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Crystalline Silicon Solar Cells Used with Al and Au Metals

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1. Introduction

Semiconductor solar cells have been attractive as a device producing electrical power from sun light [1]. Simple processing is attractive for low cost fabrication of solar cells. We propose a simple fabrication of crystalline silicon solar cell with Al and Au metals. No pn junction formation is necessary. We discuss physics of our solar cell model. We then experimentally demonstrate fabrication of a solar cell according to our model. We report solar cell characteristics of our solar cell.

2. Physics

Figure 1 shows a schematic energy band image of our solar cell model. Al and Au are selected. Their work functions are reported as 4.18 and 5.1 eV, respectively [2]. P-type crystalline silicon is sandwiched by Al and Au metals. The difference of work functions of those metals can cause distribution of internal built-in potential in silicon. Because the initial Fermi level of silicon is near the work function of Au and far different from that of Al, a large internal potential distribution associated with a depletion region is spatially formed near the Al metal electrode. Hole and electron excited by light illumination in silicon separate each other according to the internal potential distribution. We introduce thin SiO_2 layers between silicon and the two metals, as shown in Fig. 1 because SiO_2/Si interface can be stable and can have a low density of interface states. SiO_2 will maintain the internal built-in potential barrier high. Thin SiO_2 layer is essential to make photo-induced carrier flow from silicon to the two metals by a tunneling effect. SiO_2 layer should be thinner than 2 nm to achieve sufficient Fowler-Nordheim current [3]. In conclusion, our solar cell structure consists of semiconductor, two different metals, thin insulators between metal and semiconductor. No pn junction formation is necessary because difference in the work functions causes internal built-in potential in semiconductor.

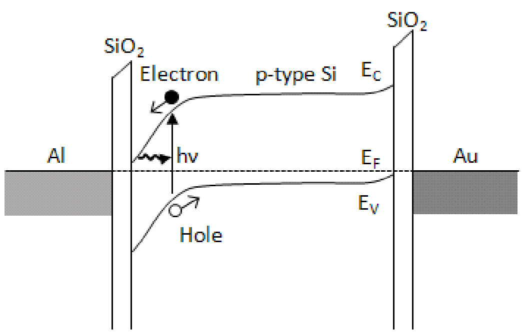

Fig. 1. Schematic energy band image of the present solar cell.

3. Experimental

Figure 2 shows a schematic cross section of solar cell fabricated with Al and Au metals and light illumination image for measurement of solar cell characteristics. P-type single crystalline silicon substrates with a thickness of 520 μm and a resistivity 30 Ωcm were used. The top mirror polished surface and rough rear surface were thermally oxidized and 100 nm thick thermally grown SiO_2 layers were formed on both surfaces. The SiO_2 layer at the top surface was then thinned to 1.5 nm by buffered hydro-florin acid. Samples were then annealed at 260°C for 3 h in 1.3×10^6 Pa H_2O vapor for silicon surface passivation [4]. The minority carrier lifetime was measured using 9.35 GHz microwave transmission measurement with light illumination [5]. Stripes of Al with a width of 0.5 mm and Au with a width of 1.0 mm were formed with a gap of 0.29 mm on the top surface by thermal evaporation. Electrical current as a function of voltage was measured under light illumination of a halogen lamp at 21.7 mW/cm^2 to the top and rear surfaces.

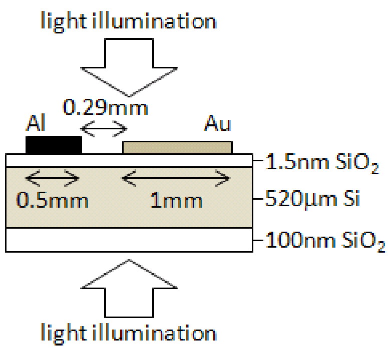

Fig. 2. Schematic cross section of solar cell structure and light illumination image for measurement of solar cell characteristics.

4. Results and discussion

The minority carrier effective lifetime was 185 μs for the initial silicon substrates with the both surfaces coated with 100 nm thick SiO_2 layers. The silicon surface was well passivated with a low recombination velocity of 141 cm/s, which was estimated when the bulk lifetime was assumed very large. When the thickness of SiO_2 films at the top surface was decreased to about 1.5 nm by buffered hydro-florin acid, the effective lifetime decreased 16 μs. The subsequent 1.3×10^6 Pa H_2O vapor heat treatment at 260°C for 3 h increased the effective lifetime to 47 μs. The recombination velocity at the top surface was 970 cm/s. Figure 3 shows the absolute electrical current as a function of voltage for samples with Al and Au stripes when samples were in dark and illuminated with light to the rear surfaces. The electrical current increased as the voltage increased in dark condition. We believe that substantial FN current was observed. Light irradiation markedly increased the electrical current. A substantial current at 0 V indicating the short circuit current density was observed for the sample with Al and Au stripes, as shown in Fig. 3. It shows that photo-induced current was generated because holes and electrons were separated flowed toward Au and Al respectively according to the internal built-in potential. No current appeared at 0.49 V indicating the open circuit voltage, as shown in Fig. 3. Figure 4 shows solar cell characteristics for light illumination to the rear and top surface for samples with Al and Au stripes, whose structure was shown in Fig. 2. Typical solar cell current voltage characteristic was obtained. In the case of light illumination to the rear surface, the short circuit current density, J_{sc}, the open circuit voltage, V_{oc}, and fill factor, FF, were 5.8 mA/cm^2. 0.49 V, and 0.57, respectively. The conversion efficiency was therefore 7.5%. Holes and electrons generated at the rear surface traveled across the 520 μm thick silicon substrate and flowed into Au and Al respectively. The results of Figs. 3 and 4 demonstrate our solar cell model discussed in the section of physics. In the case to light illumination to the top surface, V_{oc} and FF were 0.48 V and 0.57. On the other hand, Jsc was 1.8 mW/cm^2 lower than that for illumination to the rear surface because the top surface was shaded by Al and Au electrodes.

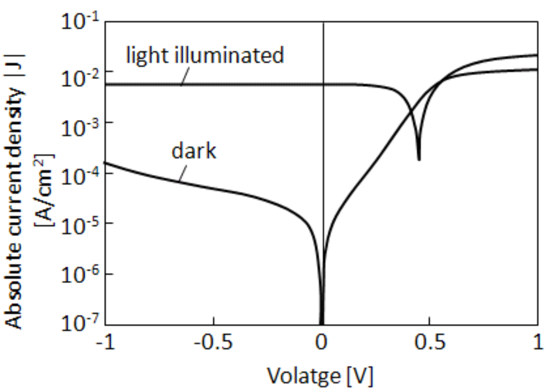

Fig. 3. Absolute electrical current as a function of voltage for samples with Al and Au stripes

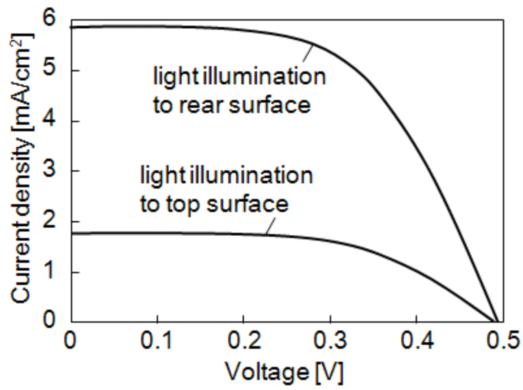

Fig. 4. Solar cell characteristics for light illumination to the rear and top surface for samples with Al and Au stripes,

5. Conclusions

Crystalline silicon solar cells were demonstrated. P-type 520 μm thick 30 Ωcm single crystalline silicon substrates coated with 100 nm thick thermally grown SiO_2 layers were used. The SiO_2 layer at the top surface was thinned to be about 1.5 nm. Samples were then annealed at 260°C for 3 h in 1.3×10^6 Pa H_2O vapor. The minority carrier effective lifetime was 47 μs with a recombination velocity of 970 cm/s at the top surface. Stripes of Al and Au were formed on the top surface by thermal evaporation. Electrical current as a function of voltage was measured between Al and Au stripes under light illumination of a halogen lamp at 21.7 mW/cm^2 to the rear surface. Typical current voltage characteristics of solar cells were obtained. J_{sc}, V_{oc}, and FF were 5.8 mA/cm^2. 0.49 V, and 0.57, respectively. The conversion efficiency was 7.5%. Holes and electrons generated at the rear surface traveled across the 520 μm thick silicon substrate and flowed into Au and Al electrodes respectively owing to FN tunneling effect. Those results demonstrated our solar cell with two different kinds of metals caused an internal built-in potential in silicon. Many other choices of metals will be possible besides Al and Au used in the present report. Many semiconductors could be used if their work function is positioned middle between those of two different metals. Passivation of semiconductor surface will be essentially important for our solar cell.

Acknowledgements

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