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Application of Nano Texturing on Multi-crystalline Silicon Solar Cells

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Nano texturing has been confirmed as an effective structure to improve the efficiency of multi-crystalline silicon solar cells by reducing optical loss. In this study, nano textured solar cells are fabricated by the Reactive Ion Etching (RIE) method based on a conventional production line. Several characterization methods are employed to evaluate the morphology, minority carrier lifetime, quantum efficiency and electricity performance of both nano textured and micro textured solar cells. The results show that nano textured solar cells have a maxiumum efficiency of 19.21 % and an average efficiency that is 0.57 % higher than that of micro textured solar cells. Thus, the RIE method is an effective way to manufacture nano textured solar cells. It can demonstrably improve the photoelectric conversion efficiency of mass-produced solar cells and reduce the production cost, which is significant to the development of solar cell industry.
Keywords: nano texturing, reactive ion etching, silicon, solar cell.

1. INTRODUCTION

In the conventional solar cell process, anti-reflective microstructures (textures) are usually fabricated to improve conversion efficiency of solar cells [1 – 3]. Due to the uniform distribution of crystal orientation in monocrystalline silicon, small and uniform pyramid structure can be obtained by alkaline anisotropic etching [4, 5]. The average reflectivity can be controlled below 10 %, which is helpful to the improvement of solar cell efficiency [6, 7]. However, because the alkaline etching method can not be used in multi-crystalline silicon due to its random crystal orientation, the acid etching method is adopted as a substitution to fabricate the texture on multi-crystalline silicon [8 – 10]. However, the reflectivity obtained by the acid etching method is around 20%, leading to a decrease in efficiency [11 – 13]. Recently, several other etching methods, including metal-assisted chemical etching [14 – 16], reactive ion etching (RIE) [12, 17 – 19], plasma immersion techniques [20], and laser etching [21, 22], have been employed to prepare nano texture. By using these methods, the light trapping performance of solar cells can be significantly increased, which is benefit to the decrease of reflectivity. Among all these methods, RIE has been widely studied due to its advantages, such as a stable reaction, easy-to-control process and uniformity. In 2013, Jinsu Yoo et. al [23] achieved an efficiency of 17.4 % by fabricating nano texture on conventional multi-crystalline silicon using the RIE method. Shiyong Liu et. al [24] using the RIE method and the matched process, achieved 0.51 % higher efficiency than that of conventional solar cells. The short-circuit current can be easily increased by preparing nano texture in laboratory scale; however, this is harder to achieve at the mass production scale. In mass production, it is more difficult for the SiN_x thin film to cover the wafer uniformly because of the larger wafer size and smaller etch pits. Low-quality SiN_x will influence the passivation performance and increase the recombination center. To solve this problem, the RIE method was employed to fabricate nano textured solar cells based on a conventional production line in this study. Passivation and anti-reflection film coating processes were also optimized to match the RIE process. Several characterization methods were employed to evaluate the differences in morphology, minority carrier lifetime, quantum efficiency and electricity performance between nano textured and micro textured solar cells.

2. EXPERIMENT

For this experiment, P-type mc-Si wafers with 1 – 3 Ω·cm resistivity, a thickness of 200 μm and dimensions of 156 cm × 156 cm were used. The production process of micro texturing solar cells consisted of the following steps: acid etching (etching weight of 0.3 – 0.32 g), high temperature phosphorus diffusion (sheet resistance of 85 Ω – 90 Ω), PSG removal, SiN_x antireflection thin film depositing by PECVD (thickness of 85 – 90 nm, refractive index of 2.05 – 2.10), screen printing and sintering. After acid etching, the RIE process was used to fabricate the nano texture on the wafer surface, a radio frequency (RF) power supply with a frequency of 13.56 MHz RF power is applied as the plasma source. Three kinds of gases including chlorine (Cl_2), sulfur hexafluoride (SF_6) and oxygen (O_2) are used as the reactant gas. Under the effect of RF power, the gases were changed into plasma and reacted with the surface of silicon, forming the nano texturing of solar cells. The morphology of the texture was characterized by SEM (Hitachi s4800). Reflectivity and

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quantum efficiency were measured by a spectral response measurement system (EnliTech QE-R3011). Thickness and refractive index were measured by an ellipsometer (EnliTech SE400adv). Electrical performance of the solar cells was measured by HALM equipment (CestisPV-BI) under 25 °C, 1000 W/m^2.

3. RESULTS AND DISCUSSION

3.1. Characterization of morphology

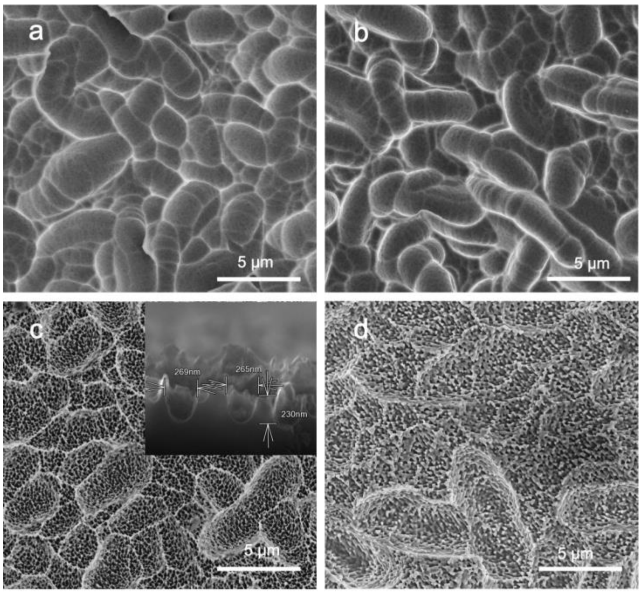
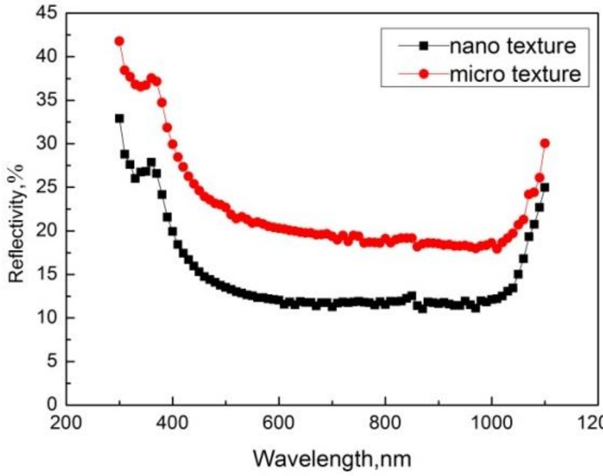


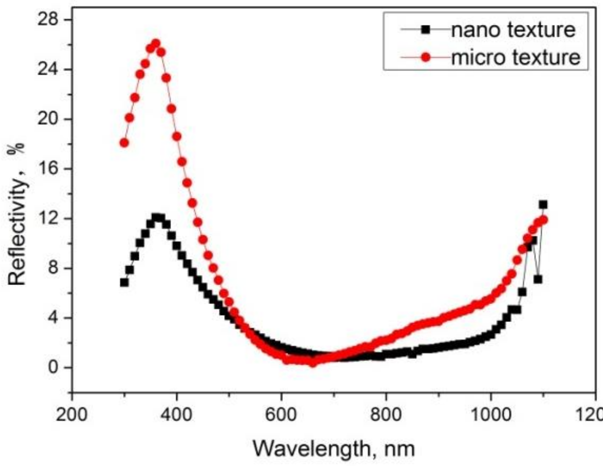
Fig. 1. a and b – SEM pictures of conventional texturing before and after coating; c and d – SEM pictures of nano texturing before and after depositing

Fig. 1 shows the SEM pictures of micro/nano textures before and after depositing. Fig. 1 a shows that uniformed etching pits were formed by acid etching; each of the pits is about 4 – 6 µm long and 2 µm wide. Fig. 1 c shows the morphology of the nano texture, it can be seen that many small pits were formed inside the larger pits. Because the nano texture was fabricated by the RIE method on a micro-textured base, it retained the morphology profile of micro pits, and formed many nano pits on the smooth surfaces of the micro texture. The cross section SEM picture (insert in Fig. 1 c) shows more details with higher magnification, the open size of the nano pits are around 260 – 270 nm, the depth is around 230 nm. Those nano pits can measurably reduce reflectivity and increase light absorption. During solar cell manufacture, the SiN_x depositing is a very important process because it decided the passivation effect of the solar cells [26]. On one side, the nano texture can reduce the reflectivity of silicon wafer and increase the short current of solar cells. On the other side, it will also increase the surface area of silicon and destroy the uniformity of SiN_x film, leading to a decrease in open voltage. So it is very crucial to control the size of nano pits. Fig. 1 b shows the micro texture morphology after SiN_x depositing; the SiN_x thin film has uniformly covered the smooth surface of the micro texture, so there is no difference in the morphology before and after covering. Fig. 1 d displays the nano texture morphology after depositing. Comparison to Fig. 1 c shows that the morphology has changed; because the pits in the nano texture are tiny, the morphology can easily be affected by SiNx depositing. It can be seen in Fig. 1 d that although some of the etch pits are small and deep, the surface is well covered by the SiNx thin film, which proving that the size of pits is very suitable for the solar cell.

3.2. Reflectivity



a



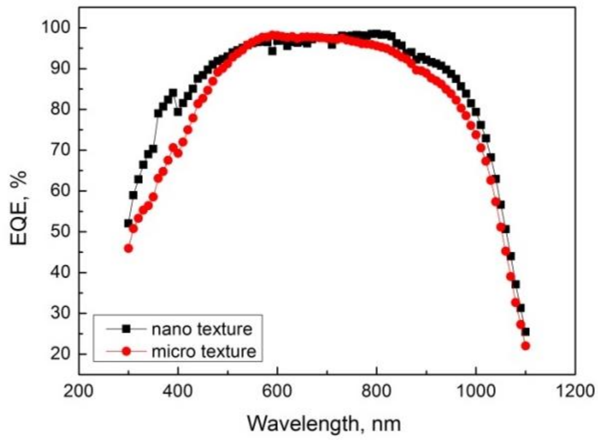
b

Fig. 2. a – reflectivity curve of conventional texturing and nano texturing; b – reflectivity curve of conventional texturing and nano texturing after depositing

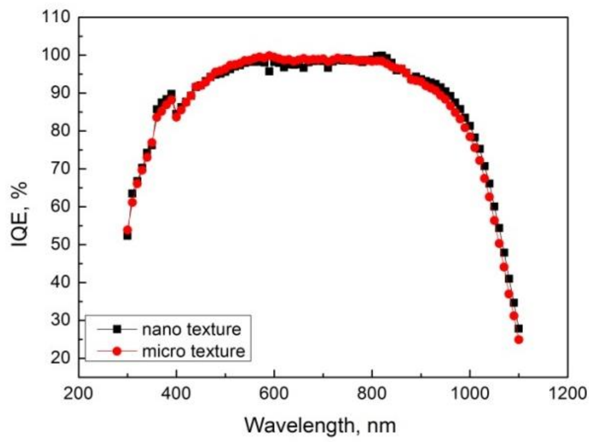
Fig. 2 a displays the reflectivity curves of nano and micro textures, they are measured under wavelength between 300 nm to 1100 nm [25]. The average reflectivity during the set wavelength of the micro and nano textures was 22.69 % and 14.91 %, respectively. For the whole wavelength range (300 – 1100 nm), the average reflectivity of the nano texture was 7.78 % lower than that of the micro texture. Fig. 2 b shows the reflectivity curves after depositing; the average reflectivity of the micro and nano textures after depositing was 7.06 % and 2.99 %, respectively. The reflectivity of the nano texture remained 4.07 % lower than that of the micro texture. It can also be seen from Fig. 2 b that after SiN_x depositing, the reflectivity of the nano texture was 2.69 % at long wavelengths (600 – 1000 nm), 1.72 % lower than that of the micro texture, which was 4.41 %. At short wavelengths

(300 – 600 nm), the reflectivity of the nano texture was 4.22 %, 7.12 % lower than that of the micro texture, which was 11.34 %. The results demonstrate that nano texturing has an advantage of reflectivity over micro texturing throughout the whole range of wavelengths.

3.3. Quantum efficiency



a



b

Fig. 3. EQE and IQE curve of conventional and nano texturing

Fig. 3 a and b are the External Quantum Efficiency (EQE) and Internal Quantum Efficiency (IQE) curves of nano and micro textured solar cells. It can be seen from Fig. 3 a that the EQE of the nano texturing is higher than that of the micro texture in the short wavelength range. According to the reflectivity results, the advantage in EQE of nano texturing is more obvious at short wavelengths. The reflectivities are almost the same at the middle wavelengths. As Fig. 3 b shows, the IQE curves of the nano texture and micro texture are very similar at short and middle wavelengths; however, at long wavelengths, the IQE of nano textured solar cells is slightly higher than that of micro textured solar cells, illustrating that the passivation effect of nano texturing is better than that of micro texturing.

3.4. Electrical properties

The comparison of average electrical properties between nano texturing and micro texturing is shown in Table 1. The tested quantity of nano and micro texturing solar cells are 1682 and 476 pieces respectively, the open circuit voltage (V_{oc}) of nano textured solar cells is 2 mV higher than that of conventional textured solar cells because the passivation effect of nano texturing was improved after thermal oxidation and the optimized PECVD process.

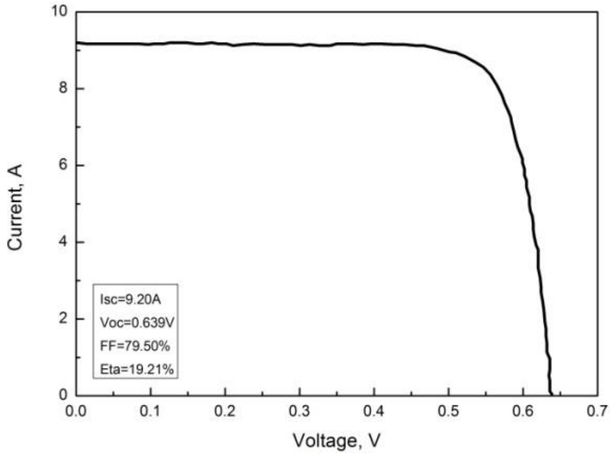


Fig. 4. I – V curve of nano texturing solar cell

This can also be explained by the IQE curve in Fig. 3 b. The short circuit current (I_{sc}) of a nano textured solar cell is 227 mA higher than that of micro textured solar cells, due to the decreased reflectivity and increased short wave response of the nano textured cell. The improvement of short circuit current makes a substantial contribution to the increased efficiency (Eta) of nano textured solar cells. Although the fill factor (FF) of a nano textured solar cell is lower than that of a micro textured solar cell, the average efficiency of nano textured solar cells is 0.5 7% higher than that of micro textured solar cells because of the increased short circuit current.

Table 1. Electrical properties parameter of conventional and nano texturing solar cells

	Quantity, pcs	V_{oc}, V	I_{sc}, A	FF, %	Eta, %
Nano texturing	1682	0.634	9.087	79.64	18.86
Micro texturing	476	0.632	8.818	79.92	18.29

Moreover, the highest efficiency reached by nano textured solar cells was 19.21 %, with an open circuit voltage of 639 mV, a short circuit current of 9.2 A and a fill factor of 79.50 %, the relative error is below 1 %. The good results are attribute to the suitable size of nano pits (as shown in Fig. 4).

4. CONCLUSIONS

Nano textured solar cells were fabricated by the RIE method based on an optimized conventional mass production process. The reflectivity of nano texturing is lower than that of acid-etched micro texturing. After SiN_x depositing, the reflectivity of a nano textured solar cell was 2.99 %, 4.07 % lower than that of a micro textured cell. The passivation effect of nano textured solar cells improved after the optimized PECVD process. The IQE of nano textured solar cells was remarkably better than that of micro textured solar cells. As for the electrical properties, open circuit voltage increased by 2 mV, short circuit current was raised by 227 mA, average efficiency increased by 0.57 % and the maximum efficiency reached 19.21 %. According to a comprehensive analysis, nano texturing is able to considerably improve the conversion efficiency of multi-crystalline solar cells, which is of great significance in reducing production costs and promoting the development of the photovoltaic industry.

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