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Design and Preparation of Reflection-Reducing Thin Films and Their Optical Characteristics

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In recent years, with the development of optical communication and thin film process technology, the application of optical multilayer films has attracted considerable interest. In this research, the aim is to prepare reflection-reducing thin films which can be applied to solar cells and raise their performance. The optical films were designed using Essential Macleod simulation software, and then were fabricated by radio frequency (RF) sputtering equipment. Two kinds of targets were set, and prescribed flow rates of oxygen and argon gas were introduced into the chamber. The multilayer films were deposited on two sides and on one side of quartz glass substrates while controlling the materials and thickness under the simulation designs. The optical characteristics of the designed and experimented multilayer films were measured by a spectrophotometer. From the results of transmittance, it was found that the aimed multilayer films which have a high transmittance in the visible spectrum were able to be prepared successfully. If necessary the reflection-reducing wavelength range can be controlled by changing the accumulated sequence, materials, number of layers and thickness of each layer.

Key words: Reflection-reducing thin film, Transmittance, RF sputtering, simulation

1. INTRODUCTION

Currently, polycrystalline silicon solar cells are widely used in most houses and businesses because of their high efficiency and abundant silicon reserves. However, one of the drawbacks of these solar cells is the glass substrate, which only has 92% average transmittance in the visible spectrum, and which will prevent the solar cells from absorbing solar radiation efficiently. From Fig. 1, it can be known that the main solar radiation is in the visible wavelength spectrum. So we think that preparing a reflection-reducing thin film which has high transmittance in the visible wavelength spectrum is an effective way to overcome this drawback of solar cells. And recent advances in film process technology are making it possible to achieve high-transmittance optical multilayer coatings [1]. However, the preparation of rugate reflection-reducing film is still difficult due to its continuous change of refractive index following a sine wave cycle with thickness [2-3].

In this paper, we have designed and prepared two kinds of reflection-reducing thin films which have high transmittances in the visible spectrum. As expected, when these films are applied to solar cells they can overcome the drawbacks caused by quartz glass substrates, so that the performance of solar cells will be promoted by these fabricated reflection-reducing thin films.

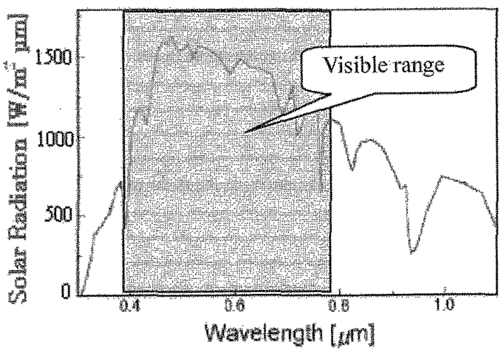


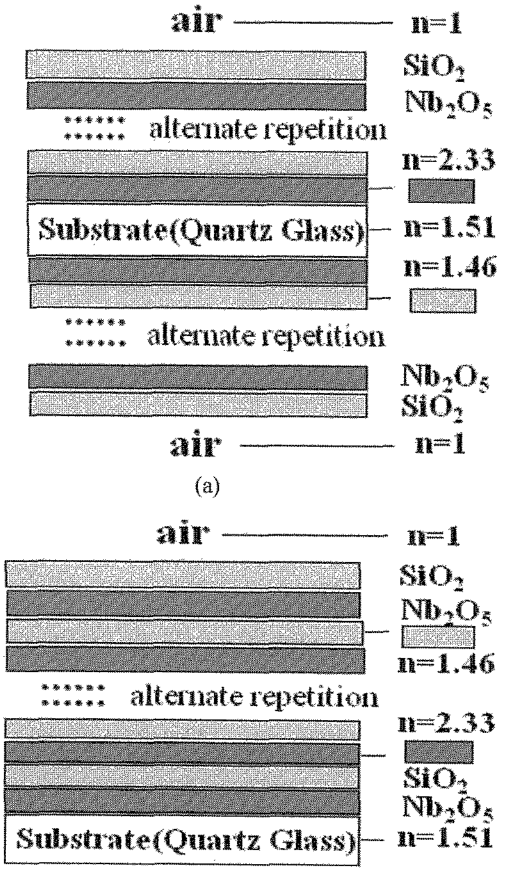
Fig. 1 Solar radiation change with wavelength

2. SIMULATION AND EXPERIMENTS

2.1 The simulation design of reflection-reducing thin films

At first we designed the reflection-reducing thin films using Essential Macleod simulation software. The reflection-reducing thin films were fabricated as shown in

Fig. 2. One design is SiO_2 and Nb_2O_5 layers deposited alternately on two sides of quartz glass substrate symmetrically as shown in Fig. 2 (a). The reflection-reducing thin film A has the following configuration: air-LH···LH-quartz glass substrate-HL···HL-air, where L and H are SiO_2 (with a low refractive index) and Nb_2O_5 (with a high refractive index) layers.



(a)

(b)

Fig. 2 The fabrication of SiO_2-Nb_2O_5 reflection-reducing thin films on two sides (a) (sample A) and one side (b) (sample B) of quartz glass substrates

The other design is SiO_2 and Nb_2O_5 layers deposited alternately on one side of quartz glass substrate as shown in Fig. 2 (b). The configuration of reflection-reducing thin film B can be written as follows: air-LHLH···LHLH-quartz glass substrate.

2.2 Preparation of the reflection-reducing thin films

The series of Nb_2O_5 and SiO_2 single layer film were prepared, and their thicknesses were measured preliminarily by auto-Ellipsometer (ESM-1T/1AT). The thickness change with deposition time of these two materials is shown in Fig. 3. From the figure, it can be known that the deposition rates of Nb_2O_5 and SiO_2 are 4.9 nm/min (100 W) and 8.5 nm/min (75 W), respectively. These results make it possible to precisely control the thickness of each layer of reflection-reducing multilayer films when they were deposited by RF sputtering equipment [4-6].

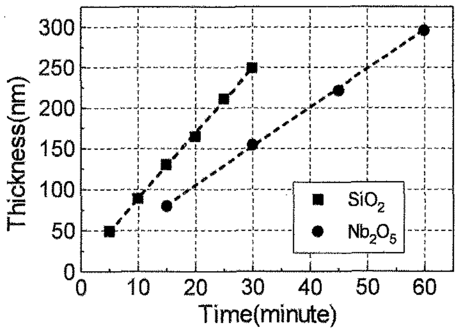


Fig. 3 The thickness of the SiO_2 and Nb_2O_5 monolayer changed with sputtering time

RF sputtering equipment (ULVAC, VTR-150M/SRF) was used for preparing the reflection-reducing thin films. The multilayer thin films were deposited on two sides and one side of quartz glass substrates. Two kinds of targets were set, and prescribed flow rates of oxygen and argon gas were introduced in the chamber of RF sputtering. The multilayer films were deposited on quartz glass substrates while controlling the materials and thickness based on the simulation designs. During the deposition of all films, the flow rate of argon gas in both the SiO_2 and Nb_2O_5 cathodes were held constant at 15 sccm (sccm denotes standard cubic centimeter per minute), and the flow rate of oxygen was maintained at 15 sccm with an rf power of 75 W during deposition of SiO_2, and at 25 sccm with an rf power of 100 W during deposition of Nb_2O_5.

2.3 Characteristics measurement of reflection-reducing thin films

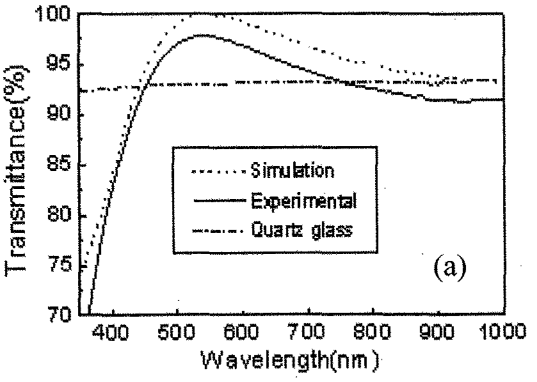
Transmittance measurements of the films were carried out using a scanning spectrophotometer (Shimadzu, UV3150) in the wavelength range of 190-3200 nm. The surface properties of quartz glass substrate and experimental samples of reflection-reducing thin films were observed with an atomic force microscope (AFM, Epolead Service, SPI 3800N). The thicknesses of monolayer deposited preliminarily were measured by an auto-Ellipsometer (ULVAC, ESM-1T/1AT).

3. RESULTS AND DISCUSSIONS

3.1 Discussion about the transmission of the films

Fig. 4 shows the transmittances of simulation designs, experimental samples and quartz glass. From Fig. 4 (a), we can know that the transmittance of simulation design of reflection-reducing thin film on two sides of quartz glass substrate reaches 100% from 500 nm to 600 nm, and from 440 nm to 950 nm, the transmittance is higher than that of quartz glass. The transmittance of experimental reflection-reducing thin film reaches 98% from 500 nm to 593 nm, and from 450 nm to 760 nm, the transmittance is higher than that of quartz glass. The results mean that the experimental sample in this range can promote solar cells to absorb the solar radiation effectively.

From Fig. 4 (b), the simulation design of reflection-reducing thin film on one side of quartz glass substrate in a wide wavelength range, from 380 nm to 680 nm has a 100% transmittance, and in 370 nm - 690 nm, it is higher than that of quartz glass. The transmittance of experimental sample approaches 96% from 460 nm to 650 nm and maintains a relative stabilization. From 450 nm to 660 nm, transmittance is higher than that of quartz glass. However, compared with the simulation design, transmittance of the experimental one has an evident shift. We think it is maybe because a variety of parameters such as interface between layers, thickness, flow rates of oxygen and argon, and so on have interacted with each other, and because the temperature of the substrates increased unexpectedly during the experiment [7-8].



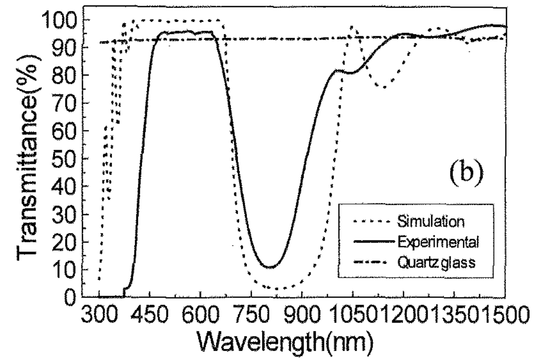
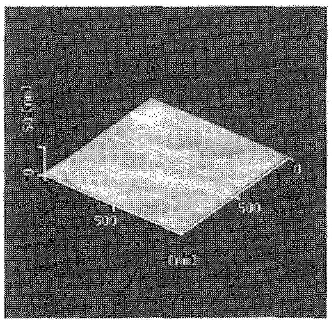


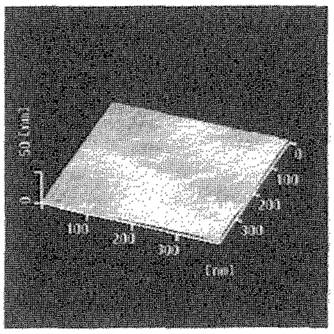
Fig. 4 The transmittances of designed samples, experimental samples and quartz glass; (a) The reflection-reducing thin film A deposited on two sides of quartz glass substrate; (b) The reflection-reducing thin film B deposited on one side of quartz glass substrate

3.2 Discussion of the AFM images of surfaces for the films

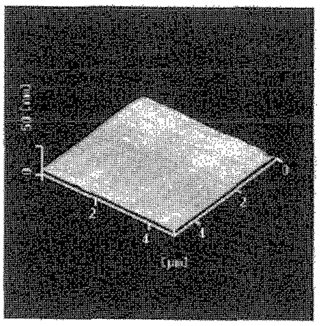
AFM images of the surface for quartz glass and experimental reflection-reducing thin films are shown in Fig. 5. Compared with the surface condition of quartz glass, we can know that the surfaces of experimental reflection-reducing thin films are smooth too. This means that these thin films maybe will not cause unexpected dispersion and scattering when they are applied to solar cells.



(a)



(b)



(c)

Fig. 5 AFM images of the surface for quartz glass (a), experimental reflection-reducing thin film A (b) and experimental reflection-reducing thin film B (c).

4. CONCLUSIONS

Two kinds of reflection-reducing thin films have been successfully designed and experimentally prepared. The conclusions obtained in this study are summarized as follows:

(1) The reflection-reducing thin films were designed using simulation design software and prepared by RF sputtering on two sides or one side of quartz glass substrates successfully.

(2) The transmittance of simulation designed reflection-reducing thin film A reaches 100% from 500 nm to 600 nm, and in the range of 440 nm - 950 nm is higher than that of quartz glass. The transmittance of experimental sample A reaches 98% from 500 nm to 593 nm, and is higher than that of quartz glass in the range of 450 nm - 760 nm.

(3) The transmittance of simulation designed reflection-reducing thin film B reaches 100% from 380 nm to 680 nm and in this wide range remains a relative stabilization. From 370 nm to 690 nm, the transmittance is higher than that of quartz glass. Transmittance of experimental sample B approaches 96% from 460 nm to 650 nm, and is higher than that of quartz glass from 450 nm to 660 nm.

(4) There are advantages and disadvantages of both designs and samples. Transmittance of the one on two sides of quartz glass is higher, but the reflection-reducing range is narrower. Transmittance of the one on one side of the substrate is lower, but the reflection-reducing spectrum range is wider.

These conclusions mean that the reflection-reducing thin films can be applied to solar cells and improve the solar cells to absorb the solar radiation efficiently and improve the performance. In the sequential research, two kinds of reflection-reducing thin films prepared will be applied to solar cells respectively.

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