Measurement and Analysis of Optical Properties of Polymer Films with Triangular Pyramid Optical Functional Texture

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Abstract. A poly (vinyl chloride) film with triangular pyramid array structure was designed and fabricated. In this paper, a plane to plane hot embossing technique is used to fabricate a triangular pyramid antireflection film on the surface of single crystal silicon solar cells. By testing the optical properties of optical functional textured films, it is found that the reflectivity of triangular pyramid textured films obtained by hot embossing is significantly lower than that of smooth flat films; The absorption and antirefection of high light on the film surface are obvious; The photoelectric conversion efficiency of the solar cell is further improved. Triangular pyramid optical functional structure has great potential in improving the performance of silicon solar cells, which can be applied to different types of solar cells. These improvements are of great significance to the commercialization of silicon solar cell devices.

Keywords: Hot embossing; Polymer film; Composite structure cell; Optical property

1. Introduction

At present, crystalline silicon solar cells account for about 90% of the solar energy market. Light escape loss and electrical loss are two major factors that affect the photovoltaic conversion efficiency of crystalline silicon solar cells [1-3]. Among them, reducing the escape of incident light on the surface is an important factor to improve the battery efficiency.

By using surface texturing technology, the surface of solar cell is made into suede structure to reduce the reflection and escape of surface light, which can greatly reduce the reflection loss of incident light on the surface of solar cell and increase the short-circuit current of solar cell [4-7]. It can also increase the optical path of light in the solar cell body and increase the number of reflections, so as to reduce the escape of incident light [8-11].

The research group proposed a micron scale triangular pyramid optical functional texture, which has the advantages of large specific surface area and is an ideal structure for solar cell textured film and reflective film. The original triangular pyramid texture mold is obtained by machining, and the concave triangular pyramid texture template is obtained by reverse casting the triangular pyramid texture array on the copper core. The large area concave triangular pyramid working template can be obtained by splicing process. On the other hand, hot embossing is a low-cost, simple equipment, which can be used to produce triangular pyramid optical functional texture film.

In order to reduce the light loss caused by the surface reflection of monocrystalline silicon solar cells, a triangular pyramid light functional texture film with antireflection was compounded on the surface of monocrystalline silicon solar cells. As shown in figure 1, the light trapping film monocrystalline silicon solar composite structure cell can effectively capture the light shining on the solar cell. This kind of film is defined as the light trapping texture film, so as to reduce the light reflection and light loss on the surface of the cell, and at the same time, it will not have a negative impact on the photogenerated carrier...
life of the cell. Therefore, the preparation of light trapping textured film and its characteristics are of great significance to improve the photoelectric conversion efficiency of solar cells.

**Figure 1.** Light trapping film monocrystalline silicon solar composite structure cell.

2. Preparation of Composite Structure Cell with Optical Functional Texture

2.1. Hot Embossing Test

Firstly, the triangular pyramid texture was machined on the surface of copper by planning, and the design size of triangular pyramid array of original brass core was 20 mm×20mm. The length of the bottom edge of each triangular pyramid texture is 175μm, height 70μm. The angle between two adjacent triangles is 70°, the original master mode of triangular pyramid array is obtained. The impression die for the hot embossing process is obtained by electroforming. The Ni template is made by Zhejiang elite laser Polytron Technologies Inc. The triangular pyramid array texture with inner concave was obtained and cut into a circle with a diameter of 40mm. The strength of the stainless-steel sheet was enhanced by adhesion with the same size of the original sheet, and the stamping die was prepared.

The base material is PVC film, which Tg value is 87 ℃ and thickness is 0.23mm. The process of hot embossing is to transfer the inherent microstructure of the mold to the polymer substrate. Effective micro junction transfer manufacturing needs to be able to accurately and high-resolution copy the mold pattern in the polymer substrate.

A plane to plane hot pressing test device was obtained by refitting a tensile testing machine. A 3mm thick stainless-steel plate and silicone rubber composite gasket is placed between the PVC base material and the top lower pressing plate to compensate the unevenness between the two plates, reduce the loss of the pressing plate during the imprinting process, and avoid the adhesion caused by the direct contact between the PVC base material and the upper pressing plate. In addition, in order to monitor the real-time temperature change near the nickel mold core, a thermocouple temperature sensor with measurement accuracy of 0.1 ℃ is installed on the bottom support plate to achieve dynamic data feedback [12].

2.2. Preparation of Composite Structure Cell with Optical Functional Texture

The single crystal silicon wafer battery provided by Anyang sunshine science and education Energy Co., Ltd. is selected, and the size of the battery is 20mm×20mm (figure 2 (a)). In the ultrasonic bath, ethanol was used to clean the photo textured polymer film and monocrystalline silicon cell. Limited by the experimental conditions, the UV curing agent with similar optical properties to PVC film was used as the bonding medium. Firstly, the UV curing agent droplets were coated on the surface of crystalline silicon cell, and then the photo textured polymer film was pasted on the surface of crystalline silicon cell and cured under UV lamp. As the bubbles between the interfaces will cause light refraction and scattering, which weakens the antireflection ability of the light functional texture film, attention should be paid to the cleaning of the sticking surface during the film sticking process. In order to ensure the adhesion effect, high-intensity ultraviolet lamps are used to irradiate until it is completely cured. The sample of the light functional texture composite structure battery is shown in figure 2 (b).
3. Performance Test and Analysis

3.1. Analysis of Optical Properties of Optical Functional Textured Films

As shown in figure 3, the reflectance spectrum of the optical functional polymer films with triangular pyramid texture was measured by the ultraviolet / visible / near infrared spectrophotometer (lambda 750S, Perkin Elmer, Inc., USA). The antireflective properties of the films were measured to characterize the optical properties of the films.

![UV/Vis/NIR spectrophotometer](image)

**Figure 3.** UV / Vis / NIR spectrophotometer.

The black cardboard is used as the background layout of the film in the test process. The test results are shown in figure 4: the change of the reflectivity spectrum of the polymer film in the 300nm-800nm band is consistent. The reflectivity maintains at a low level in the 300nm-350nm band. The reflectivity of the thin film climbs from 3% to 8% in the 350nm-400nm band, and then maintains at a stable level. However, the reflectivity of the polymer film fabricated at 140 °C - 240s-1KN is significantly higher than that of the other eight groups. It can be seen from the figure that the antireflection performance of the polymer film obtained with the process parameters of 180 °C - 240s-2KN, 160 °C - 300s-1KN and 160 °C - 300S-2KN is better, which is consistent with the integrity trend of the triangular pyramid texture.
According to the above test results, the polymer film obtained by using the process parameters of embossing temperature 170 ℃, holding time 300s and embossing pressure 2Kn is compared with the PVC flat film, as shown in figure 5, which depicts the reflectance spectrum of smooth flat film and hot embossed triangular pyramid textured film. In the wavelength range of 300nm-800nm, the reflectivity of triangular pyramid textured film obtained by hot embossing is obviously lower than that of smooth flat film.

Ideally, the triangular pyramid optical functional texture can not only reduce the reflection loss of light on the material surface, but also improve the light transmission. As shown in figure 5, in the wavelength range of 300-800nm, the reflectivity of the film can be reduced from about 11% to 7% by processing the triangular pyramid texture on the surface of the plane film. As shown in figure 6, there is a difference in the reflected light path between the incident light in the plane film and the light functional texture film, because the triangular pyramid texture changes the incident light path, produces multiple refraction, improves the light absorption on the film surface, and has obvious antireflection effect. This antireflection effect can be attributed to the influence of the triangular pyramid texture.

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**Figure 4.** Reflectivity test spectrum of polymer film in orthogonal test group.

**Figure 5.** Reflectance spectrum of planar film and textured film.

**Figure 6.** Light path diagram of planar film and textured film.
According to the light trapping principle of the composite structure battery, when the incident light irradiates the surface of the composite structure battery, the light will be reflected and refracted many times on the surface of the light trapping film, and a large part of the light will pass through the light trapping film and reach the inside of the crystal silicon battery. There are two reasons for the decrease of the reflection coefficient and the increase of the transmission coefficient of the optical functional polymer film: on the one hand, as shown in figure 7, the triangular pyramid notch texture can reflect the incident light for many times and increase the optical path length, thus improving the absorption probability of light. For the incident light of different angles, after the first pass, a part of the light is transmitted from the air to the polymer film, and the other part is reflected to the adjacent triangular pyramid texture to realize multiple reflections and reduce the light reflection on the surface of the film. Therefore, the triangular pyramid textured surface can achieve quasi omnidirectivity (that is, the angle dependence of reflection and transmission characteristics is small). On the other hand, the triangular pyramid array texture forms a thin film layer with refractive index gradient on the surface of the macro angle composite cell, which has effective anti reflection performance [5].

![Figure 7. Light trapping principle of crystalline silicon light trapping film composite battery.](image)

The composite structure solar cell can capture the incident light which may be reflected and scattered back to the air, so as to reduce the escape of the incident light and further improve the photovoltaic conversion efficiency of the solar cell. In order to further verify the antireflection effect of optical functional textured film in practical composite application, the best optical functional textured film sample was selected by compounding optical functional textured film on the surface of crystalline silicon and comparing the antireflection performance of crystal silicon surface before and after compounding (process parameters: embossing temperature 170 °C, holding time 300s. The imprint pressure 2KN) was compounded with smooth crystal silicon. Figure 8 shows the reflectance spectrum of the crystal silicon before and after the composite. It can be seen that the reflectance of the smooth crystal silicon surface is significantly reduced after the composite antireflection film. Due to the triangular pyramid texture and size design, the antireflection performance of the composite structure is more outstanding in the 300 nm-400 nm band.
Figure 8. Reflectivity of crystal silicon surface before and after composite triangular pyramid film.

From the optical characteristic curve of reflectance spectrum in the wavelength range (300nm ~ 800nm), we can directly reflect the reflectance of light functional texture film at specific wavelength. However, the solar radiation energy (solar irradiance energy $\varepsilon_s \approx 827.4 \text{w/m}^2$ in the visible spectrum) is mainly concentrated in the visible spectrum, and the energy is not uniformly distributed according to the wavelength. Therefore, the integral weighting method is used to quantitatively calculate the solar reflection loss of crystalline silicon cells.

The measured reflectivity is weighted according to the band to obtain the weighted reflectivity in the whole band. The calculation formula of the weighted reflectivity $[R]$ is shown in equation (1) [3].

$$ [R] = \frac{\int_{300}^{1000} R(\lambda) I_{AM1.5}(\lambda) d\lambda}{\int_{300}^{1000} I_{AM1.5}(\lambda) d\lambda} $$(1)

Where $R(\lambda)$ is the reflectivity, $I_{AM1.5}$ is the photon flux density of AM1.5G solar spectrum, and $[R]$ is the weighted reflectivity.

| Film type                                           | Weighted reflectivity | Proportion of reducing reaction efficiency |
|----------------------------------------------------|-----------------------|-------------------------------------------|
| Smooth planar film                                 | 11.36%                | 33.89%                                    |
| Optical functional textured films                   | 7.51%                 |                                           |
| Smooth crystal silicon surface                      | 21.47%                |                                           |
| Composite crystalline silicon with optical          | 17.97%                |                                           |
| functional textured film                            |                       |                                           |

By introducing the calculation of weighted reflectance to compare the antireflection efficiency, the results show in table 1 that the weighted reflectance of smooth planar film can be reduced from 11.36% to 7.51%, and the antireflection efficiency can be increased by 33.89%. In addition, the reflectivity of the smooth crystalline silicon surface can be reduced from 21.47% to 17.97%, and the antireflection efficiency can be increased by 16.59%.

The above test results did not take into account the light absorption of polymer film materials. Further, the electrical parameters of the composite structure solar cell prepared by triangular pyramid photo textured polymer film and monocrystalline silicon solar cell were tested to verify and evaluate the final effect of the photo textured polymer film.

4. Conclusion
Using the hot embossing technology, the triangular pyramid light function textured polymer film was prepared and compounded on the surface of single crystal solar cells to form light function textured
composite structure cells, which can effectively improve the photoelectric conversion efficiency of solar cells. This process can avoid the surface damage caused by direct texturing on the surface of monocrystalline silicon. These results indicate that the triangular pyramid light textured films with antireflective and self-cleaning properties can be used in different types of solar cells.

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