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Influence of porous silicon on parameters of silicon solar cells

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The silicon solar cells with PS /n^+/p-Si structure (PS – porous Si) have been realised. Porous silicon obtained by stain etching or by electrochemical etching on standard alkaline textured surface has reduced effective reflectance coefficient to about 3% in a wavelength range of 400–1000 nm. Improved performance of solar cells due to formation of PS layer on the top surface between grid fingers has been demonstrated. Increases in efficiency of more than 25% have been achieved. In one chemical process antireflection coating as well as the selective emitter could be simultaneously obtained.

Keywords: porous silicon, stain etching, antireflection coating.

1. Introduction

Strong research activity in the field of porous silicon (PS) has been noticed recently. Technology of PS manufacturing is very simple, cheap and it is believed that it can be adapted to mass production of solar cells. It is known that the PS layer can play many roles but the most important ones are: porous layer as antireflection coating, new kind of surface passivation and texturisation [1–4].

2. Experimental

The substrates used in this work were Cz-Si (100), 3" diameter and mc-Si (CRYSTALOX), 50×5 cm, type p, 1 Ω cm silicon wafers. The monocrystalline wafers were previously texturised by anisotropic etching in alkaline solution. The wafers were thermally doped by phosphorous, the sheet resistance was about 30 Ω/□. Finally electrical contacts were carried out by silver screen printing and fired at 700°C. Porous silicon layers were formed on the wafers after diffusion process with or without the contacts. The grid contacts of solar cells were not protected before PS formation. The PS layer was formed by two methods: electrochemical etching or electroless chemical etching (stain etching). Electrochemical etching of silicon wafers was performed in a teflon vessel using a standard two-electrode set-up in a solution hydrofluoric acid in ethanol. Stain etching of silicon was performed in a mixture of hydrofluoric acid, nitric acid, and water. The etching time (for both PS processes) was ranging from 3–60 s.

3. Results

3.1 Structure

SEM- micrographs of double texturised surfaces by alkaline etching with additional microtexturisation made by electrochemical etching and stain etching are shown in Fig. 1(a) and (b).

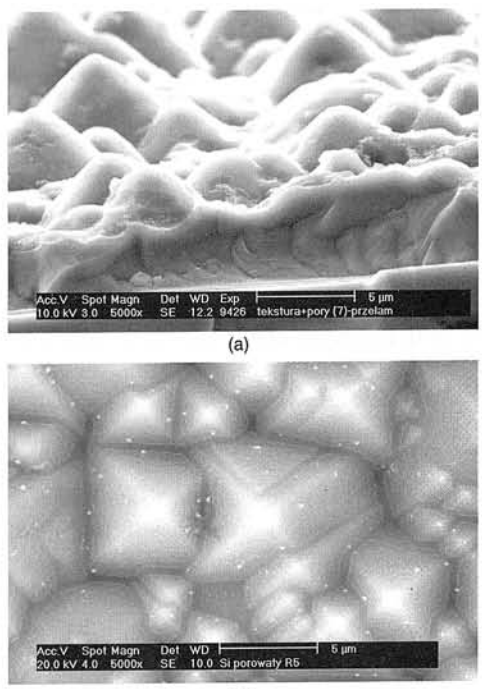

Fig. 1. SEM micrographs of Cz-Si wafer surfaces after electrochemical etching (a) and stain etching (b). The wafers were previously textured by standard anisotropical alkaline etching.

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3.2. Reflectance

Total reflectances of the samples as a function of wavelength were measured using Perkin–Elmer Lambda spectrophotometer equipped with an integrating sphere. They are presented in Fig. 2 and Fig. 3. Table 1 contains effective reflectance values for different samples, i.e., the reflectance $R(\lambda)$ normalised to the solar flux $N(\lambda)$ according to equation

$$R_{eff} = \frac{\int R(\lambda)N(\lambda)d\lambda}{\int N(\lambda)d\lambda}. \qquad (1)$$

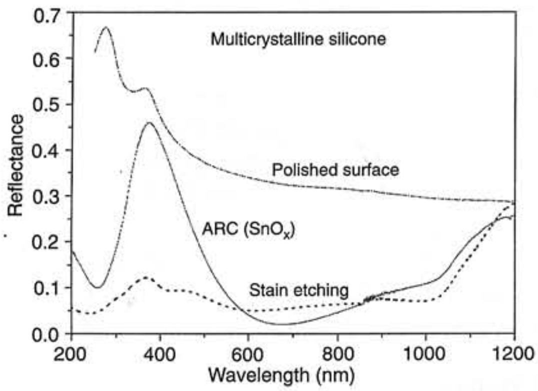

Fig. 2. Total reflectance as a function of wavelength of different multicrystalline Si samples: with a polished surface, with and without antireflection coating (SnO_x) and with porous silicon layer made by stain etching.

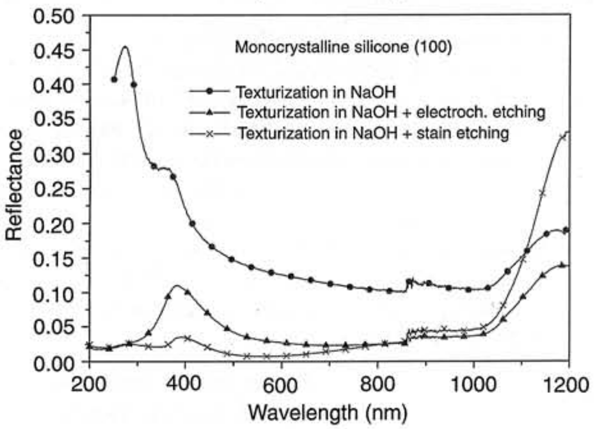

Fig. 3. Total reflectance as a function of wavelength of monocrystalline Si wafers after electrochemical and chemical etching.

The integration limits are 400 nm and 1000 nm for the standard AM1.5 spectral distribution. It can be seen that the effective reflectance coefficient has its minimum (about 3%) for a double texturisation: by alkaline etching and additionally by PS etching. It can be seen from Table 1, that the reflectance of mc-Si with PS layer, obtained by stain etching (6.6%), is smaller than that obtained with ARC (9.4%).

Table 1. Effective reflectance coefficient for different Si samples.

Samples	Effective reflection coefficient R_{eff} (%)
Polished surface	33.9
mc-Si with ARC (SnO_x)	9.4
PS by stain etching (mc-Si)	6.6
Texturisation by alkaline etching (Cz-Si)	12.6
Texturisation by alkaline etching + PS by electrochemical etching (Cz-Si)	3.4
Texturisation by alkaline etching + PS by stain etching (Cz-Si)	3.1
PS by electrochemical etching (Cz-Si polish surface)	9.7

3.3. Solar cells

The silicon solar cells were etched by electrochemical or electroless chemical method. Because the grid contacts have not been protected, the time of etching was very short: about 3 s for stain etching and 8 s for electrochemical etching. In Table 2, all the parameters of solar cells I_{sc}, V_{oc}, E_{ff} as well as the parameters obtained from fitting of I-V characteristics by double exponential model with diode ideality factor 2 are presented. J_{s1}, J_{s2} are the densities of the saturation currents, R_s and R_{sh} are the series and shunt resistance, respectively.

It can be seen from Table 2 that increase in short circuit current is about 26% and efficiency about 28% for solar cell (a). For the better solar cell (b) this increase is smaller: short circuit current 19% and efficiency 11%. This effect is caused by the antireflection coating, and by removing emitter dead layer too. The electrochemical etching of solar cells give similar increase in short circuit current and efficiency.

Table 2. Parameters of silicon solar cells without and with PS layer obtained by stain etching (a,b – Cz-Si, c – mc-Si).

No	I (mA)	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	Eff (%)	J_{o1} (pA/cm^2)	J_{o2} (μA/cm^2)	R_s (Ω cm^2)	R_{sh} (kΩ cm^2)
a	1053	23.82	573.6	69	9.39	2.2	0.17	1.7	1.1
a(PS)	1331	30.11	570.7	70	12.06	2.8	0.27	1.0	3.5
b	1058	23.9	588	74	10.42	1.4	0.12	1.6	18.0
b (PS)	1263	28.6	574	71	11.61	3.6	0.16	1.6	20
c	412	16.5	545.6	73	6.58	5.3	0.25	0.7	2.2
c(PS)	521	20.8	532.3	73	8.13	7.9	0.42	0.02	7.3

Table 3. Parameters of solar cell with PS layer obtained by stain etching after a test at 100°C with relative humidity 85%.

Days	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (%)	E_{ff} (%)	J_{o1} (pA/cm^2)	J_{o2} (μA/cm^2)	R_s (Ω cm^2)	R_{sh} (kΩ cm^2)
0	1331	571	70	12.06	2.8	0.27	1.0	3.5
1	1299	577	71	11.98	2.7	0.22	1.1	5.1
3	1294	583	72	12.22	2.2	0.16	1.2	29.9
4	1300	577	72	12.21	2.8	0.18	1.0	16.6
5	1294	581	72	12.25	2.4	0.17	1.1	21.4
8	1305	587	73	12.74	1.9	0.15	1.1	185.3
9	1303	589	72	12.48	1.9	0.14	1.2	8.9

4. Cells reliability

The cells have been investigated using accelerated life testing. The tests were performed at the temperature 100°C, with the relative humidity of 85%. The authors performed a test to check if the environmental stressing causes increase in the series resistance and, subsequently, a degradation of the cell fill-factor. The results of this test are presented in Table 3. It can be seen from Table 3 that very shortly etched solar cell was not degraded after nine days of testing. On the contrary, the efficiency of the solar cell increases what can be explained by passivation of the PS layer.

5. Conclusion

The work reported here demonstrates that porous silicon technology used for manufacturing of terrestrial solar cells in industrial process is very promising. Significant increase in the I_{sc} and efficiency of solar cells was observed and what is very important these solar cells are reliable. The stain etching has proved to be more applicable to solar cells production than the electrochemical etching. This method gives comparable increase in I_{sc}, but the stain etching is particularly suitable to large area processing. No contact grid protection was used, as being not suitable for low cost processing. In our technology the PS layer was made in a very short time (about 3 s). During this time the contacts were not destroyed but on the other hand it is too short time to receive optimal PS layer with the minimal effective reflectance. The work is currently in progress in order to overcome this problem and in order to find new etching conditions that are more suitable for industrial production.

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