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Gold-Free Fully Cu-Metallized InGaP/InGaAs/Ge multi-junction solar cell

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Abstract

A gold-free, fully Cu-metallized InGaP/InGaAs/Ge multi-junction solar cell has been successfully fabricated. The electrodes use Pd/Ge/Cu and Pt/Ti/Pt/Cu ohmic contact system for n-type GaAs and p-type Ge, respectively. The Pd/Ge/Cu ohmic contact provides a low specific contact resistance of 4.9 x 10^{-6} Ω-cm^2 contact to n-type GaAs. Also, the Pt/Ti/Pt/Cu alloyed structure forms an ohmic contact characteristic to p-type Ge with a low specific contact resistance of 6.6 x 10^{-6} Ω-cm^2. The 0.254 cm^2 Cu-metalized InGaP/InGaAs/Ge solar cell demonstrated the conversion efficiency of 23.78% at condition of AM1.5 spectrum, 25°C; moreover, the Cu-metallized systems compared with conventional Au-metallized ohmic contact.

1. Introduction

Conventionally, n-type Au/Ge/Ni/Au and p-type Ti/Pt/Au ohmic contacts have been widely used metallization structures for the fabrication of GaAs-based Devices since Au-based ohmic system has high thermal stability, not easily oxidized and low contact resistance. However, the Au-based ohmic contact system has several drawbacks, such as poor contact edge definition, the annealing temperature was high due to the eutectic Au/Ge alloy, particularly the high production costs. But, if the production cost of III-V solar cell is increased, that is equal to decrease the application degree of solar cell.

The focus of this paper is to provide a new alloyed system on Pd/Ge/Cu and Pt/Ti/Pt/Cu for n-type and p-type ohmic contacts were used respectively to fabricate the Cu-metalized InGaP/InGaAs/Ge solar cell. The Cu-based alloy has been used in metallization for the silicon based very-large scale integration because of its lower electrical resistivity, higher electro migration resistance, and lower cost.[1-3] However, there are only a few reports on the copper metallization of GaAs devices like metal semiconductor field-effect transistors, high electron mobility transistors have been reported but not for III-V solar cell[4-6] since Cu diffuses very fast into the operated areas and is an deep acceptor for III-V based material.[7, 8] So an effective barrier between Cu and the active region of the device is needed if Cu is to used be for the metallization of III-V based devices.

In the III-V solar cell structure, Pd/Ge/Cu and Pt/Ti/Pt/Cu metals are used for the n-type and p-type ohmic contacts, respectively. In n-type ohmic contact system, Germanium is used as the diffusion barrier that formed Cu_3Ge with Copper to prevent Cu diffuse into the GaAs substrate[9]. In the other hand, the Platinum is used as the diffusion barrier for p-type ohmic contact system because it has a high melting point. Here, we are reporting for the first time about fabrication and electrical performance of the Au-free, fully Cu-metallized InGaP/InGaAs/Ge multi-junction solar cell.

2. Experimental

First, using the transmission line model (TLM) to measure the specific contact resistance of the Pd/Ge/Cu and Pt/Ti/Pt/Cu after annealing, then further to optimize the condition of ohmic contact. The other hand, these two kinds of ohmic contact systems were analyzed by the TEM and AES to confirm whether the copper diffuse into the substrate. These two kinds of ohmic contact systems were used in the Cu-metallized solar cell process.

The InGaP/InGaAs/Ge multi-junction solar cells that layer structure consists of (from bottom to top) a p-type Ge substrate (200 um, ~10^{18} cm^{-3}), an InGaAs junction, an InGaP junction, and an n-type GaAs capping layer (500 nm solar cell devices were fabricated using a standard lithography process. The wafer was cleaned with ACE and IPA solutions, and followed, the Pd/Ge/Cu and Pt/Ti/Pt/Cu metals were sequentially deposited using an e-gun evaporator that used for the front side and backside electrodes contacts, respectively, then to form alloy after annealing. Silicon nitride (75nm) of AR coating was grew by PECVD. The structure of the InGaP/InGaAs/Ge multi-junction solar cell in this study is shown in Fig. 1. And the conversion efficiency of the solar cell devices was measured using a solar simulation (AM1.5, 25°C).

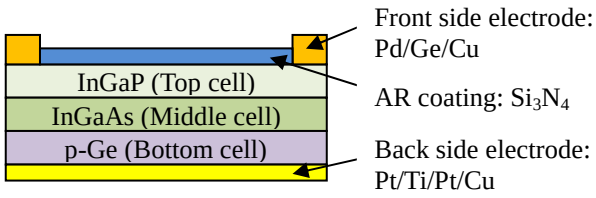

Fig. 1. Cross section of Au-free fully Cu metallized InGaP/InGaAs/Ge multi-junction solar cell.

3. Device Electrical Characteristics

The specific contact resistance of the alloyed Pt/Ti/Pt/Cu is 6.9 x 10^{-6} Ω-cm^2, and Pd/Ge/Cu is 4.4 x 10^{-6} Ω-cm^2, Figure 2 and Figure 3 shows the specific contact resistance of

the n-type GaAs and p-type Ge ohmic contact extracted from the TLM as a function of annealing temperature, respectively. The result also indicated the resistance of conventional Au/Ge/Ni/Au is 1.4 x 10^{-6} Ω-cm^2, and Ti/Pt/Au is 4.2 x 10^{-6} Ω-cm^2. The TEM image and the EDX profiles of the Pd/Ge/Cu ohmic metal structure after 250°C annealing were shown in Fig. 4. From Fig. 4(a) and 4(b), it could be observed the Cu_3Ge compound started to form with vertical grain boundary. Fig. 4(c) indicated that there was no Cu atom diffused into the GaAs substrate near the Pd/GaAs interface after 250°C annealing. Fig. 5 is the Auger electron spectroscopy (AES) depth profiles of the Ti/Pt/Cu ohmic structure after annealing, as estimation for the figure, the Pt can effectively prevent Cu diffusion into the substrate when annealing temperature up to 350°C. The I-V curves (Fig. 6) show the comparison between the novel Cu-metallized and conventional Au-metallize which were processed on the same wafer. The fill factors (FF) of Cu-metallized solar cell and Au-metallized solar cell are 79.88% and 84.64%, respectively; and conversion efficiency values are 23.78% and 24.06%, respectively. The FF value of copper contact system decreasing was due to R_{sh} value raising by instable dicing process, which not caused by Pd/Ge/Cu ohmic structure.(Fig.6) When the yield rate of dicing could be improved in the future, the FF value and efficiency of Cu-metallized solar cell will be increased.

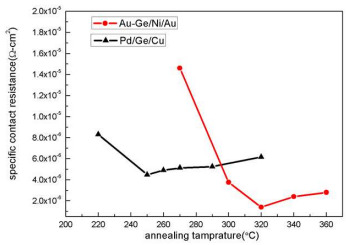

Fig. 2. TLM result of n-type GaAs ohmic contact after annealing at various temperatures.

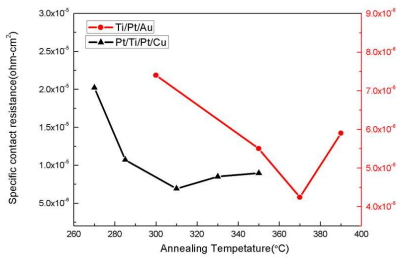

Fig. 3. TLM result of p-type Ge ohmic contact after annealing at various temperatures.

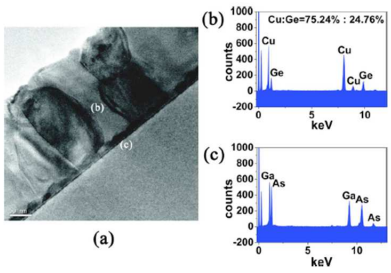

Fig. 4. (a)The TEM image of the Pd /Ge /Cu Ohmic contact. (b) The EDX profiles of the Cu_3Ge compound grain. (c)The EDX profiles of the GaAs substrate near the Pd/GaAs interface after annealing at 250 °C.

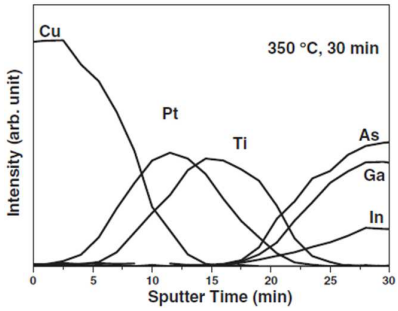

Fig. 5. AES depth profiles of the InGaAs/Ti/Pt/Cu sample after 350°C for 30 min annealing.

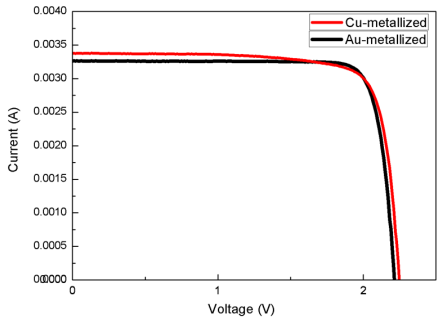

Fig. 6. Conversion efficiency of the solar cell with Cu and Au metallization.

4. Conclusion

An Au-free, fully Cu-metallized solar cell was fabricated and reported for the first time. The Pd/Ge/Cu and Pt/Ti/Pt/Cu were supplied the good electrical characteristics, and Ge, Pt can effectively prevent the Cu diffusion. These results show that it is possible to fabricate fully Cu-metallized InGaP/InGaAs/Ge multi-junction solar cell.

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