A Cu Metalized Power InGaP/GaAs Heterojuction Bipolar Transistor with Pd/Ge/Cu Alloyed Ohmic Contact

S. P. Wang, Y. C Lin, Y. L. Tseng, K. S. Chen, J. C. Huang and E. Y. Chang

Department of Materials Science and Engineering,
National Chiao-Tung University, Hsinchu 30010, Taiwan, R.O.C.,
E-mail: edc@mail.nctu.edu.tw,
Phone number: +886-35712121 EXT: 31536

Keywords: Cu, InGaP, HBT, ohmic contact, power

Abstract

The Cu-metalized InGaP/GaAs HBTs using Pd/Ge/Cu ohmic contact to n-type GaAs, Pt/Ti/Pt ohmic contact to p+-type GaAs, and Ti/Pt/Cu for interconnect metals with Pt as the diffusion barrier has been successfully fabricated for power application. The Pd/Ge/Cu metal structure forms a low contact resistance ohmic contact to n-type GaAs with a low specific contact resistivity of 5.73 x 10^{-7} Ω-cm2 after annealed at 250 °C for 20 minutes. The 4 x $20\mu m^2$ Cu-metalized InGaP/GaAs HBTs demonstrated a power of 10.06dBm with power efficiency of 35.6%.

INTRODUCTION

Copper metallization has been extensively used in the silicon industry since IBM announced its success in silicon very large scale integration process [1-3]. However, even though copper metallization has become very popular in the fabrication of Si devices, there are only a few reports on the copper metallization of GaAs devices [4-5]. Comparing to the commonly used Au metallization for GaAs industry, Cu has lower resistivity, higher thermal conductivity, higher electromigration resistance and lower cost [4-5]. Therefore, it is the candidate for the metallization process on GaAs device in recent years. In previous reports, backside copper metallization, Cu schottky structure in GaAs metal semiconductor field-effect transistors (MESFETs) [6], the use of a copper air-bridge in low-noise GaAs high-electron-mobility transistors (HEMTs) [7], and the interconnect copper metallization using WN_X as the diffusion barrier in InGaP/GaAs heterojunction bipolar transistors (HBTs) [8] has been studied. However, there is no report on the power performance at related reliable issues of the copper metalized power HBTs. Consequently, a Cu-metalized GaAs power HBTs with alloyed ohmic contact is investigated and characterized in this paper

Conventionally, n-type Au/Ge/Ni/Au and p-type Pt/Ti/Pt/Au ohmic contacts, and Ti/Au interconnect metals have been widely used metallization structures for the fabrication of GaAs-based HBTs. Nevertheless, the Au/Ge/Ni Ohmic contact system has several drawbacks, such as large spread of the contact resistance, poor contact edge definition, and the annealing temperature was high due to the eutectic Au/Ge alloy. Hence, Pd/Ge and Pt/Ti/Pt/Cu for n-type and p^+-type ohmic contacts were used respectively, and Ti/Pt/Cu for interconnect metals with platinum as the diffusion barrier to fabricate the Cu-metalized InGaP/GaAs HBTs [9]. In this paper, Pd/Ge/Cu alloyed ohmic contact is used for the InGaP/GaAs HBTs to improve the surface morphology of the ohmic contact as well as reduce the production cost. The fabrication, electrical performance and power performance of the power InGaP/GaAs HBTs with Pd/Ge/Cu ohmic contact metal are discussed in this study. In addition, the traditional InGaP/GaAs power HBTs using Au metallization as the ohmic and interconnect metals were also fabricated for the comparison with Cu-metalized InGaP/GaAs HBTs.

Layer	**Material**	**Type**	**Doping**	**Thickness□ Å□**
Emitter Cap	GaAs	*n+*	5×10^{18}	2000
Emitter	InGaP	*n*	3×10^{17}	500
Base	GaAs	*p+*	4×10^{19}	800
Collector	GaAs s	*n-*	2×10^{16}	7000
Subcollector	GaAs	*n+*	5×10^{18}	5000
Substrate	GaAs			

Fig. 1 The epitaxial layer structure of the InGaP/GaAs HBT.

EXPERIMENT

The epitaxial layers of the InGaP/GaAs single heterojunction bipolar transistors (SHBTs) were grown by MOCVD on a 3-inch diameter semi-insulating (100) GaAs substrate as shown in Fig. 1.

The fabrication of the Cu metalized power InGaP/GaAs HBTs includes the following steps. The first step was to define the emitter mesa areas. The emitter mesa was etched and stopped on the InGaP emitter layer. After emitter mesa etch, the collector mesa was etched and stopped on the GaAs subcollector layer. The third step is isolation etching. In this step, the GaAs subcollector was etched with undercut to separate each device. Then, the emitter and collector ohmic contacts were formed by a standard lift off process and followed by a high temperature alloying at 250 ^{0}C for 20 minutes. The emitter and collector ohmic metal was Pd (15 nm)/Ge (150 nm)/Cu (150 nm). For the P-type ohmic contact on the base, the Pt (5 nm)/Ti (20 nm)/Pt (60 nm)/Cu (100 nm) metal was used. After the Ohmic process, the device was passivated with 100nm PECVD silicon nitride. Then, nitride vias were etched by reactive ion etching process (RIE). After that, the Ti (30 nm)/Pt (60 nm) /Cu (400 nm) metals were sequentially deposited by an e-gun evaporator as the seed layer for electro-plating. Finally, 2µm copper was plated on the seed layer as interconnected metal.

Power InGaP/GaAs HBTs with traditional n-type ohmic metal (Au/Ge/Ni/Au), and p-type ohmic metal (Pt/Ti/Pt/Au), and interconnect metal (Ti/Au) were also processed on half of the same wafer for comparison. The DC characteristics and power performance of the HBT devices were measured. The emitter dimension of InGaP/GaAs HBT was 4 x 20µm^2.

DEVICE PERFORMANCES

The Emitter and Collector n-type ohmic contacts of the copper metalized HBT device was fabricated with alloyed Pd/ Ge/ Cu ohmic contacts. The specific contact resistances of the n-GaAs/ Pd (15nm)/ Ge (150nm)/ Cu (150nm) were measured by transmission line method (TLM). To optimize the annealing condition, the samples were annealed at various temperatures from 200°C to 425°C for 20 minutes. As shown in Figure 2, the lowest specific contact resistivity was 5.73 x 10^{-7} Ω-cm^2 after annealing at 250°C for 20 minutes.

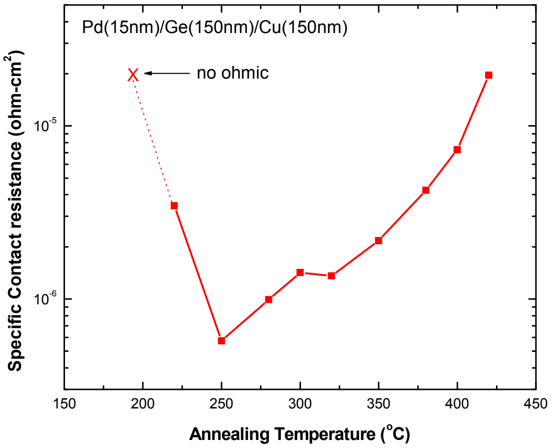
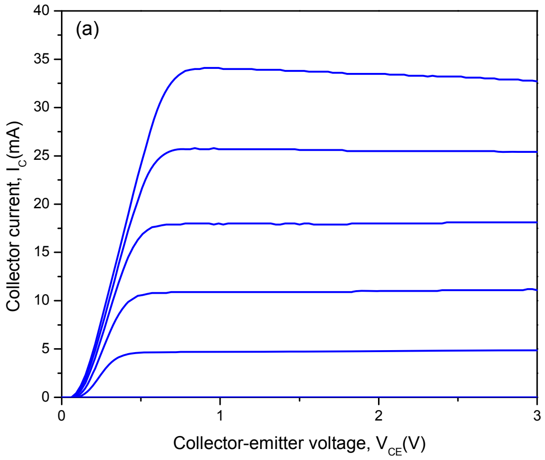


Fig. 2 Specific contact resistivity as the function of annealing temperature

Figure 3 shows the common emitter characteristics of the Cu-metalized and the traditional Au-metalized HBTs, both with an emitter area of 4 x 20µm^2. It can be seen that these two devices show similar knee voltage and offset voltage. The saturation collector current of both devices were almost the same, which indicates that the characteristics of the Pd/Ge/Cu ohmic contact on InGaP/GaAs HBTs is reasonably good. The common emitter current gain was around 130 for both cases. Gummel plots of the HBTs with the traditional Au HBT and Cu-metallized HBT were also compared. The results are shown in Figure 4. Both HBTs also showed similar behaviors.



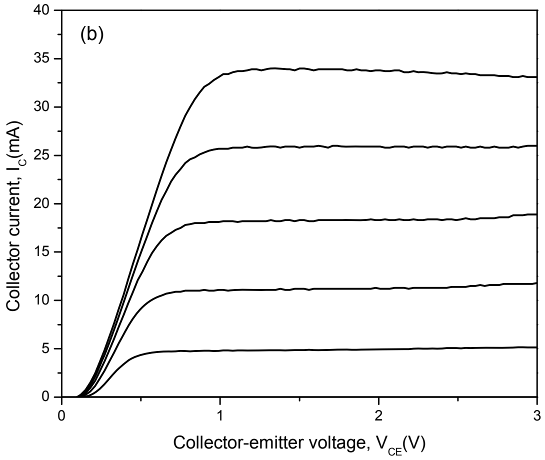


Fig. 3 The typical I_C-V_{CE} characteristics of power HBTs with (a) Au metallization and with (b)Cu metallization.

The power performances of the HBTs were measured at 2 GHz by using a load–pull system, the results are as shown in Figure 4. For Cu InGaP/GaAs HBTs, turning for maximum power-added efficiency (PAE) match, the output power (Pout) was 10.06dBm and the maximum PAE was 35.6%, with the DC bias conditions of V_{CE} = 2 V and I_C =12mA . With the same DC bias conditions, Au-metalized

InGaP/GaAs power HBTs showed output power (Pout) of 10.87dBm and the maximum PAE was 39.4%.

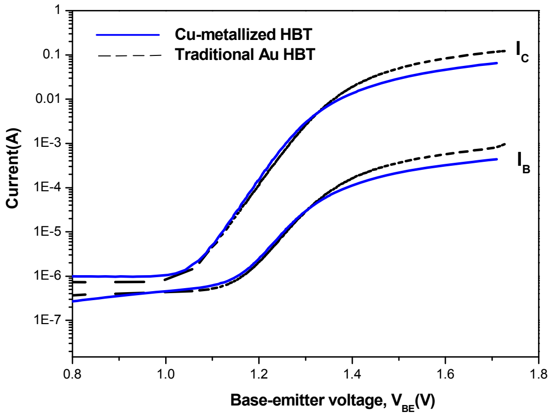


Fig. 4 Comparison of Gummel plots for the emitter area(4 x 20μm^2) HBTs with Cu and with Au metallizations.

CONCLUSIONS

In this study, Cu-metalized InGaP/GaAs HBTs using Pd/Ge/Cu ohmic contact to n-type GaAs, Pt/Ti/Pt ohmic contact to p$^+$-type GaAs and Cu-electroplating interconnect has been successfully fabricated. The lowest specific contact resistivity of Pd/Ge/Cu ohmic contacts was 5.73 x 10^{-7} Ω-cm^2 after annealing at 250°C for 20 minutes.

Cu-metalized HBT using Pd/Ge/Cu ohmic contact showed similar electrical characteristics as those conventional Au-metalized HBT. The common emitter current gain for the 4x20-μm^2-emitter-area Cu-metalized HBT using Pd/Ge/Cu ohmic contact and the traditional Au-metalized HBT were both around 130. The power performance of the 4x20-μm^2-emitter-area Cu-metalized HBT showed the output powers of 10.01 dBm and PAE of 35.6% under the bias of V_{CE}=2 V and I_C=12 mA. It is clear that the microwave performance of the Cu-metalized HBT with Pd/Ge/Cu ohmic contact was comparable with those of Au-metalized HBT.

ACKNOWLEDGEMENTS

The authors would also like to acknowledge the assistance from the National Science Council, and the Ministry of Economic Affairs, Taiwan, R.O.C., under the contracts: 97-2221-E-009-156-MY2 and 97-EC-17-A-05-S1-020.

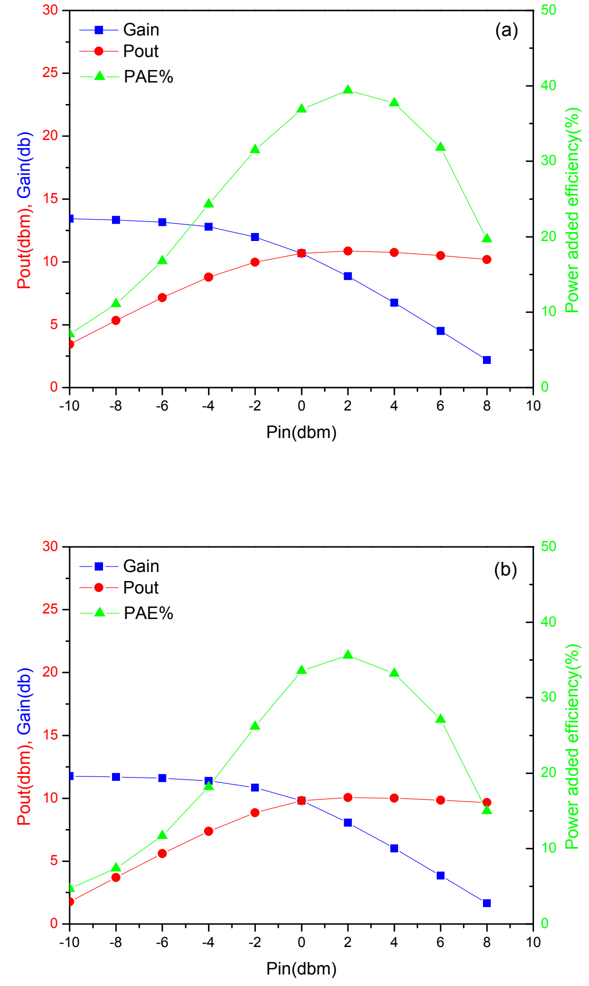


Fig. 5 Output power performance of InGaP/GaAs HBT with (a)Au-metallization and (b)Cu-metallization HBTs at 2 GHz with bias V_{CE}=2V, I_C=12mA.

REFERENCES

[1] K. Holloway, P. M. Fryer, “Tantalum as a diffusion barrier between copper and silicon,” *Appl. Phys. Lett.*, vol. 57, no. 17, pp. 1736-1738, Oct. 22, 1990.

[2] K. Holloway, P. M. Fryer, C. Cabral, Jr., J. M. E. Harper, P. J. Bailey, and K. H. Kelleher, “Tantalum as a diffusion barrier between copper and silicon: failure mechanism and effect of nitrogen additions,” *J. Appl. Phys.*, vol. 71, no. 11, pp. 5433-5444, 1992.

[3] D. S. Yoon, H. K. Baik, and S. M. Lee, “Effect on thermal stability of a Cu/Ta/Si heterostructure of the incorporation of cerium oxide into the Ta barrier,” *J. Appl. Phys.*, vol. 83, no. 12, pp. 8074-8076, 1998.

[4] C. Y. Chen, L. Chang, E. Y. Chang, S. H. Chen, and D. F. Chang, “Thermal stability of Cu/Ta/GaAs multilayers,” *Appl. Phys. Lett.*, vol. 77, no. 21, pp. 3367-3369, 2000.

[5] C. Y. Chen, E. Y Chang, L. Chang, and S. H. Chen, “Backside copper metallisation of GaAs MESFETs,” *Electronics Lett.*, vol. 36, no. 15, pp. 1318-1319, 2000.

[6] C. Y. Chen, E. Y. Chang, L. Chang, and S. H. Chen, “Backside copper metallization of GaAs MESFETs using TaN as the diffusion barrier”, *IEEE Trans. Electron Devices*, vol. 48, no. 6, pp. 1033-1036, 2001.

[7] H. C. Chang, E. Y. Chang, Y. C. Lien, L. H. Chu, S. W. Chang, R. C. Huang and H. M. Lee, " Use of WN_X as the diffusion barrier for copper airbridged low noise GaAs PHEMT", *Electron. Lett,* Vol. 39, pp. 1763, 2003.

[8] S. W. Chang, E. Y. Chang, C. S. Lee, K. S. Chen, C. W. Tseng, T. L. Hsieh, "Use of WN_X as the Diffusion Barrier for Interconnect Copper Metallization of InGaP-GaAs HBTs", *IEEE TRANSACTIONS ON ELECTRON DEVICES*, VOL. 51, NO. 7, 2004.

[9] S. W. Chang, E. Y. Chang, "Gold-Free Fully Cu-Metallized InGaP/GaAs Heterojunction Bipolar Transistor", *Jpn. J. Appl. Phys.*, vol. 44, No. 1A, pp. 8-11, 2005.

[10] A. Gupta, A. Young and B. Bayraktaroglu, "InGaP makes HBT realibility a non-issue", in GaAs Mantech Tech. Dig., 203, 2001