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Defect Passivation of Solar Cells by High Pressure H_2O Vapor Treatment

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1. Introduction

The market of solar cells has been recently increased. Especially, polycrystalline Silicon solar cells have most spread because of their low manufacturing cost. However, it remains a problem that the conversion efficiency is inferior to the single crystalline solar cells. The recombination probability of photo induced carrier is large because of the existence of dangling bonds at the grain boundary. Therefore, defect passivation is important for improving the characteristics of polycrystalline solar cells. The high pressure H_2O vapor heat treatment has been established as a technology for defect passivation of poly-Si thin film transistors (TFTs) and improvement of their characteristics [1,2]. This treatment is attractive for defect passivation of solar cells which consist of layered structure with PN junction, transparent electrodes and passivation insulators because the steam permeates semiconductors and insulators in deep and passivate defect states.

The present paper reports improvement in characteristics of commercial crystalline silicon solar cells by the high-pressure H_2O vapor heat treatment. Through investigation of different conditions, we propose effective conditions of high pressure H_2O vapor heat treatment for improvement in solar cells characteristics.

2. Experimental

Two types of commercial solar cells were prepared. One was cast type polycrystalline silicon solar cell with the efficiency of 9.5% with a structure of SiN_x/ITO/n+Si/p-Si/Al. The other was single crystalline silicon solar cell with the efficiency of 13.5-16.4%, with a structure of SiN_x/ITO/n+Si/p-Si/Al. The single crystalline solar cells were divided into the pieces with area ranging from 1 to 2 cm^2. The polycrystalline solar cells were also divided into the almost same area. However, the grain boundaries differently distributed among the pieces. High-pressure H_2O vapor heat treatments were applied to the samples with pressures ranging from $1.0x10^5$ to $1.0x10^6$ Pa, at temperatures ranging from 150 to 270°C and for duration from 10 to 240 min. Electrical properties of as fabricated and the vapor annealed samples were measured by Agilent 4156 parameter analyzer. A light emitting diode array with a wavelength of 590nm at an intensity of 24 mW/cm^2 was used for the light illumination source. The open circuit voltage (V_{oc}), short circuit current (I_{sc}), and conversion efficiency were experimentally measured.

3. Results and Discussion

Figure 1 shows the best result observed in single crystalline silicon solar cell (a) and poly-crystalline silicon solar cell (b) for the heat treatment for 60 min at 190°C in $1.0x10^6$ Pa H_2O vapor environment. I_{sc}, V_{oc} and conversion efficiency were increased from 9.3 to 14.1 mA/cm^2, 0.56 to 0.57 V, and 14.3 to 20.0%, respectively for single crystalline silicon solar cell. They increased from 7.2 to 8.4 mA/cm^2, 0.53 to 0.55 V, and 9.2 to 10.0%, respectively, for polycrystalline silicon solar cell. These results strongly suggest that the high-pressure H_2O vapor treatment effectively passivates defects in the solar cells. The improvements in V_{oc}, I_{sc} and conversion efficiency were

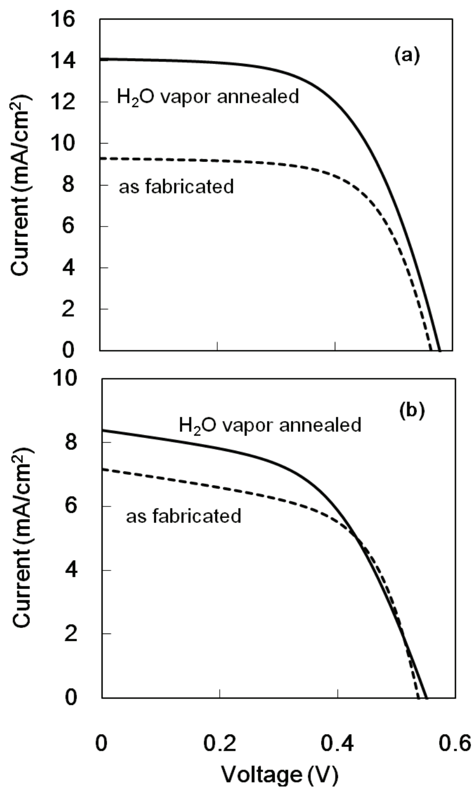

Fig. 1 Characteristics of (a) single crystalline and (b) poly-crystalline silicon solar cell for the heat treatment for 60 min at 190°C in $1.0x10^6$ Pa H_2O vapor environment.

probably caused by the decrease in the probability of photo induced carrier recombination, and then the increase in the minority carrier life time.

Figure 2 shows V_{oc} and conversion efficiency as a function of temperature for the H_2O vapor heat treatment for single crystalline silicon solar cells (a) and polycrystalline crystalline silicon solar cells (b). The average values of about 50 samples were plotted as initial values. V_{oc} and conversion efficiency increased and reached the maximums at 190°C for single crystalline silicon solar cells. The average conversion efficiency was improved from 15.2 to 16.7% by H_2O vapor heat treatment at 190°C. On the other hand, the average V_{oc} increased from 0.48 to 0.53 V by H_2O vapor heat treatment at 190°C for polycrystalline silicon solar cells. The average conversion efficiency slightly increased from 9.1 to 9.6% by the treatment at 150°C as shown in Fig. 2 (b).

Degradation of solar cell characteristics was observed for treatment temperature above 190°C, as shown in Fig.2. Figure 3 shows photo and dark current-voltage characteristics as fabricated and $1.0\text{x}10^6$ Pa H_2O vapor annealed for 60 min at 270°C for single crystalline silicon solar cell. The heat treatment decreased voltage output and fill factor of the solar cell. Those decreases result from increase in the series resistance of solar cells. $1.0\text{x}10^6$ Pa H_2O vapor treatment for 60 min at 270°C caused change in color of the silver electrode lines pasted on the ITO. The color became gray. Moreover, the resistance of the silver electrode lines markedly increased after the H_2O vapor heat treatment. These observations suggest that degradation of solar cell characteristics caused by high pressure H_2O vapor heat treatment at high temperature mainly resulted from oxidation of Ag electrodes.

4. Conclusion

High-pressure H_2O vapor heat treatment was applied to improving the crystalline silicon solar cell characteristics. This investigation revealed that application of $1\text{x}10^6$ Pa H_2O vapor heat treatment at 190°C achieved defect passivation and improved characteristics of silicon solar cells. On the other hand, $1\text{x}10^6$ Pa H_2O vapor heat treatment above 190°C caused oxidation of Ag electrodes. This suggests that high pressure H_2O vapor heat treatment should be carried out before Ag electrode pasting in order to look for much more improvement in solar cell characteristics.

Acknowledgments

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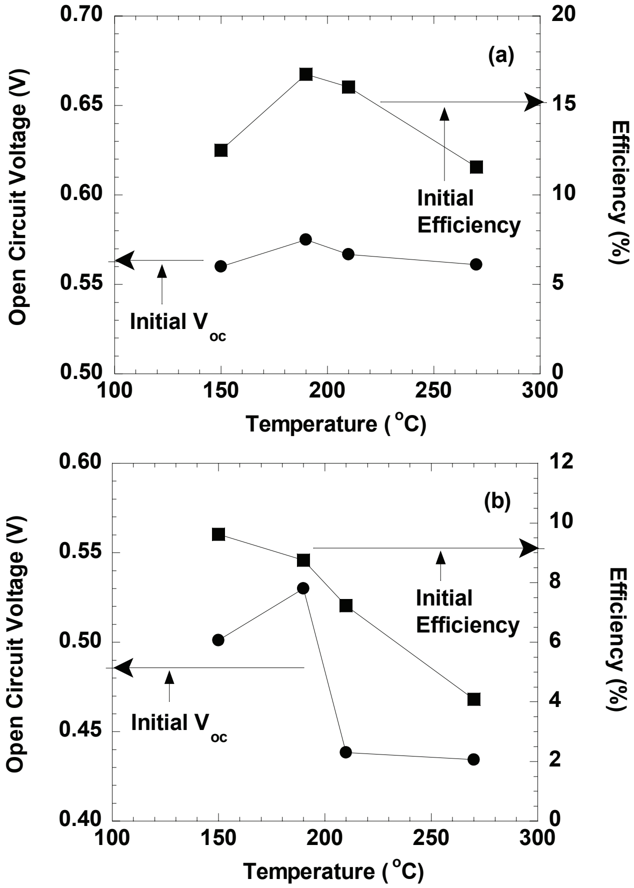

Fig. 2 The treatment temperature dependence of open circuit voltage (Solid Circle) and conversion efficiency (Solid Square) for (a) single crystalline and (b) polycrystalline silicon solar cells. The initial values before the treatment are also indicated.

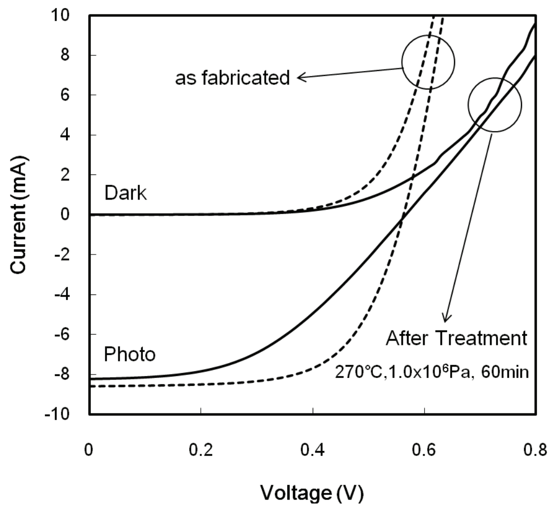

Fig. 3 Photo and dark current-voltage characteristics of single crystalline Silicon solar cell before and after $1.0\text{x}10^6$ Pa H_2O vapor treatment for 60 min at 270°C. Dashed line and solid line show as fabricated and H_2O vapor heat treatment, respectively.