm × 20 μm. The structure of the InGaP/GaAs HBTs in this study is shown in Figure 1. The DC current-voltage (I-V) characteristics of the HBT devices were measured by HP4142B. The devices were stressed using current accelerated test and high temperature thermal annealing test for reliability evaluation. The high current test was performed at high current density of 140 kA/cm^2 for 24 hours. The thermal test were carried out by annealing at 250 ℃ for 24 hours in nitrogen ambient .

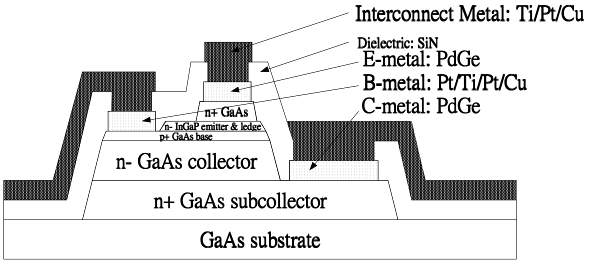

Fig. 1. Cross section of the Au-free fully Cu metallized InGaP/GaAs HBT.

III. THERMAL STABILITY OF TI/PT/CU MULTILAYERS

To study the diffusion barrier property of platinum, the Ti (50 nm)/Pt (60 nm)/ Cu (400 nm) films were first evaporated onto a blank GaAs wafer using e-gun evaporator and then annealed for 30 min at different temperatures in nitrogen ambient for material analysis. X-ray diffraction (XRD), and the sheet resistance measurement were used to monitor the interfacial reactions. Figure 2 shows the sheet resistances of the samples as-deposited and after 300℃ to 450 ℃ annealing for 30 min. The sheet resistance of the GaAs/Ti/Pt/Cu film structure increased drastically after 400 ℃ annealing, suggesting that atomic diffusion and inter-atomic reactions had occurred between these layers at this temperature. Additional evidence showing that the GaAs/Ti/Pt/Cu multiple layers were stable up to 350 ℃ annealing was obtained from the X-ray diffraction data. Figure 3 shows the XRD results of the Ti/Pt/Cu samples as-deposited and after annealed from 300℃ to 400℃ for 30 min. The XRD data clearly shows that the peaks of Cu, Pt, and Ti remained unchanged up to 350 ℃ annealing, indicating that the Ti/Pt/Cu structure remained quite stable up to 350 ℃. However, after 400 ℃ annealing, additional peaks which were identified as Cu_4Ti diffraction peaks appeared. The formation of Cu_4Ti after 400 ℃ annealing suggested that Cu atoms had diffused through the Pt layer into the Ti layer. From the data shown above, it is evident that the Ti/Pt/Cu material system is quite stable up to 350℃ annealing.

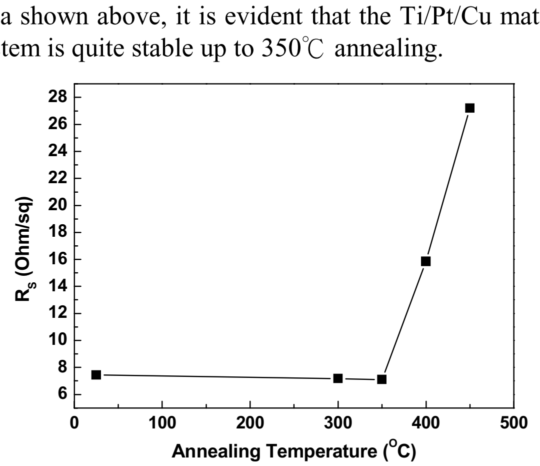

Fig. 2. Sheet resistance of the GaAs/Ti/Pt/Cu samples as deposited and after annealing at various temperatures.

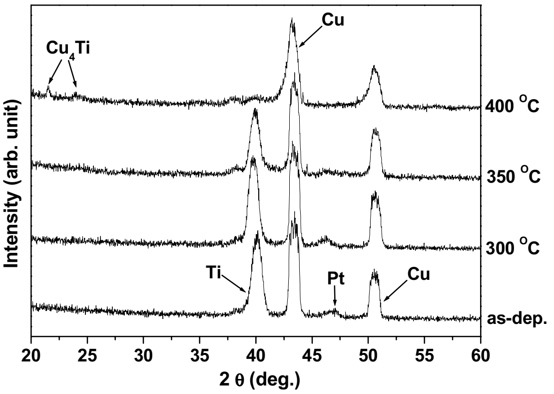

Fig. 3. Sheet resistance of the GaAs/Ti/Pt/Cu samples as deposited and after annealing at various temperatures.

IV. DEVICE ELECTRICAL CHARACTERISTIC

The HBTs with conventional n-type ohmic metal (AuGe/Ni/Au), p-type ohmic metal (Pt/Ti/Pt/Au), and interconnect metal (Ti/Au) were also processed on half of the same wafer for comparative understanding of the material system. Figure 4 shows the typical common emitter characteristics for the emitter area 4×20 μm HBTs, in this figure, one curve is Au-free, fully Cu metallized HBT and the other curve is traditional Au metallized HBT. From Figure 4, these two devices show similar knee voltage and offset voltage, which indicates that there was no stress effect for the copper metallized films and the quality of the multilayer materials was quite good. The common emitter current gain was around 150 for both cases.

To test the reliability of the Au-free, fully Cu metallized HBT, the device with 4 × 20 μm emitter area were subjected to current accelerated stress test with high current density of 140 kA/cm^2. Figure 5 plots the current gain (β) of the Au-free, fully Cu metallized HBT after stressed at the high current density of 140 kA/cm^2 at V_{CE} of 1.5 V for a period of 24 hours. The measurement was made at an ambient room temperature of 25 ℃. Under this test condition, the estimated junction temperature, T_j was about 280℃. It can be seen from the data of Figure 5, the current gain of the device showed no significant change and was still higher than 140 after 24 hours current accelerated stress test. No additional degradation mode was found for the fully Cu metallized HBT.

In order to study the thermal stability of the Pt diffusion barrier, the 4 × 20 μm emitter area Au-free fully Cu metallized HBT was annealed at 250℃ for 24 hours and tested for the electrical performance. Figure 6 shows the common emitter I-V curves before and after annealing for the fully Cu metallized HBT. As can be seen from the data of Figure 6, there was no change in the offset voltage, knee voltage, and saturation current after annealing. It suggested that there was no ohmic degradation, copper oxidation, and copper diffusion for the fully Cu metallized HBTs using Pt as the diffusion barrier. It suggested that no additional degradation mode had occurred and that no copper diffusion into the active device region and no copper oxidation after the thermal stress, these results are consistent with the material analysis results.

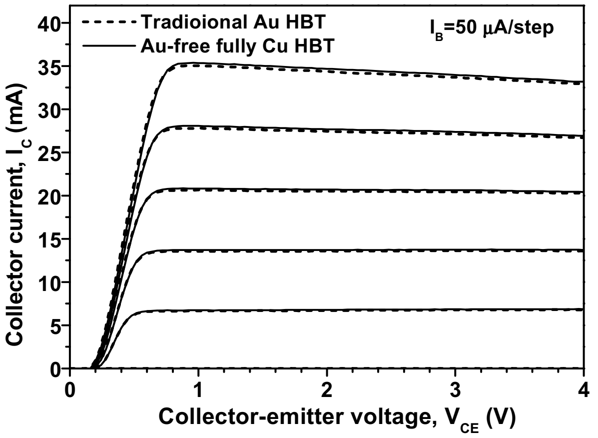

Fig. 4. Comparison of the typical I_C-V_{CE} characteristics for the 4x20 μm emitter area HBTs with fully Cu metallized and traditional Au metallized.

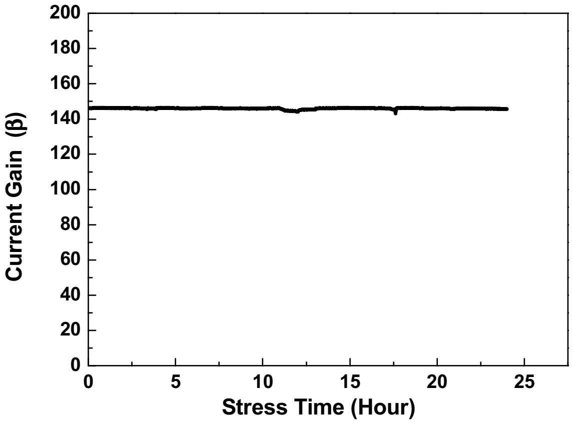

Fig. 5. Current gain as a function of the stress time at a constant I_B for the 4x20 μm emitter area fully Cu metallized HBT.

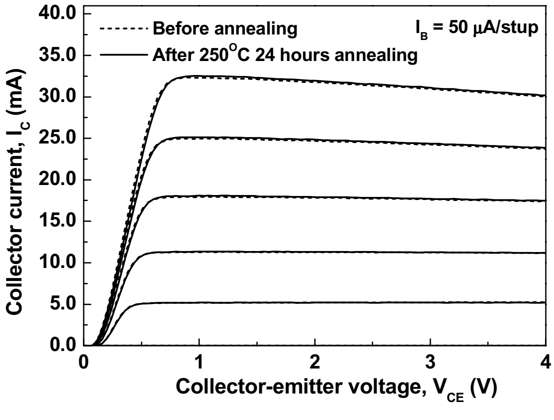

Fig. 6. Common emitter I-V curves measured before and after 250 ℃ 24 hours annealing for the emitter area 4x20 μm fully Cu metallized HBT.

V. CONCLUSION

Au-free, fully Cu metallized HBT using Pt as the diffusion barrier was fabricated and reported for the first time. From the XRD data and the sheet resistance study, the Ti/Pt/Cu was very stable after annealing at 350℃. The common emitter I-V curves of the Au-free fully Cu metallized HBTs showed similar electrical characteristics as those for HBTs with conventional Au metallized layers. Both current accelerated stress test (140 kA/cm^2 stress for 24 hours) and thermal stress test (annealing at 250 ℃ for 24 hours) for the fully Cu metallized HBTs show almost no change in the electrical characteristics. The results show that it is possible to fabricate a fully Cu metallized InGaP/GaAs HBTs by using Pd/Ge and Pt/Ti/Pt/Cu as contact metals and Pt as the diffusion barrier metal.

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