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Stacked Solar Cells using Transparent and Conductive Adhesive

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1. Introduction

Semiconductor solar cells have been widely investigated as a device directly generating electrical energy from solar light. Stacked type multi-junction solar cells combined with solar cells with different band gaps has been taken attention to achieve high conversion efficiency by collection of solar lights with wide wavelength range [1]. Image of stacked-type-multi-junction solar cell shown in Fig. 1 indicates that transparent and electrically conductive intermediate adhesive layers are necessary to connect optically and electrically between a top solar cell with a wide band gap and a bottom solar cell with a narrow band gap [2]. The intermediate layer should be transparent to light passing through the top solar cell in order to operate the bottom solar cell with a narrow band gap. It has to be electrically conductive to give electrical current and voltage which the both cells generate.

In this paper, we propose Polyimide transparent adhesive layer dispersed with In_2O_3-SnO_2 conductive particles. We report transmittance characteristics in visible and near-infrared wavelength ranges, electrical conductance of the adhesive layers. We also discuss changes in solar cell characteristics with the resistance the adhesive layers. We demonstrate multi-junction solar cells by stacking an hydrogenated amorphous silicon (a-Si:H) p-i-n thin film solar cell on a Hetero-junction with Intrinsic Thin-layer (HIT) type silicon solar cells and show increase in the open circuit voltage (V_{oc}) owing to multi-junction effect.

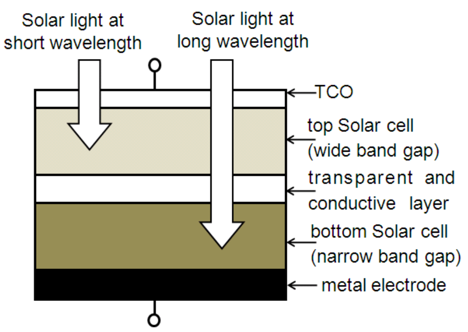

Fig. 1 Image of multi-junction solar cell

2. Experimental Procedure

In_2O_3-SnO_2 (ITO) conductive particles with a diameter of about 70 μm were dispersed in Polyimide organic liquid. The volume of ITO particles was 0.05 g per 1 cm^3 of Polyimide organic liquid. Liquid of Polyimide included with ITO particles (Polyimide-ITO) was coated on glass substrates using a spinner. Thickness of the Polyimide-ITO layer was controlled from 60 to 100 μm by rotation frequency of the spinner. Another glass substrate was then placed on the Polyimide-ITO layer. The Polyimide-ITO layer was subsequently solidified by heating the sample at 160°C for 2 h with a mechanical pressure at 0.5 kg/cm^2 during heating. Optical transmissivity of the samples was measured for wavelength ranging from 250 to 1000 nm by a spectrometer. Polyimide-ITO liquid was also coated on doped silicon substrates with a resistivity of 0.01 Ωcm. Another silicon substrate was then placed on the Polyimide-ITO layer. The silicon samples sandwiched with the Polyimide-ITO layer were subsequently by heated at 160°C for 2 h with a mechanical pressure at 0.5 kg/cm^2 for solidification. The electrical current was measured by applying voltage between the two silicon substrates to investigate connecting resistivity of the Polyimide-ITO intermediate layer.

We calculated change in solar cell characteristics with series connecting resistance (R_c) as shown by inset in Fig. 4 using two-dimensional finite element numerical calculation program. A circuit of solar cell formed in 150-μm thick p-type silicon substrate with an area of 1 cm^2 connected with a series resistance ranging from 0 to 30 Ωcm^2 was modeled. Irradiation of a light with a wavelength of 500 nm at 0.1 W/cm^2 was assumed for calculation.

We experimentally demonstrate multi-junction solar cells by stacking a-Si:H p-i-n cells with an area of 1.08 cm^2 on a Hetero-junction with Intrinsic (HIT) type silicon solar cells with an area of 0.58 cm^2 using the Polyimide-ITO intermediate layer. a-Si:H p-i-n cells were formed on glass substrate coated with textured SnO_2 layer. P-, i-, and n-type a-Si:H layers were subsequently formed by plasma enhanced chemical vapor deposition (PECVD). Finally an ITO layer was coated on the n-type a-Si:H surface. HIT type silicon solar cells were fabricated in n-type silicon substrates by forming i-, and p-type a-Si:H thin film using PECVD. ITO layer was finally coated on the p-type a-Si:H surface. Air mass 1.5 (AM 1.5) type solar simulator at 0.1 W/cm^2 was used for measurement solar cell characteristics. Table I shows short circuit current density (J_{sc}), V_{oc}, fill factor (FF) and conversion efficiency for a-Si:H p-i-n cell and HIT type cell. The a-Si:H p-i-n cell had a high V_{oc} of 0.86 V, and a low J_{sc} of 1.14×10^{-2} A/cm^2. On the other hand, the HIT type cell had a low V_{oc} of 0.58 V, and a high J_{sc} of 3.2×10^{-2} A/cm^2. The area of HIT type cells, 0.58 cm^2 was used to estimate J_{sc} and conversion efficiency for the multi-junction cells.

Table I: Characteristics for a-Si:H p-i-n and HIT type cells used for multi-junction solar cell

	J_{sc}(A/cm^2)	V_{oc}(V)	FF	conversion efficiency(%)
a-Si:H p-i-n	1.14×10^{-2}	0.861	0.76	7.49
HIT	3.2×10^{-2}	0.579	0.75	14.4

3. Results and discussion

Figure 2 shows transmissivity spectra for samples of glass/ Polyimide-ITO layer/glass, glass/air gap/glass, and glass/Polyimide without ITO/glass. The sample of glass/Polyimide-ITO layer/glass gave a high transmissivity of 80% for wavelength ranging from 500 to 1000 nm. Polyimide-ITO layer was transparent over the wide wavelength range in visible and near infrared. The sample of glass/ air gap/glass also gave almost same transissivity of 80 %, which resulted from reflection loss at the glass surfaces. The most high transmissivity of 88% was obtained for sample of glass/Polyimide without ITO/glass. Index matching well decreased reflection loss at Polyimide/glass interface. Optical scattering at Polyimide/ITO interfaces probably decreased transmittance by 8%.

Figure 3 shows the electrical current as a function of voltage

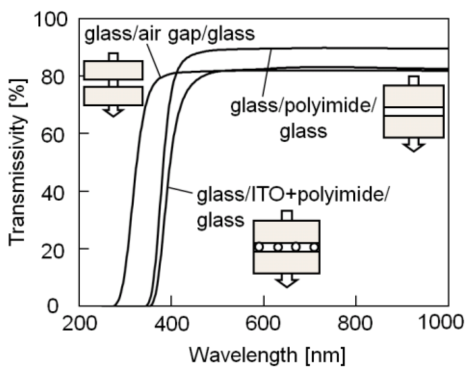

Fig. 2 Transmissivity spectra for samples of glass/ Polyimide-ITO layer/glass, glass/air gap/glass, glass/Polyimide without ITO /glass.

applied to sample of doped silicon/Polyimide-ITO layer/doped silicon with an area of 1 cm^2. A high electrical current of 0.1 A was obtained by application of 0.23 V. It means that connecting resistance of the intermediate Polyimide-ITO layer was 2.3 Ωcm^2. The connecting resistance depends on experimental condition at present. It distributes from 2.3 to 10 Ωcm^2.

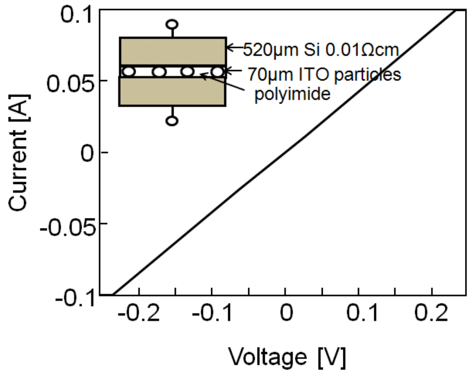

Fig. 3 Electrical current as a function of voltage for sample doped silicon/Polyimide-ITO layer/doped silicon with a area of 1 cm^2.

Figure 4 shows calculated solar cell characteristics with different series resistances. A steep and box-shaped I-V characteristic was obtained for a connecting resistance (R_c) of 0 Ωcm^2. I-V shape changed gently as the R_c increased. This means the FF decreased as the R_c increased. Figure 5 shows the conversion efficiency, J_{sc}, and V_{oc} as functions of R_c. Although J_{sc} and V_{oc} were not sensitive to the R_c, the conversion efficiency strongly depended on the R_c. It decreased from 17.4 to 3.0% as the R_c increased from 0 to 30 Ωcm^2 because of decrease in FF. Those calculations suggest that the R_c should be low to maintain the conversion efficiency high. It should be lower than 3 Ωcm^2 to maintain 80% of the initial value.

Figure 6 shows solar cell characteristic of a multi-junction cell sample stacking a-Si:H p-i-n cell on the HIT type cell. Light AM 1.5 was illuminated to the surface of the glass substrate of a-Si:H p-i-n cell as shown by the inset. Solar cell characteristics of individual a-Si:H p-i-n cell and the HIT type cell are also presented by dashed curves in Fig. 6. A typical J-V curve was obtained in the stacked multi-junction cell, as shown in Fig. 6. This clearly shows that the present Polyimide-ITO adhesive layer well played a role of optical and electrical connection between the two solar cells. J_{sc}, V_{oc}, FF and the conversion efficiency were 1.27×10^{-2} A/cm^2, 1.34 V, 0.61 and 10.3 %, respectively. The high V_{oc} of 1.34 V means that a series of top and bottom solar-cells simultaneously generated electric powers. The J_{sc}, of 1.27×10^{-2} A/cm^2 was probably governed by that of top a-Si:H p-i-n cell, as shown in Fig. 6. There might be also possibility of J_{sc} limitation caused by the top a-Si:H p-i-n cell seriously shading the bottom HIT type cell because of their similar optical absorption properties.

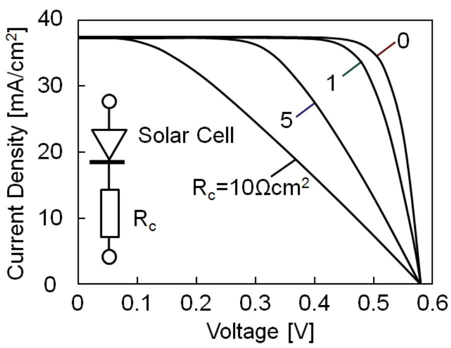

Fig. 4 Calculated solar cell characteristics with different connecting resistances.

The results of Figs. 2 to 6 show a capability of fabrication of multi-junction solar cell by mechanical stacking method using Polyimide transparent adhesive layer dispersed with ITO conductive particles.

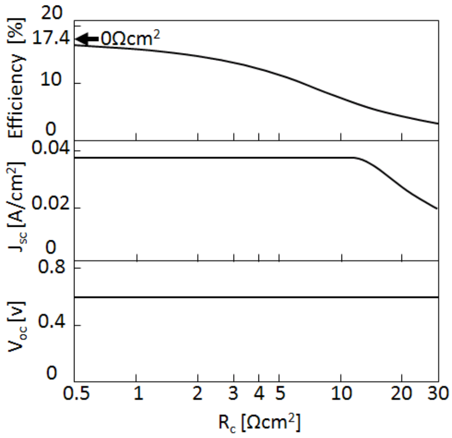

Fig. 5 Conversion efficiency, J_{sc} and V_{oc} as functions of connecting resistance.

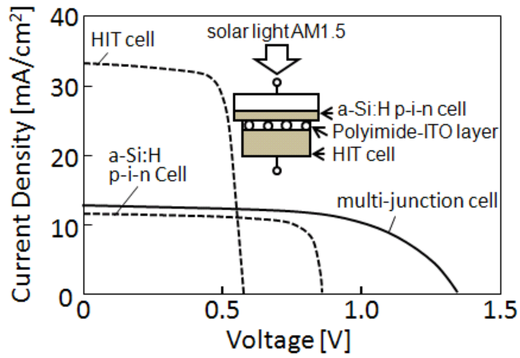

Fig. 6 Multi-junction solar cell characteristics by stacking a-Si:H p-i-n on HIT type cell.

4. Conclusions

Polyimide transparent adhesive layer dispersed with In_2O_3-SnO_2 conductive particles was used for mechanical stacking of solar cells for fabrication of multi-junction solar cells. 100 μm thick Polyimide-ITO layer had a high transmissivity of 80% for wavelength ranging from 500 to 1000 nm. This transparednt characteristic is suitable to give solar light to the undelying solar cells. The connecting resistance of the Polyimide-ITO layer was 2.3 Ωcm^2 at minimum at present stage. The low connecting resistance is important to maintain FF and the conversion efficiency high. The connecting resistance lower than 3 Ωcm^2 were recommended from numerical calculation. A high V_{oc} of 1.34 V was successfully obtained in the case of multi-junction solar cell by stacking the top a-Si:H p-i-n cell on the bottom HIT type cell. Simultaneous electric power generation from the top and bottom solar cells was achieved. Those results show a capability of fabrication of multi-junction solar cell by mechanical stacking method using Polyimide transparent adhesive layer dispersed with ITO conductive particles.

Acknowledgements

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