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Preparation of SiO_2/Nb_2O_5 Wavelength Selective Transmission Thin Film for Solar Battery

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Optical films are currently used for a range of optical components. The aim of this research was to prepare wavelength selective transmission thin films which can improve the performance of solar cells. Radio frequency (RF) sputtering equipment was used for depositing the wavelength selective transmission thin film. The deposition of layers of various materials and of different thicknesses was carried out after software simulation of the wavelength selective transmission thin film. The experimental wavelength selective transmission thin film was deposited on quartz glass, and the optical characteristics of the thin film were measured with a spectrophotometer. The transmission results showed that the designed wavelength selective transmission thin film could be fabricated. The transmission range can be controlled by depositing layers of different materials and thicknesses.

Key Words : RF sputtering, Wavelength selective transmission thin film, Simulation, Transmittance

1. INTRODUCTION

Currently, polycrystalline silicon solar cells are widely used in most houses and businesses because of abundant silicon reserves and high efficiency[1,2]. However, the drawback of these solar cells is that their conversion efficiency decreases as their temperature rises[3,4]. We think the infrared solar spectrum is one possible reason for this. The aim of this research was to use the films of TiO_2, Nb_2O_5 and SiO_2 to prepare wavelength selective transmission thin films. These thin films were designed to have a transmittance approaching zero in the near infrared solar spectrum and approaching 100% in the visible solar spectrum. The intention was to improve the conversion efficiency of solar cells by effectively absorbing solar radiation but preventing most temperature increase[5-8]. In the future, wavelength selective transmission thin films will be applied to solar cells as shown in Figure 1.

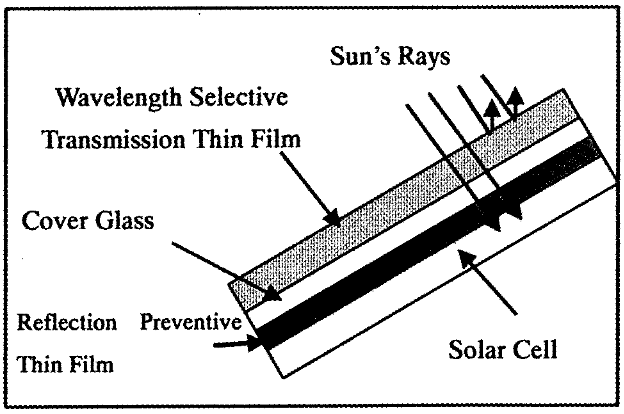


Figure 1 Wavelength selective transmission thin film applied to a solar cell

The experimental sample was prepared by RF sputtering on a quartz glass substrate. The transmission properties of the sample were measured, and the results showed that we succeeded in preparing the designed wavelength selective transmission thin film. The wavelength selective transmission thin film we successfully prepared as an optical film that reflected only in the near infrared spectrum at about 1000-1350 nm. The reflection range was controlled by alternately depositing three different layers (TiO_2, Nb_2O_5 and SiO_2 films) and changing their thicknesses if necessary.

2. DESIGN AND EXPERIMENTAL PREPARATION OF WAVELENGTH SELECTIVE TRANSMISSION THIN FILMS

2.1 Simulation design of wavelength selective transmission thin films

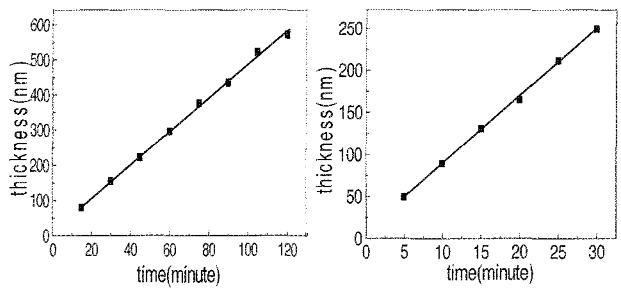
We designed the wavelength selective transmission thin film using simulation software (Essential Macleod). In the design of the thin film, the number of layers and the thickness of each layer can be changed to satisfy the condition that the multilayer can effectively absorb solar radiation in visible region and cut off a part of infrared spectrum to prevent the increasing of temperature. After comprehensively considering a number of possible designs, we chose the best multilayer combination. In the design we chose, the SiO_2 and Nb_2O_5 layers were deposited alternately at the thicknesses shown in Table 1. According to

Table 1 Multilayer simulation design of a SiO_2/Nb_2O_5 wavelength selective transmission thin film

Layer Number	Material	Thickness (nm)
1	SiO_2	159.96
2	Nb_2O_5	12.52
3	SiO_2	176.60
4	Nb_2O_5	6.93
5	SiO_2	57.09
6	Nb_2O_5	140.23
7	SiO_2	213.82
8	Nb_2O_5	137.40
...	...	...

the design an experimental 20-layer SiO_2/Nb_2O_5 multilayer was prepared.

The series of Nb_2O_5 and SiO_2 films were prepared and their thicknesses were measured by auto-Ellipsometer (ESM-1T/1AT). The change in thickness of these two materials with deposition time is shown in Figure 2. From the figure, the deposition rates of these two materials have been known. The deposition rates of Nb_2O_5 and SiO_2 were 4.9 nm/min and 8.5 nm/min respectively. And these results make it possible to precisely control the thickness of each layer of wavelength selective transmission thin film[3].



(a) Nb_2O_5 4.9 nm/min (b) SiO_2 8.5 nm/min

Figure 2 Deposition rates of (a) Nb_2O_5 and (b) SiO_2

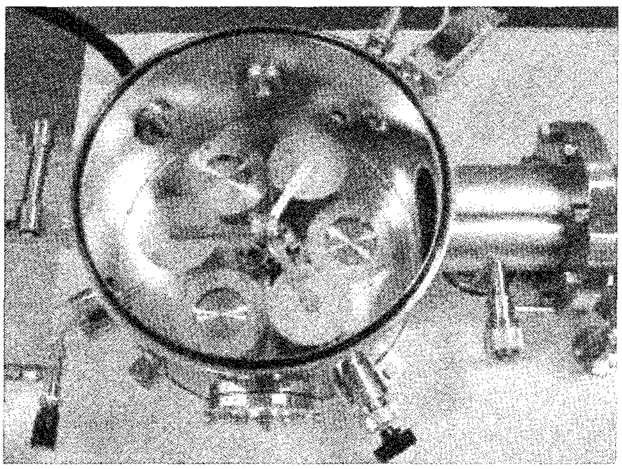


Figure 3 Chamber interior of the RF sputtering equipment

2.2 Equipment and experimental

RF sputtering equipment was used to make the wavelength selective transmission thin film. Figure 3 shows the chamber interior of the RF sputtering equipment. There were three targets (Ti, Nb and Si) in the chamber, and during the experiment, the target could be changed freely under vacuum.

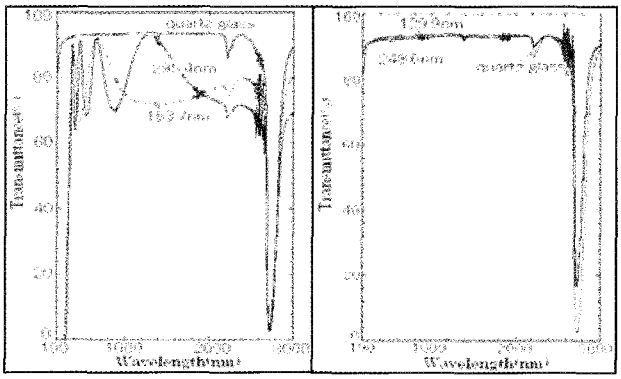
The wavelength selective transmission thin film was prepared on a quartz glass substrate. Three kinds of targets were used, and a set amount of oxygen and argon gas was introduced into the chamber. Then a high frequency voltage causing an electrical discharge was applied between the substrate and targets. A thin film of set thickness was deposited on the substrate by the electrical discharge. It was deposited while changing the materials and thickness according to the simulation design of the wavelength selective transmission thin film.

2.3 Measurements

The optical characteristics of the wavelength selective transmission thin film and the single-layer samples were measured with a spectrophotometer (UV3150). The results showed that the designed wavelength selective transmission thin film could be fabricated. The surface properties of the experimental thin film were observed with an atomic force microscope (AFM). And the thicknesses of single-layer samples were measured by auto-Ellipsometer (ESM-1T/1AT).

3. RESULTS AND DISCUSSIONS

Figure 4(a) told us that the transmittances of single-layer Nb_2O_5 films are lower overall than quartz glass, and the trend of transmission change differs by film thickness. 153.7 nm Nb_2O_5 thin film is about 20% lower than quartz glass around 1000 nm-1800 nm. 295.4 nm Nb_2O_5 film is irregular, so we think that it is too thick to fit for a wavelength selective transmission thin film. Figure 4(b) displays the transmittances of SiO_2 films. The transmittance of quartz glass, 129.9 nm SiO_2 and 248.6 nm SiO_2 are almost identical to each other, so this result tells us that SiO_2



(a) (b)

Figure 4 Transmittance of monolayer Nb_2O_5(a) and SiO_2(b) films have transmittances as good as quartz glass from 190 nm-2700 nm.

Figure 5 shows the transmittance of the simulation design. It was designed to achieve a transmittance average of 95% in the 400-1000 nm wavelength range and so it can efficiently absorb solar radiation in the visible range, which is just about the sun's strongest radiation range. Furthermore, we successfully designed the transmittance to approach zero in the 1000-1400 nm wavelength range, which is the sensitive spectrum for solar cells. If solar cells absorb solar radiation in this range, the cell's temperature increases and efficiency decreases. The simulation design succeeded in absorbing solar radiation in the visible range as well as reflecting the solar radiation in the near infrared solar spectrum. These design considerations will increase conversion efficiency by maximizing the absorption of solar radiation and preventing the increase of temperature.

Figure 6 shows the transmittance of the experimental sample. The experimental results are very similar to those of the simulation design. The transmittance of the experimental sample averaged 84%, just 8% lower than quartz glass from 400 nm to 1000 nm, while the transmittance approached zero between 1000 nm and 1350 nm. These results show that we successfully made the designed wavelength selective transmission thin film. As expected, this sample should effectively absorb solar radiation in the visible range and reflect the main wavelengths that cause the temperature to increase.

Figure 7 shows the AFM photographs of the experimental samples. The surface experimental wavelength selective transmission thin film is smooth compared with the surface of quartz glass and it has no obvious defects, indicating a high surface crystallinity. The surface shapes of single-layer Nb_2O_5 thin films are similar, although their thicknesses are different, which means that the thickness has little influence on the surface of Nb_2O_5 thin films. The surface shape of single-layer 248.6 nm SiO_2 is more uneven than 129.9 nm SiO_2 thin films.

4. CONCLUSIONS

A SiO_2/Nb_2O_5 wavelength selective transmission thin film was successfully designed and experimentally prepared. The transmission results showed that the experimental sample's transmittance approached zero in the near infrared spectrum and approached 84% in the visible spectrum. This means that it can efficiently absorb the main solar radiation as well as reflect the main spectral range that causes the temperature increase in solar cells. So it is likely that the wavelength selective transmission thin film will be applied to solar cells and will improve their

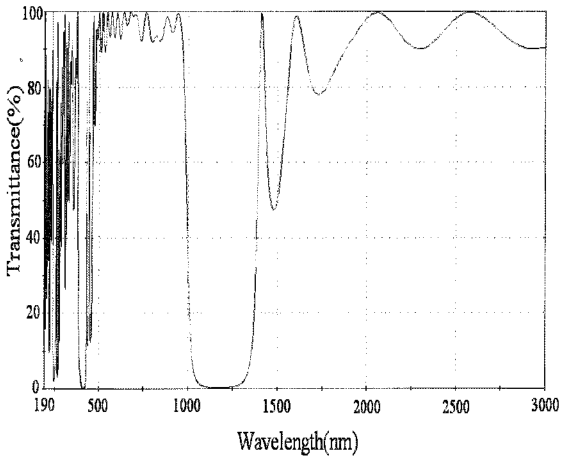


Figure 5 Transmittance of the simulation design of wavelength selective transmission thin film

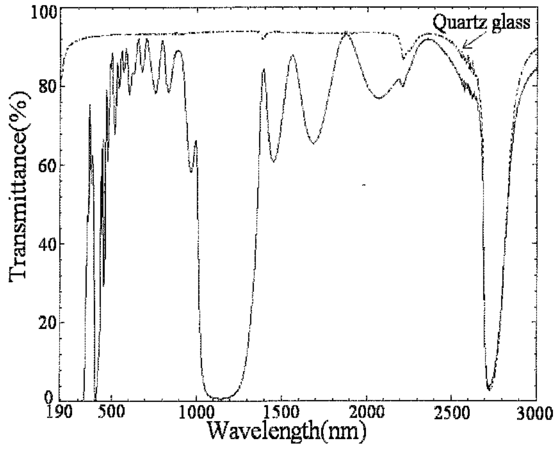


Figure 6 Transmittance of the experimental sample

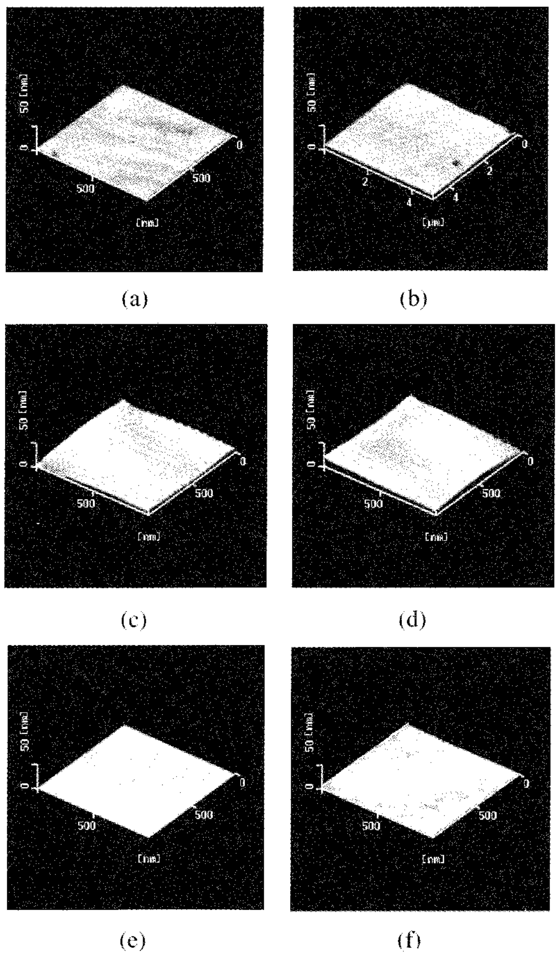


Figure 7 AFM photographs of quartz glass (a), experimental wavelength selective transmission thin film (b), 153.7 nm Nb_2O_5 (c), 295.4 nm Nb_2O_5 (d), 129.9 nm SiO_2 (e), and 248.6 nm SiO_2 (f)

performance.

In the future, we schedule to examine and compare the efficiency increase according to the prevention of the temperature increase in solar cells by wavelength selective transmission, and the efficiency change according to the transmission decrease in the visual region.

References

[1] Mai, Y., Klein, S. and Carius, R., "Open Circuit Voltage Improvement of High-Deposition-Rate Microcrystalline Silicon Solar Cells by Hot Wire Interface Layers," Appl. Phys. Lett., Vol.87, pp.073503-1～073503-3 (2005).

[2] Mai, Y., Klein, S. and Carius, R., "Microcrystalline Silicon Solar Cells Deposited at High Rates," J. Appl. Phys., Vol.97, pp.114913-1～114913-12 (2005).

[3] Jin, L. and Shigetaka, F., "Preparation and Characteristics of Several Transmission Thin Films," Proc. ICMR 2005 Akita, pp.391-394, (2005).

[4] Shigetaka, F., "Research on Preparation of Nano Films and Application to Electronic Devices," Vacuum Journal of Japan Vacuum Industry Association, No.99, pp.20-21, (2005).

[5] Jeffrey, B. T., "Center Wavelength Shift Dependence on Substrate Coefficient of Thermal Expansion for Optical Thin-Film Interference Filters Deposited by Ion-Beam Sputtering," Appl. Opt., Vol.43, pp.4506～4511 (2004).

[6] Shiuh, C., Wen., Hsiang, W. and Hsu., Min., Y., "Characteristics of Ion-Beam-Sputtered High Refractive Index TiO_2/SiO_2 Mixed Films," J. Opt. Soc. Am. A, Opt. Image Sci., Vol.16, pp.1477～1483 (1999).

[7] Honda, T., Sakaguchi, T. and Koyama, F., "Optically Pumped ZnSe-Based Vertical Cavity Surface Emitter with SiO_2/TiO_2 Multilayer Reflector," J. Appl. Phys., Vol.78, pp.4784～4786 (1995).

[8] Wold, E., Bremer, J. and Hunderi, O., "Enhancement and Quenching of Berreman Polaritons in SiO_2/TiO_2 and Al_2O_3/Pt Superlattices," J. Appl. Phys., Vol.75, pp.1739～1747 (1994).