Development of Optical Multilayer Thin Films and Their Application to Solar Cells

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Increasing use of clean photovoltaic energy generation is being looked as a key measure to prevent global warming, but with a conversion efficiency of about 15%, solar cells are not yet up to the task. Moreover, the conversion efficiency of solar cells decreases with temperature rise caused by solar infrared radiation, and necessary visible radiation is reduced by 8% with the solar cell's cover glass. In this study we developed and evaluated optical multilayer thin films to reduce the infrared-caused temperature rise and to improve the transmission of visible light to solar cells. The optical multilayer thin films were designed using Essential Macleod simulation software, prepared with radio frequency (RF) sputtering equipment, and their transmission characteristics were evaluated. The in-operation temperature change and the current-voltage (I-V) characteristic curves of solar cells were measured with and without the optical multilayer thin films, and the results show that they suppressed the temperature rise and improved efficiency of solar cells.
Keywords: Wavelength selective transmission thin film, Reflection reducing thin film, Solar cell, Conversion efficiency, Optical multilayer thin film,

1. INTRODUCTION

In recent years, with the development of optical fiber communication and thin film process technology, the application of multilayer films for optical filters has attracted considerable interest. And recent advances in film technology enabled us to realize high quality optical multilayer films. However, commonly the application fields of multilayer optical films are optical apparatus, optical fiber communication, image apparatus etc. [1,2]. There are hardly any reports on that the optical multilayer films are applied to solar cell to improve the conversion efficiency [3].

On the other hand, polycrystalline silicon solar cells are widely used in many houses and businesses because of their relatively high efficiency and abundant silicon reserves. However, one drawback of this solar cell is that its light-electricity conversion efficiency decreases when its temperature rises. It is thought that the near infrared in sun light is one of the causes of solar cell's temperature rise. Moreover, the available sunlight reaching the solar cell is reduced by 8% with interfacial reflections at the surfaces of cover glass on solar cell.

In this study, optical multilayer films were prepared for overcoming the drawbacks of polycrystalline silicon solar cell to improve the efficiency,. At first, considering the solar radiation and silicon PV cell spectral response (Fig. 1), the authors prepared a wavelength selective transmission thin film which has 0% transmittance in 1053nm-1365nm wavelength range to minimize infrared heating of polycrystalline silicon solar cell. But the transmittance of quartz glass with wavelength selective transmission thin film is only 88% in visible range. Next, according to this result, two reflection reducing thin films were prepared to increase the transmission of incident sunlight through the cover glass of solar cell to maximize the generation of electricity by a solar cell.

The experimental optical multilayer films were applied to solar cells, and the surface temperatures and conversion efficiencies were measured with and without the optical multilayer thin films respectively. As a result, the wavelength selective transmission thin film and the combinations of wavelength selective transmission film and reflection reducing film improved the conversion efficiency of solar cell.

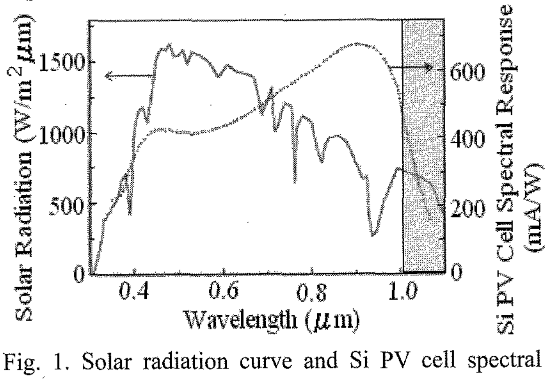


Fig. 1. Solar radiation curve and Si PV cell spectral response curve. [4]

2. DESIGN AND EXPERIMENTAL PREPARATION OF OPTICAL MULTILAYER THIN FILMS

2.1 Preparation equipment and characteristic measurement equipment of optical multilayer thin films

RF sputtering equipment (ULVAC, VTR-150M/SRF) was used to prepare these optical multilayer thin films by deposition on quartz glass. The transmittances of optical multilayer thin films on quartz glass were measured with a scanning spectrophotometer (Shimadzu, UV3150) in the wavelength range of 190–3200nm. The IV (Current-Voltage) curves of solar cells with and without optical multilayer thin films were measured using a solar simulator (Peccell Technologies, PEC-L11), and the thermo images of the cover glass surfaces on solar cells were observed by thermo tracer (NEC San-ei Instruments, TH9100ML, CAT I).

2.2 Preparation of optical multilayer thin films

In the chamber of RF equipment, two kinds of targets were set, and baseline flow rates of oxygen and argon gas set to optimal values for each material were introduced into the chamber. The deposition rates for Nb_2O_5 (4.9nm/minute) and SiO_2 (8.5nm/minute) were measured for the instrument prior to manufacture of the optical multilayer thin films, providing an estimated deposition time for each layer of films [5]. The optical multilayer thin films were deposited while controlling the materials and thickness according to the designs. During the deposition of all films, the mass flow rates of argon gas at both the SiO_2 and Nb_2O_5 cathodes were held constant at 15sccm (sccm: standard cubic centimeters per minute), and the flow rate of oxygen was maintained at 15sccm with 75W of RF power during deposition of SiO_2 layers, and at 25sccm with 100W of RF power during deposition of Nb_2O_5 layers.

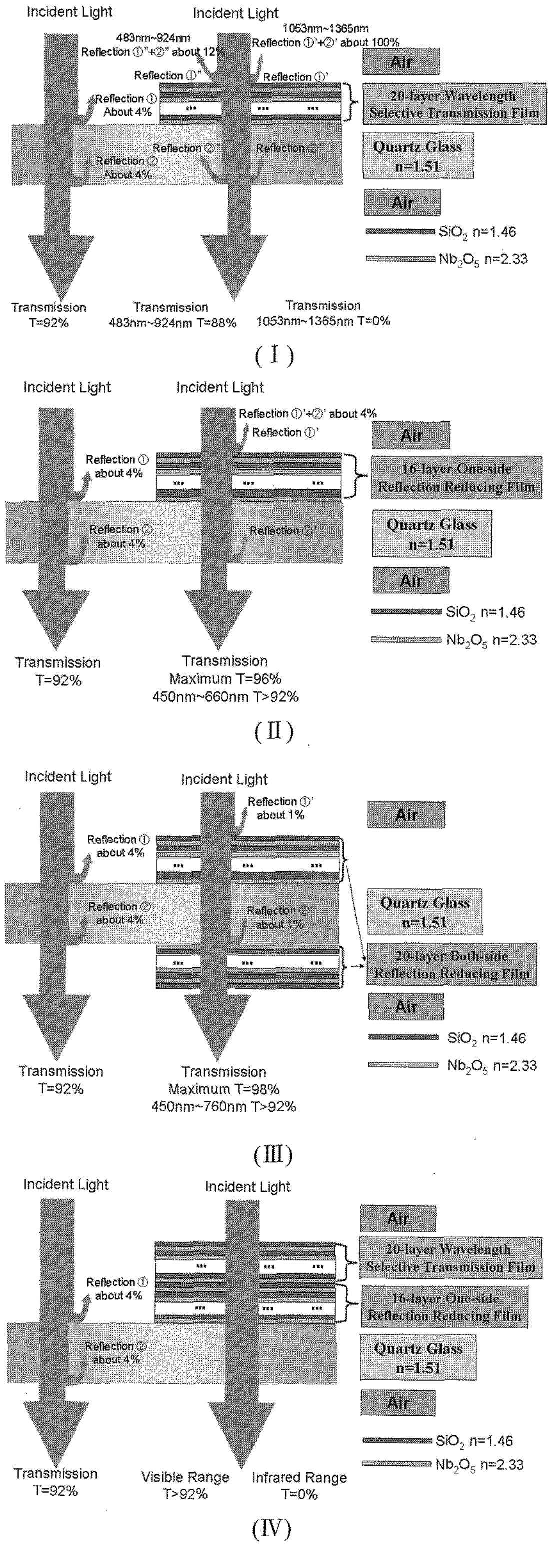
2.3 Designs and Transmission Characteristics of optical multilayer thin films

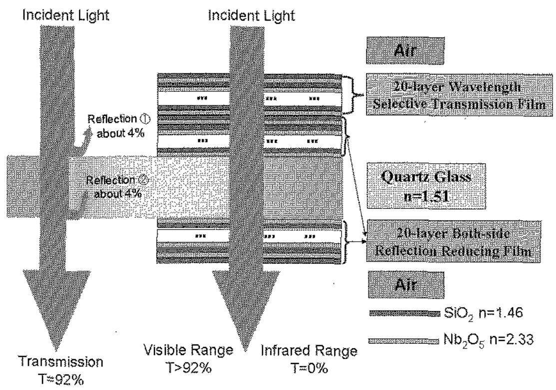
As shown in Fig. 2, five optical multilayer thin films were designed and prepared which consist of quarter-wave stacks. Optical multilayer thin films with appropriate reflection characteristic were designed using theoretical formula [6]:

$$\Delta g = \frac{2}{\pi}\sin^{-1}\left(\frac{n_H / n_L - 1}{n_H / n_L + 1}\right) \qquad (1)$$

Where Δg, n_H, n_L is relative reflection range width, refractive index of Nb_2O_5, refractive index of SiO_2.

The transmittance of 20-layer wavelength selective transmission thin film averaged 88% in 483nm-924nm, while the transmittance was zero between 1053nm and 1365nm [7]. To improve the transmittance in visible range, two reflection reducing thin films were designed and prepared too. One of 16-layer reflection reducing thin films deposited on one side of quartz glass with transmittance that approached 96%, from 450nm to 660nm transmittance is higher than that of quartz glass.





(V)

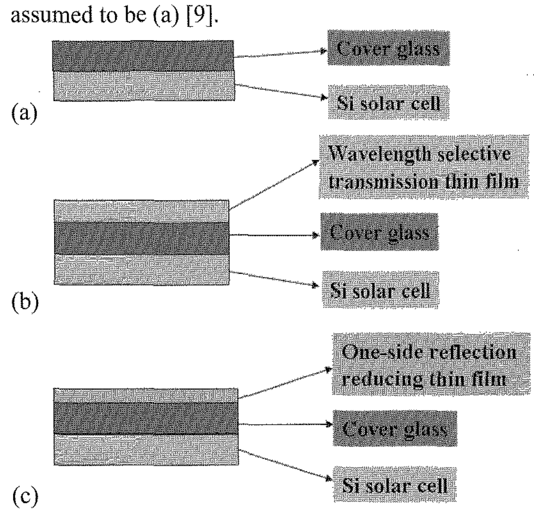
Fig. 2. The structures of optical multilayer thin films: (I) 20-layer wavelength selective transmission thin film; (II) 16-layer reflection reducing thin film on one side of quartz glass; (III) 20-layer reflection reducing thin film on both sides of quartz glass symmetrical; (IV) 20-layer wavelength selective transmission thin film and 16-layer reflection reducing film on one side of quartz glass; (V) 20-layer wavelength selective transmission film and 20-layer reflection reducing film on both sides of quartz glass.

The other are 20 layers, Nb_2O_5 and SiO_2 were alternately deposited on both sides of quartz glass symmetrically. Maximal transmittance approached 98%, in 450nm-760nm the transmittance is higher than that of quartz glass [8]. For getting characteristics both wavelength selective transmission thin film and reflection reducing thin film, it was combined (I) and (II) to (IV), (I) and (III) to (V).

3. RESULTS AND DISCUSSION

3.1 The structures of solar cell

The solar cells structured with five optical multilayer thin films respectively are shown in Fig. 3. To compare with customary solar cell, customary solar cell with cover glass (quartz glass as mentioned before) only is assumed to be (a) [9].



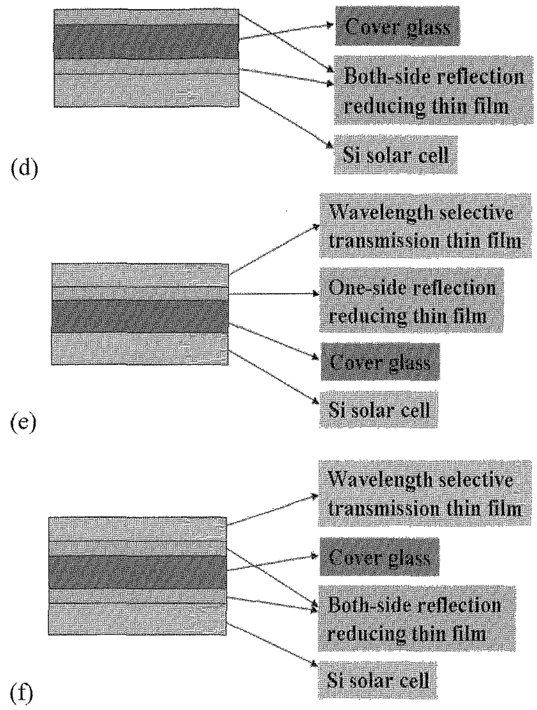


Fig. 3. The structures of solar cell with optical multilayer films: (a) Solar cell with cover glass only; (b) Solar cell with sample (I); (c) Solar Cell with Sample (II); (d) Solar cell with sample (III); (e) Solar cell with sample (IV); (f) Solar cell with sample (V).

3.2 Temperature change and conversion efficiency of solar cell

Surface temperatures and conversion efficiencies of solar cell structures (a)-(f) were measured using the solar simulator circuit (Fig. 4). Six structures of solar cell were heated by heating source from 0 minute to 20 minutes, and surface temperatures (as shown in Fig. 5) and conversion efficiencies (as shown in Fig. 6) were measured every two minutes. Six series of surface temperature changes of solar cells are shown in Fig. 7. It is obvious that the surface temperatures of solar cells with optical multilayer thin film were lower than those without the film, showing that IR cutting performance

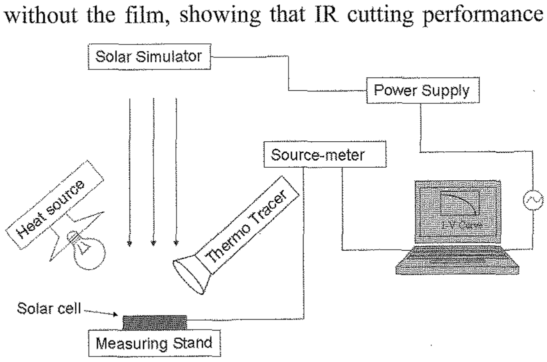


Fig. 4. The measurements of surface temperature and I-V curve of solar cell.

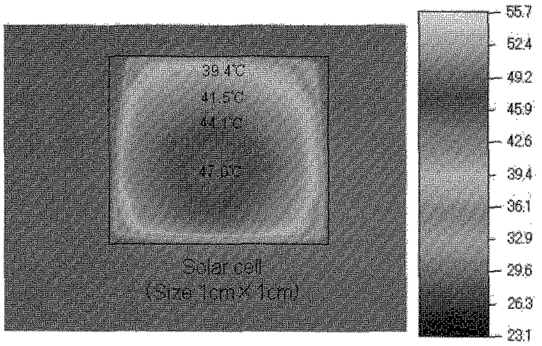


Fig. 5. Surface temperature of solar cell measured by thermo tracer.

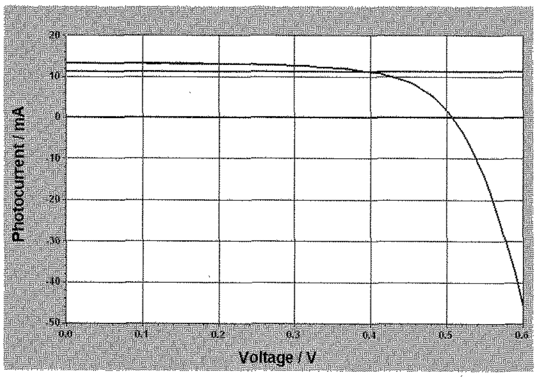


Fig. 6. The I-V curve of solar cell measured by solar simulator.

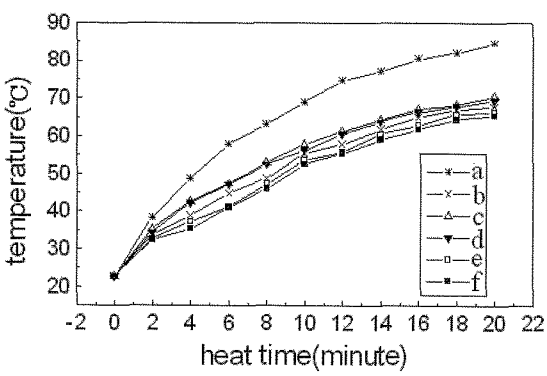


Fig. 7. Relation between heating time and surface temperature of solar cell.

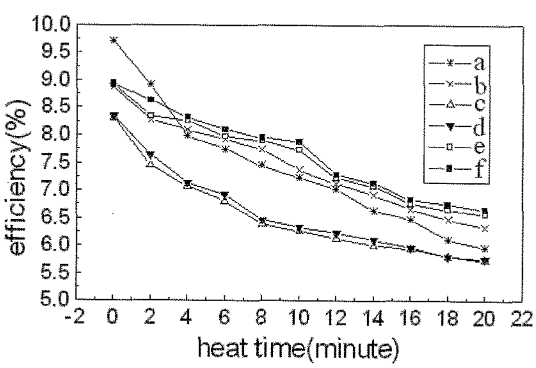


Fig. 8. Relation between the heating time and conversion efficiency of solar cell.

of optical multilayer films was effective. Six series of conversion efficiencies of solar cells with and without optical multilayer films are shown in Fig. 8. At higher temperatures after longer heating times, higher efficiencies were obtained of structures (b), (e), (f). Thus it can be thought the wavelength selective transmission thin film reduced the IR-induced temperature rise and the reflection reducing thin films allowed more transmission of the incident light in visible range, consequently, conversion efficiencies of solar cell were improved.

4. CONCLUSIONS

Optical multilayer thin films that shut off the transmission of infrared and increase the transmission of visible light were designed, prepared and applied to solar cells. The infrared shutoff wavelength selective transmission thin film suppressed the temperature rise in a normal operating cell, thus increasing its efficiency. The reflection reducing films increases the percentage of incident light reaching to the cell. The two films could be used together, combining to produce a significant increase in overall solar cell efficiency. Application of such optical multilayer films appears to present practical advantages.

5. REFERENCES

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