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Texturing of multi-crystalline silicon wafer by ultrasonic standing wave

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Abstract. Nowadays solar energy receives more and more attention for its clear, non-pollutant and renewable characteristics. Although the production cost of electricity by solar cell is much higher than those by fossil fuels currently, solar cell has partly substituted traditional energy and be used in some fields. Silicon wafer surface texture act an important role in solar cell, which can trap the incident lights and influence the photoelectric conversion. In this paper, a new method using ultrasonic standing wave is present based on the previous researches. The acid molecules are droved to distribute regularly in terms of the standing wave. Then regular morphology can be textured on the surface of mc-Si by the acid molecules etching with silicon. SEM experiment illustrate the present method can texture regular morphology on the surface of multi-crystalline silicon (mc-Si) , also the antireflection of 9.4% is much lower than that of traditional acid etching.

Introduction

Nowadays, solar energy receives more and more attention for its clear, non-pollutant and renewable characteristics [1-3]. Compared with traditional energy, although the production cost of electricity by solar cell is much higher than those by fossil fuels currently, solar cell has partly substituted traditional energy and be used in some fields. Silicon is as main material to produce solar cell because of its photovoltaic function, which can effectively converse incident lights into electric energy. However, the lower conversion efficiency is the main bottleneck that limits the solar cell further application.

Silicon wafer surface texture act an important role in solar cell, which can trap the incident lights and influence the photoelectric conversion. Many researches have focused on this field, and several methods of texturing, such as wet etching, mechanical etching, reactive ion etching and laser etching, are presented to texture the surface of silicon. Early attention was paid to mono-crystalline silicon, because its (100) grain orientations are conventionally textured regular morphology [2]. Compared with mc-Si, the ratio of function and cost is much low for mono-crystalline silicon. Thus, lots of attempts have been proposed and developed to texture mc-Si wafer since recent years. Kyunghae Kim studied the texturing of large area mc-Si wafers through different chemical approaches, the results on the effect of texturing of these three solutions on the surface morphology of very large area (125mm×125mm) mc-Si wafer are presented, but the regular morphology can not be textured for its stochastic etching [3].

Hiroaki Morikawa adapted a high speed laser to study the controllable texture for the mc-Si, the regular pyramid morphology can be manufactured to increase the photoelectric conversion [4]. While the process is so complicated and can not be applied in large-scale mc-Si silicon solar cell. Jinsu Yoo studied reactive ion etching in texturing solar cell by using SF6/O2 as reactive materials to fabricate a large-area (156×156mm) mc-Si silicon solar cell in maskless surface, the result showed that surface texturing by RIE was efficient in fabricating thin mc-Si silicon solar cells [5]. Although many researchers regard the RIE as a promising approach in texturing the surface of the mc-Si, RIE require expensive instruments and other additional steps to achieve better cell performance. L.A. Dobrzan´ ski used laser surface treatment in texturing mc-Si silicon wafers, which can ensure obtaining texture of regular structure so that incident lights may have a larger probability of being absorbed into the solar cell, but electronic carriers in inner circuit of solar cell are damaged to reduce the photoelectric conversation [6]. Chao Yan and Wu Liqun studied the effect of cavitations on texturing mc-Si by acid solution combined with ultrasonic wave [7]. Although regular morphology can be textured on the mc-Si surface, the motion of acid molecular can not be well controlled which influence the speed of texturing. In this paper, a new method using ultrasonic standing wave is present based on the previous researches. The acid molecules are droved to distribute regularly in terms of the standing wave. Then regular morphology can be textured on the surface of mc-Si by the acid molecules etching with silicon.

Experiment

Figure 1 illustrates ultrasonic standing wave system to texture the surface of mc-Si. High frequency current signal produced from the ultrasonic generator is inputted into ultrasonic transducer. Then the ultrasonic wave is generated by piezoelectric ceramic translating the current into vibration, and the amplitude of vibration is further amplified by the changing amplitude pole. The ultrasonic wave is transmitted in the standing wave tube and reflected back by the reflector. When two paths ultrasonic wave with the same frequency and amplitude are superimposed, then the ultrasonic standing wave is generated. In order to efficiently control the standing wave, the acoustic device is installed in the solution to measure data of standing wave. A numerical oscilloscope is used to illustrate the standing waveform by treating the data imported from acoustic device. The data and form of standing wave are both inputted into computer to realize controlling on the standing wave by modifying the variables of ultrasonic generator.

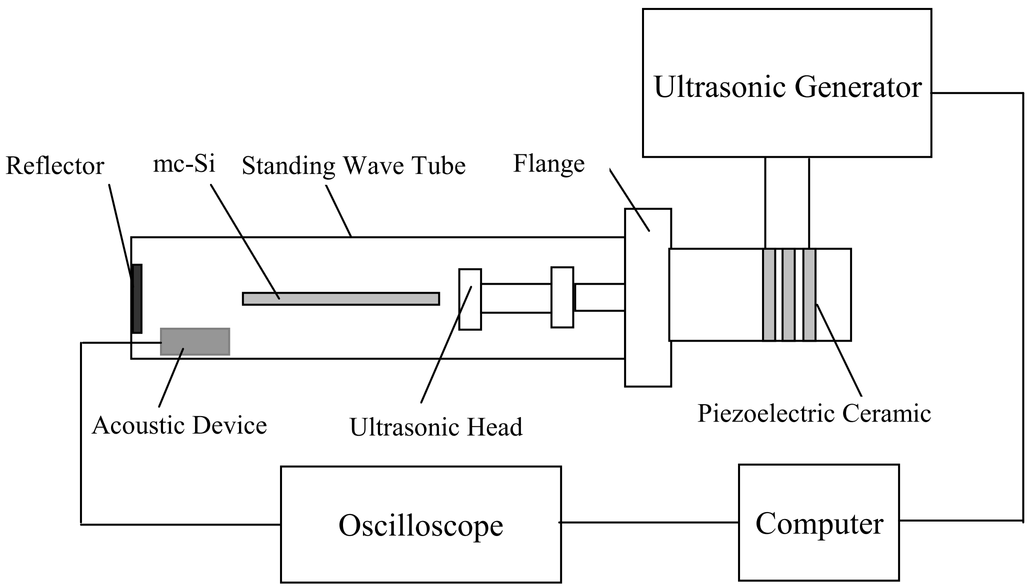


Figure 1 Ultrasonic standing wave system

Because mixed acid is applied to etch the surface of mc-Si, anti-acid material is necessary to avoid affecting the results of experiment. The ultrasonic standing wave tube uses plastic material with 10.25cm inner diameter and length of 14.5cm. The ultrasonic head is also covered with titanium material to prevent acid etching, and the maximum diameter of ultrasonic head is 5cm. In this paper, according to reference [3], the acid solution is mixed with HF–HNO3–CH3COOH, and the volume ratio of them is 2:15:5. The mc-Si sample used in experiment is the resistivity of 1.5~2Ω.cm and the area of 50×50(mm^2). After 1 minute, a stable standing wave can be observed on the oscilloscope.

Figure 2 illustrates partial standing wave produced in solution with ultrasonic wave of 1M frequency. Because the frequency is very high, cavitation is generated and many bubbles appear in the solution. Have been textured for 5 minutes, mc-Si sample is dipped into deionized water (DIW) to rinse the residual acid on the mc-Si surface. In order to analysis the characteristic of texture, the SEM (HTC 10) is employed to evaluate the morphology on the surface of mc-Si. At last, the antireflection of mc-Si sample is measured by spectrophotometer to study the absorption of incident lights.

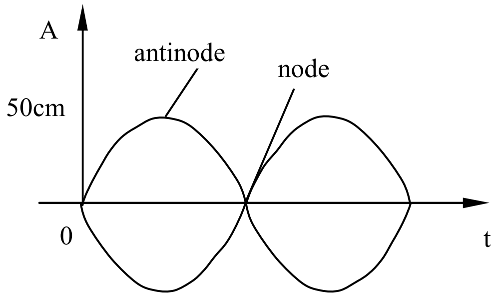
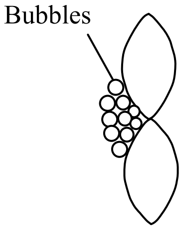


Figure 2 Partial standing wave

Result and Analysis

When the ultrasonic wave is introduced into solution, the molecules of solution are forced to vibration according to the frequency of ultrasonic wave. As the standing wave is produced, the global location of molecules keeps constant, and vibrates along the amplitude. In the maximum amplitude, the antinode is produced and the node appears in the zero amplitude. Because the sound factor between mixed acids ratio to water is bigger than zero, then the mixed acids are absorbed to the node of standing wave, while the water is force to accumulate the antinode of standing wave. At the same time, the bubbles are observed in the solution as shown in figure 3, which means that the cavitations are produced. The bubbles are absorbed into the zone of node of standing wave for its factor of sound ratio. The bubbles absorbed on the surface of mc-Si prevent the acid etching between mixed acid and mc-Si and the volume of bubble is periodical change according to the vibration. When the bubble is broken, many small holes are generated on the surface of mc-Si for cavitations etching, and the small holes can be further enlarged with the chemical etching between acid and mc-Si, figure 4 illustrates the model of cavitations etching. The chemical etching can be expressed as follow.

$$Si+6HF+HNO3=H2SiF6+HNO2+H2O+H2 \quad (1)$$



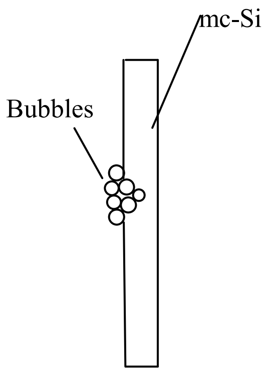


Figure 3 The Bubbles of acid absorbed into node

Figure 4 The model of cavitations etching

While on field of the antinode of standing wave, the surface of mc-Si keep unchanging because water molecules are accumulated and can not react with the surface of mc-Si. Figure 5 is the SEM image of the mc-Si after texturing 5 minutes by ultrasonic standing wave. It can be observed that many holes arrange as line, and the distance between adjacent lines is approximately to half wavelength of ultrasonic wave.

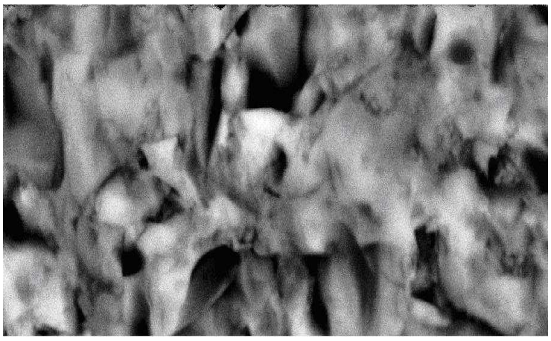


Figure 5 SEM of morphology of mc-Si

Reflectance of incident lights and trapping lights is the main indicator to evaluate the quality of texture on the surface of mc-Si. In order to study the absorption of light for the sample of mc-Si, we select the region of wavelength of light from 400nm to 800nm in experiment. Without loss of generality, we randomly select ten points on surface of mc-Si sample. After measuring, we calculate the data and use the average value as the measuring result. In order to effectively evaluate the antireflection of the surface, the measuring results are expressed as curve illustrated in Figure 4. In figure 6, we can find that the wavelength from 400 to 500 and from 750 to 800, the curve change rigidly, while from 500 to 750, the curve almost keeps constant and the value of antireflectance is 9.4%. Compared with previous approach, the antireflectance is much lower than that of other approaches.

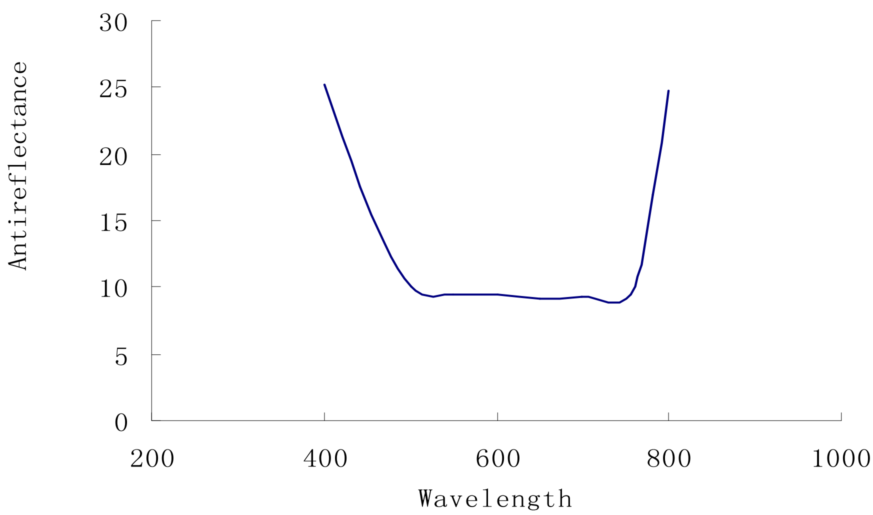


Figure 6 The antireflectance of mc-Si textured by ultrasonic standing wave in acid solution

Conclusion

In this paper, a new method to texture the surface of mc-Si is present. Ultrasonic wave is introduced into acid solution to generate the standing wave, which controls the distribution of acid molecules. SEM and antireflectance experiment are made, and the results are both better than other approaches presented previously.

Acknowledgement

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