Proceedings of 6th Thin Film Materials & Devices Meeting
November 2-3, 2009, Kyoto, Japan
http://www.tfmd.jp/

Multi-Junction Solar Cells Fabricated With Conductive Transparent Adhesive

S. Yoshidomi[1], M. Hasumi[1], T. Sameshima[1], K. Makita[2], K. Matsubara[2], and M. Kondo[2]

[1]Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan
[2]Research Center for Photovoltaic Technologies, AIST, Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8568, Japan

Email: tsamesim@cc.tuat.ac.jp

Keywords: Multi-Junction solar cells, Conductive Transparent adhesive, ITO

Abstract. We report characteristics of electrical contact between indium-tin oxide ITO particles and silicon Si substrate to apply this technique to fabrication of mechanical-stack-type-multi-junction solar cells. 25-μm-sized ITO particles were reduced in Ta boats by joule heating at 60W for 5 and 20 min. The joule heating changed the color of the particles from green (as-bought initial) to dark grey. Samples with Si/initial or reduced-ITO+Cemedine adhesive/Si structure showed ohmic current-voltage characteristics at temperatures between 22 and 70°C. Ohmic characteristics probably resulted from a high density of carrier recombination sites located at the interfaces between ITO particles and Si surfaces, whose work functions were different each other. A low connecting resistivity of 1.2 Ωcm^2 was achieved for a sample of Si/5 min-reduced ITO/Si structure. Moreover, a mechanical stack solar cell was achieved using initial ITO particles for samples of InGaP/GaAs/initial ITO+Cemedine/Ge structure. The short circuit current density, open circuit voltage and conversion efficiency were 12.6 A/cm^2, 2.13 V, and 15.9%, respectively.

Introduction

We have developed multi-junction solar cells with different band gaps by stacking individual solar cells using conductive and transparent pastes. We experimentally demonstrated a multi junction solar cell with a-Si:H and c-Si solar cells, which were stacked by the polyimide adhesive layer including indium-tin oxide ITO particles [1]. We also reported electrical and mechanical stacking of fragile 4 inch sized GaAs and Ge substrates by the adhesive described above [2]. Those results indicate that the mechanical stacking method using plastic paste has a possibility of fabricating multi-junction solar cells with a large size. Ohmic current-voltage characteristics at semiconductor/conductive adhesive interface is important to realize good characteristics of multi-junction solar cells. Low connecting resistivity is also necessary to effectively produce electrical power [1,3]. We have achieved ohmic characteristics with a connecting resistivity of 1.8 Ωcm^2 so far.

In this paper, we report decrease in resistivity of ITO particles by joule heating in a vacuum with keeping good ohmic characteristics. Moreover, we report solar cell characteristics of stacking InGaAs/GaAs and Ge solar cell by conductive-transparent adhesive.

Experimental procedure

ITO particles with the diameter ranging from 25 to 32 μm were prepared by mechanical filtering with metal mesh membranes. Then, they were carried out with reduction treatment. They were placed in a Ta board, which was set in a vacuum chamber. The chamber was evacuated to 8.0×10^{-4} Pa. The Ta board was heated by applying electrical power of 60 W for 5 and 20 min. Visual observation of dark red color light emission from the Ta boat indicated that it was heated to about 800 °C by the joule heating. ITO particles at 5.3 weight% were dispersed in Cemedine adhesive gel. The Cemedine gel including ITO particles was sandwiched with two mirror polished n-type silicon substrates with a resistivity of 0.001 Ωcm. The Cemedine intermediate layer including ITO was solidified under a high pressure at 4×10^{5} Pa for 2 h at RT to investigate current-voltage (I-V) characteristics of ITO particles under temperatures ranging from 22 to 70 °C. The optical transmissivity of the sample of glass/reduced ITO+Cemedine/glass was also measured.

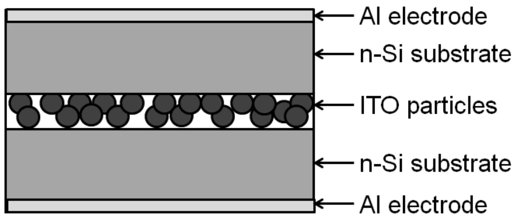

Fig.1 Structure of n-Si/adhesive/n-Si sample.

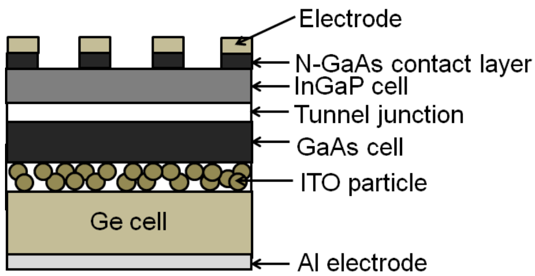

Fig. 2 Structure of InGaP/GaAs/adhesive/Ge solar cell.

Stacking InGaP/GaAs and Ge solar cells was tried with present adhesive including ITO particles to demonstrate direct contact of ITO to III-V materials as well as IV materials, as shown in Fig. 2. Top metal electrodes were formed on n-GaAs contact layer by photolithography and etching method. Conformal etching of the n-GaAs layer was carried out to form light windows. P-type GaAs surface was attached to n-type Ge surface by Cemedine. Cemedine gel dispersed with 5.3 weight% ITO particles. The gel was solidified under a high pressure at 4×10^{5} Pa for 2h at RT. Al electrode was formed on rear surface of Ge solar cell by evaporation. Solar cell characteristics were measured using a AM1.5 solar cell simulator at 1 sun.

Result and discussion

Figure 3 shows I-V characteristic for samples of n-type Si/adhesive/n-type Si with initial ITO, reduction treated for 5 and 20 min at 22 °C. Every sample showed very good ohmic characteristic. High current was obtained by reduction treatment for 5 min. The connecting resistivity was 1.2 Ωcm^2. Reduction treatment by heating in vacuum was effective to decrease resistivity of ITO particles. Color of ITO particles was markedly changed by reduction treatment for 5 min from green (initial) to dark grey. Substantial oxygen atoms released during heating and atomic bonding structure probably changed. Figure 4 shows change in connecting resistivity as a function of temperature for samples of n-type Si/adhesive/n-type Si with initial ITO, reduction treated for 5 and 20 min. The connecting resistivity gradually increased as temperature increase above 30 °C. It was still low of 2.0 Ωcm^2 at 70 °C for the sample with reduction treatment for 5 min. Physics of temperature change in the connecting resistivity is not clear yet. One possibility is that mobility of carriers in ITO particles was decreased by phonon scattering at a high temperature. I-V measurements showed good ohmic conditions for every temperature condition. Those results indicate that ITO silicon contact has an advantage of high recombination properties to realize the ohmic current-voltage characteristic between different kinds of materials with different work functions. Figure 5 shows optical transmissivity for sample of glass/5-min-reduced ITO+Cemedine/glass. It was around 80 % for wavelength ranging from 500 to 2000 nm. The transmissivity depends on refractive index of Cemedine. The conductive transparent adhesive consists of 5.3 weight% of ITO particles and 94.7 weight% of Cemedine. Reflection loss at Cemedine/glass interface limited transmissivity to 80%. At most 5.3 weight% of ITO particle doesn't decrease transmissivity.

Figure 6 shows solar cell characteristic of InGaP/GaAs/adhesive/Ge solar cell. In this case, initial ITO particles were used in the adhesive layer. A typical solar cell characteristic means that good electrical contact between p-type GaAs and n-type Ge by ITO particles. J_{sc}, V_{oc}, and the conversion efficiency were 12.6 mA/cm^2, 2.13 V, and 15.9%, respectively. V_{oc} of InGaP/GaAs solar cell was observed as 2.1 V in other individual cells. Increase in V_{oc} was much smaller than we expected. There is a possibility of unexpected short circuit formation in Ge solar cell in the fabrication process steps.

Summary

We studied decrease in connecting resistivity by joule heating reduction of ITO particles for its application to transparent conductive adhesive. ITO particles with the diameter ranging from 25 to 32 μm were heated by joule heating at 60 W for 5 and 20 min in a vacuum. ITO particles at 5.3 weight% were dispersed in Cemedine

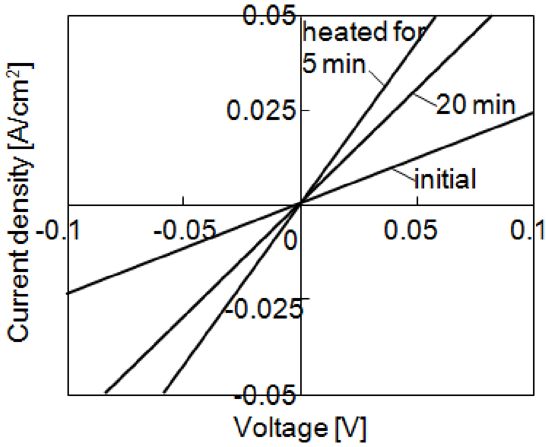

Fig. 3 Current density as a function of voltage.

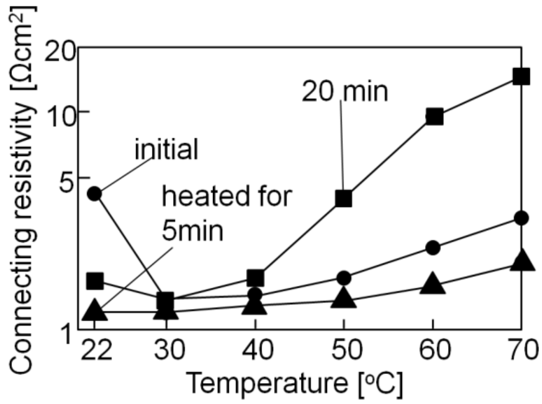

Fig. 4 Connecting resistivity as a function of temperature.

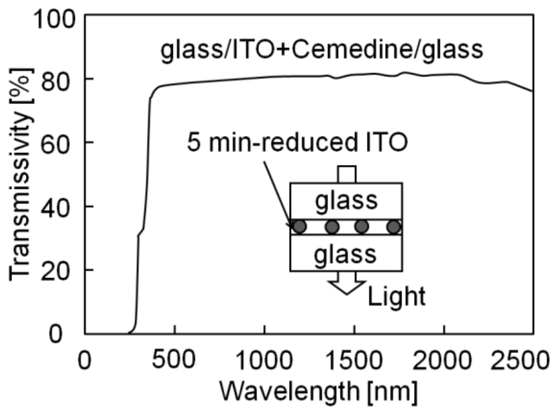

Fig. 5 Optical transmissivity for sample of glass/1min-reduced ITO+Cemedine/glass.

adhesive gel. The Cemedine gel including ITO particles was sandwiched with two mirror polished n-type silicon substrates with a resistivity of 0.001 Ωcm. The Cemedine intermediate layer including ITO particles was solidified under a high pressure at $4x10^5$ Pa for 2h at RT. I-V characteristics under temperature ranging from 22 to 70 ^oC showed good ohmic characteristics. The connecting resistivity of 1.2 Ωcm^2 was obtained at 22 ^oC in the case of 5 min joule heating reduction. The connecting resistivity increased as temperature increased from 30 ^oC probably because of decrease in carrier mobility of the ITO particles. InGaP/GaAs and Ge solar cells were stacked by the present conductive transparent adhesive. Typical solar cell characteristic was obtained. J_{sc}, V_{oc}, the conversion efficiency were 12.6 A/cm^2, 2.13 V, and 15.9 %, respectively.

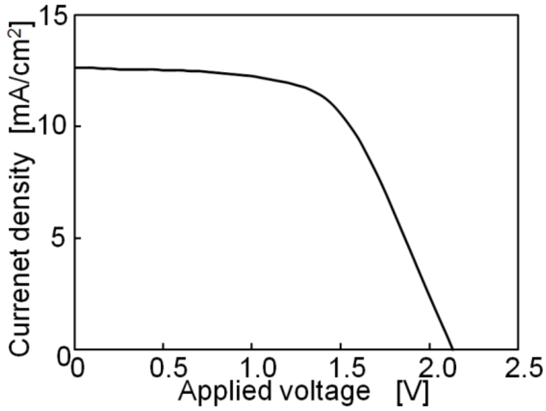

Fig. 6 Solar cell characteristic of sample for InGaP/GaAs/adhesive/Ge solar cell.

Acknowledgments

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO)

References

[1] T. Sameshima, J. Takenezawa, M. Hasumi, T. Koida, T. Kaneko, M. Karasawa, and M. Kondo. Jpn. J. Appl.Phys. **50** (2011) 052301

[2] J. Takenezawa, C. Akiyama, M. Hasumi, and T. Sameshima: International symposium on Innovative solar cells 2012, (Tokyo, 2012) p 10.

[3]J. Olivier, B. Servet, M. Vergnolle, M. Mosca, G. Garry. Synthetic Metals **122** (2001) 87-89