Improvement of Si solar cell efficiency by using surface treatments on the antireflection coating layers and electrodes

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Abstract Plasma etching was studied to obtain high-efficiency Si solar cells. SiN nanoparticles were observed upon the plasma treatment using SF6 gas. The mechanism of the nanoparticles formation has been studied. A net increase in the current density (Jsc) of the cells of 1.7mA/cm^2 and in the conversion efficiency (η) of 2.1% is obtained after the plasma treatment for 10s, thanks to the significant decrease of reflection in the shorter wavelength range.

1. Introduction

Surface treatment to reduce the reflectance is an effective method to improve the performance of silicon solar cells[1]. Antireflection coating (ARC) layers are commonly used to reduce the reflectance even after surface texturing of substrate Si using acidic or alkaline solutions[2]. For the given material, the surface morphology and the thickness of the films are the major variables for the antireflection coating to decrease the reflectance. Different treatments of the surface of the SiN films are also studied to improve the performance of the solar cells. Nanostructures may find applications in photovoltaic solar cells. Nanoparticles are also directly integrated into Si solar cells to improve the power performance. In our research, nanoparticles were obtained on the surface of the SiN films after the plasma treatment using SF_6 gas.

2. Experimental details

The solar cells used for the experiments were fabricated by standard processes including cleaning, surface texturing in alkaline solutions, doping, deposition of the SiN films and screening on the boron-doped p-type single- and multi-crystalline silicon wafers. The film thickness of the SiN antireflection coating formed by PECVD is ~75nm. An inductively coupled plasma (ICP) reactor is used for plasma treatments of SiN films. All the experiments are conducted at s source power of 300 W, an RF-bias power of 30 W, a pressure of 30 mTorr and a SF_6 gas flow of 15 sccm, while varying etching time.

3. Results and discussion

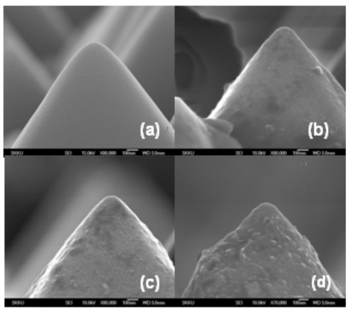

Fig.1 SEM images of treated for (a)0, (b)10, (c)20 and(d) 40 s

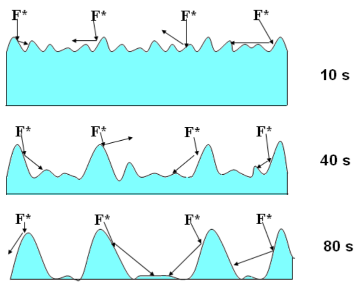

Fig.2 Schematic model on temporal evolution of nanoparticles

Fig.1 shows the SEM images of the SiN AR coating surfaces without (a) and with plasma treatments for (b) 10 s, (c) 20 s and (d) 40 s. The pyramidal structures which are larger than 2 μm are formed by the surface texturing in alkaline solutions in the fabrication process of the solar cells. Without the plasma treatment (Fig. 1(a)), the SiN AR coating surface deposited by PECVD on the pyramidal structure is flat. After the plasma treatment, some nanoparticles are formed on the SiN films surface and the diameter of the formatted nanoparticles increases with increasing treatment time. The formation mechanism of the SiN nanoparticles can be explained using the model of flux reemission[3]. For the high-density plasma, obtained by our inductively coupled plasma systems, the ratio of the ion flux to the reactive neutral flux is larger, but the physical sputtering effect is small and can be neglected. Drotar et al.[3] have proposed that the etching species, e.g. F*, do not stick on the surface on their first approach, but are reemitted and stick only on the subsequent reemission. In the beginning, some F*, which after reemitted and came again to the flat surface, reacted with the SiN atoms on the surface. Because of the probability of F* sticking to the surface is less than 1, not all the SiN atoms on the surface reacted with F*. Nanoparticles appear on the surface. The diameter of the nanoparticles is small in the beginning. After that, the etching species, such as F*, stick much less on the top than on the side of the nanoparticles. The etching depth increase with some small nanoparticles etched. As a result the number of the nanoparticles decreases but the diameter of the nanoparticles increases with the increasing of the etching time.

Fig.2 shows the schematic model on temporal evolution of nanoparticles (a) and etching results with time (b). After plasma treatment for 10s, the thickness of the SiN films decreases to 63.5nm from 75nm, and the diameter of the nanoparticles is about 3nm. With increasing time, some small nanoparticles etched by SF6 plasma, but larger nanoparticles appear on the surface. It is observed that, when the plasma treatment time is 40 s, the diameter of nanoparticles increases to ~30 nm and the top of the pyramidal structure becomes less conspicuous (Fig.1 (d)).

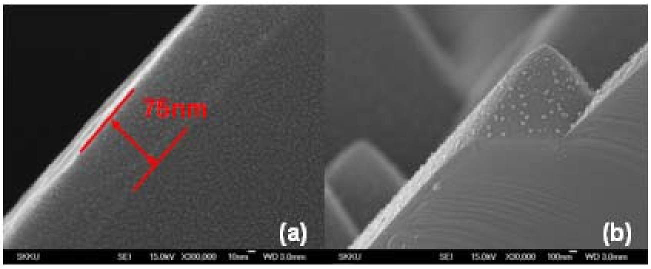

Fig.3 Cross section of the SiN AR coating before (a) and after (b) plasma treatment for 80s

After etching for 80s, the SiN films are removed but the SiN nanoparticles still on the surface of the Si. Fig.3 shows the cross section of the samples before and after the removal of the SiN films. From the Fig.3 (b), no SiN layer is observed on the surface. The diameter of the SiN nanoparticles is ~50nm and the distance of the nanoparticles is ~200nm.

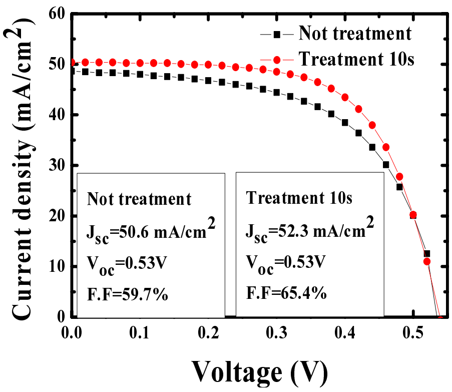

Fig.4 I-V characteristics of the crystalline Si solar cells before and after plasma treatment for 10s

Fig.4 shows the current-voltage characteristics under natural sun illumination with an intensity of 100 mW/cm^2. Net increases in the current density (J_{sc}) of the cells of 1.7 mA/cm^2 and in the conversion efficiency (η) of 2.1% are attained after the plasma treatment for 10s, thanks to the significant decrease of reflection in the shorter wavelength range. The fill factor is obviously increased.

If all the SiN films are removed, although some nanoparticles still remain on the surface, the current density (Jsc) and the conversion efficiency (η) decrease because of the removal of the antireflection coating layer. Table 1 compares the I-V characteristics of the Si solar cells before and after plasma treatment.

4. Conclusion

The nanoparticles are formed by the plasma treatment. The model of flux reemission can be used to explain the mechanism of the nanoparticles formation. The reflectance decreases due to the plasma treatment. The current-voltage characteristics are improved after the plasma treatment for 10s.

References

1. P.Verlinden,O.Evrard,E.MazyandA.Crahay,Sol.EnergyMater.Sol.Cells,71(1992)
2. W. S. Choi, K. Kim, J. Yi and B. Hong, Mater. Lett. **62**,577(2008).
3. J. Drotar, Y. P. Zhao, T. M. Lu, and G. C. Wang, Phys. Rev. B **61**(4),3012(2000).