Multicrystalline Silicon Texturing for Large Area CommercialSolar Cell of Low Cost and High Efficiency

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Abstract

Multicrystalline silicon wafers were textured in an alkaline bath, basically using sodium hydroxide and in acidic bath, using mainly hydrofluoric acid (HF), nitric acid (HNO_3) and de-ionized water (DIW). Some wafers were also acid polished for the comparative study. Comparison of average reflectance of the samples treated with the new recipe of acidic solution showed average diffuse reflectance less than even 5 percent in the optimized condition. Solar cells were thus fabricated with the samples following the main steps such as phosphorus doping for emitter layer formation, silicon nitride deposition for anti-reflection coating by plasma enhanced chemical vapor deposition (PECVD) and front surface passivation, screen printing metallization, co-firing in rapid thermal processing (RTP) Furnace and laser edge isolation and confirmed >14 % conversion efficiency from the best textured samples. This isotropic texturing approach can be instrumental to achieve high efficiency in mass production using relatively low cost silicon wafers as starting material.

1. INTRODUCTION

Multi-crystalline silicon surface texturing is a key issue to fabricate low cost and high efficiency solar cell in mass production level. For mono-crystalline silicon, the well established texturing method is anisotropic etching with aqueous solutions of potassium or sodium hydroxide which results in the surface covered with pyramids. This is due to the very different etch rates of the < 100 > and <111 > orientated planes of silicon [1]. But, conventional alkali texturing has little usefulness for the multicrystalline silicon where the grains are randomly oriented. Several texturing techniques are under investigation, but none have reached the status of mass production for standard screen printed solar cells [2].
Reactive Ion Etching (RIE) and Isotropic Etching by acidic solution are two main techniques out of · many under investigation for texturing multicrystalline silicon surface for solar cell fabrication. RIE is a complicated process and requires expensive system compared to the isotropic texturing process by acidic solution [3]. Wet acidic texturing, performed with solutions containing HF / HNO_3 that tends to etch isotropically, can result in features with rounded surfaces, as opposed flat-sided features which arise from anisotropic etches. These rounded features produce scalloped surface that can have good antireflection properties [4]. The advantageof the isotexturing is not only in the reflection reduction but also in the ability to contact shallow emitters [5].

2. EXPERIMENTAL

A series of experiments on multicrystalline silicon texturing were carried out with different solutions. The starting material for the experiment was boron doped p-type multicrystalline silicon wafers of sheet resistance 0.5 ~ 2. 0 ohm-cm of brand SOLSIX from Deutsche Solar. In the first part of the experiment, it was tried with alkali solution containing sodium hydroxide, water and isopropyl alcohol for different composition ratio and process time. The same process was repeated for the surface etching of the wafers with acidic solution mainly containing HF (~ 49 %), HNO_3(~ 69 %) and DIW in different volume ratio for different process time. Sodium phosphate tribasic ($Na_3PO_4.12\ H_2O$) was added to the acidic solution in order to have control over the reaction rate which ultimate helped to change the surface morphology of the silicon resulting in higher roughness. Diffuse reflectance of all the alkali and acid etched samples were measured and also the surface of the samples was studied using Optical Microscope. In the case of alkali textured samples, we found non-uniform structures at the different regions of the wafers during the optical microscopic observation. But, the surface that was etched with acidic solution of HF, HNO_3 and DIW in the volume ratio 12 : 1 : 5 (X1) for 2 minutes showed etched surface with uniform structures and diffuse reflectance even less than 5 % in the wavelength range of 400 to 1100 nm in some samples. Representative samples from each category were analyzed using scanning electron microscopy (SEM). The samples were then phosphorus doped using our optimized diffusion condition with phosphorus oxychloride ($POCl_3$) as the source. Sheet resistance was measured by using four point probe method after the removal of the layer of phosphosilicate glass (PSG) from the sample surface with diluted HF. The results showed slight non-uniformity in sheet resistance. Thermal oxide of thickness ~ 200 angstrom was grown on the sample surfaces at 900 °C which served as a passivating layer and also brought the sheet resistance to a uniform and expected range for solar cell fabrication. The surface was again analyzed with optical microscope and diffuse reflectance of the surface was also measured. Final study of the surface morphology using SEM confirmed the isotropic texturing of multicrystalline surface.

3. RESULTS AND DISCUSSION

Fig. 1 shows the diffuse reflectance of the untreatedbare multicrystalline silicon wafer surface. The average reflectance for the wavelength range 400 to 1100 nm is higher than 25 percent. After the treatment of the sample with acidic solution (X1), the average reflectance was found to decrease drastically to the level of below 5 percent, as shown in Fig. 2. The SEM micrograph of Fig. 3 shows the porous surface generated after the acid treatment due to which the large percentage of the incident light gets absorbed by the surface causing very low reflection. Highly magnified SEM image of the isotextured surface shows the etch pits more clearly in Fig. 4. But, as the sample was subjected to phosphorus diffusion with $POCl_3$ source at high temperature the upper porous layer got oxidized and during the PSG removal process the unstable porous layer got removed to some extent as a result of which the color of the sample changed from blackish to grey. The formation of porous surface of multicrystalline silicon involves the consumption of a portion of the surface layer of the solar cell and can therefore also be effective in the removal of the dead layers left after diffusion and damage caused by sawing. The diffuse reflectance of the surface was found to have increased, as shown in Fig. 5. Shallow pores thus obtained on the surface cause less light trapping. The lesser deep pores are clearly shown in Fig. 6. After the silicon nitride deposition on the surface as antireflection coating, the reflectance of the sample again reduced substantially, as shown in Fig. 7. Micrographs of Fig. 8 and 9 show the surfaces of alkali textured and acid polished multicrystalline silicon wafers respectively. Alkali textured surface has pyramids of non-uniform sizes whereas acid polished surface is relatively more reflective due to very small surface roughness. They were also processed for the cell fabrication along with the wafers textured with the new approach for the comparison of performance parameters of the cells. The non-uniform size of the pyramidal structures as well as the small roughness of surface in both of the other samples types make them unable to trap light as much as the acid textured surface with the new approach does. Fig. 10 shows the comparison of the performance parameters of the alkali textured and iso textured solar cells. A similar comparison is shown in the Fig. 11 between alkali textured and acid polished solar cells. The textured wafer with our novel approach showed the best combination of performance parameters including conversion efficiency (Eff) of the cell. Open circuit voltage (Voc) of the cell is 601.4 mV and short circuit current (Isc) is 4. 96 A. The open circuit voltage does not seem to be appreciably different from that of acid polished and alkali textured cells, which have Voc of 597. 6 and 598.1 mV respectively. But, Isc of the isotextured cell is 4.96 A which is 0.37 A more than alkali textured cell and 0.22 A more than acid polished cell. The difference in the short circuit current comes from the additional contribution of uniform texturing of the surface by the approach that has been reported in this paper. Slightly higher Voc in isotextured cells indicates that its surface structure does not lead to increased surface recombination . The same value of fill factor (FF) of 74 % in all types of cells shows that there is almost identical contact resistance. The difference in conversion efficiencies of cells with different surfaces basically comes from the variation in Isc, which is mainly texturing condition dependent parameter of the cell. With these results, it can be concluded that our texturing scheme with acidic solution creating porous surface is successful in achieving better Isc and hence better conversion efficiency in large area multicrystalline silicon solar cell. Also, the acid polished cell established itself better than alkali textured cell.

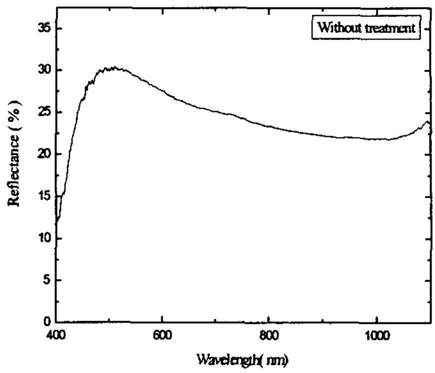

Fig. 1. Diffuse Reflectance of bare multicrystalline silicon wafer surface.

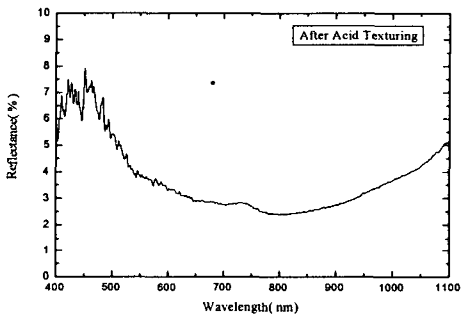

Fig. 2. Diffuse reflectance of the multicrystalline silicon surface after texturing with acidic solution.

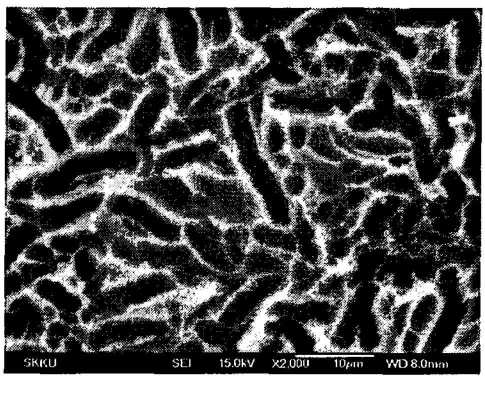

Fig. 3. SEM micrograph of isotextured multicrystalline silicon surface containing porous structures.

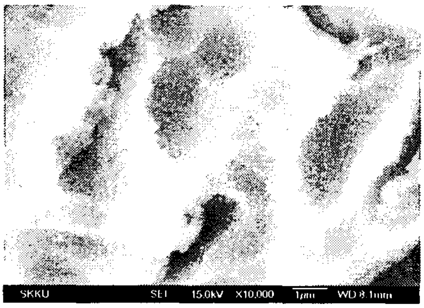

Fig. 4. Highly magnified SEM image of the porous surface on multicrystalline silicon.

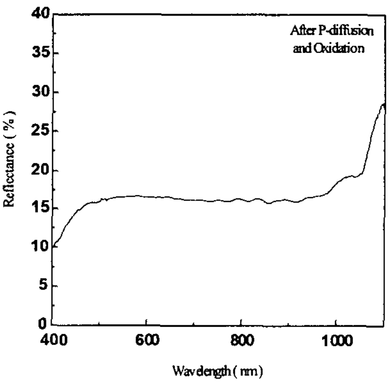

Fig. 5. Diffuse reflectance of the multicrystalline silicon surface after phosphorus diffusion and oxidation.

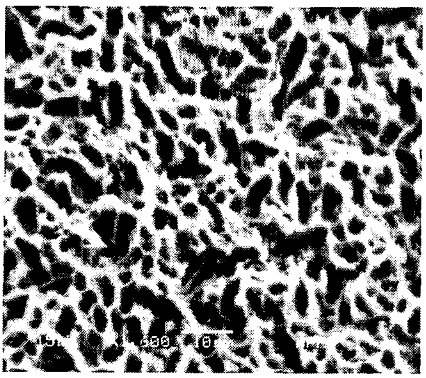

Fig. 6. SEM micrograph showing the etch pits of smaller depths after PSG removal and oxidation.

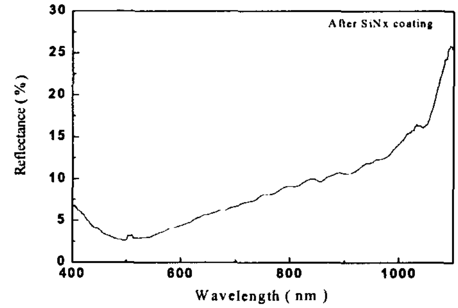

Fig. 7. Diffuse reflectance of the multicrystalline isotextured surface after silicon nitride coating as antireflection layer.

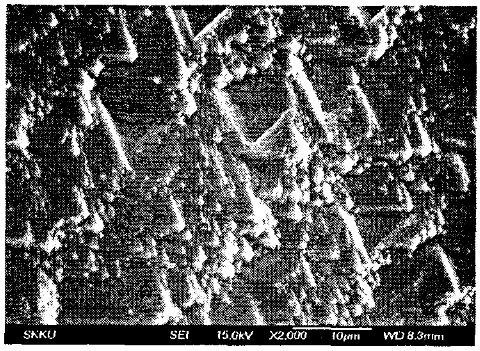

Fig. 8. SEM micrograph of alkali textured surface of multicrystalline silicon.

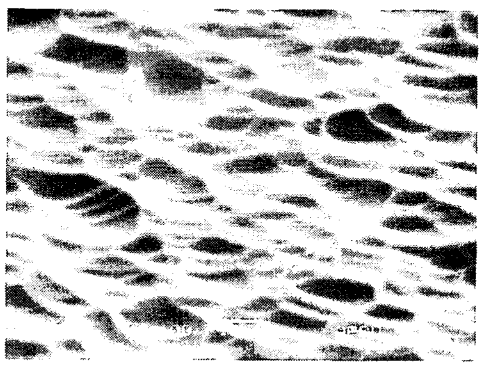

Fig. 9. SEM micrograph of acid polished surface of multicrystalline silicon.

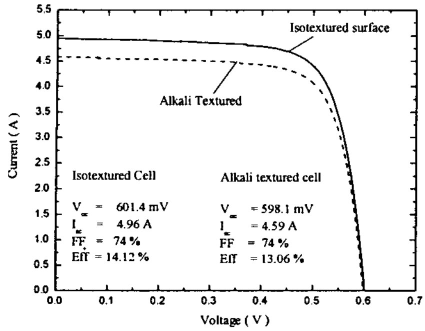

Fig. 10. Comparison of performance parameters of solar cells fabricated on alkali textured and acid isotextured surfaces of multicrystalline silicon.

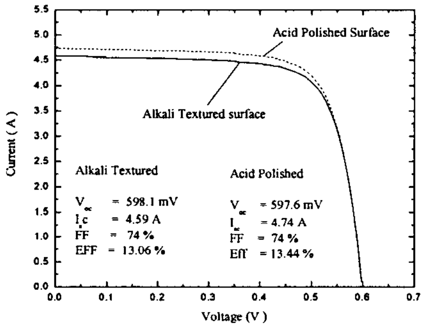

Fig. 11. Comparison of performance parameters of solar cells fabricated on alkali textured and acid polished multicrystalline silicon surface.

4. CONCLUSION

A thorough investigation was done on a new scheme of acid texturing of multicrystalline silicon surfaces for solar cell application. Solar cell was fabricated with the silicon wafers of surface area 125 X 125 cm^2 textured with three different approaches. The solar cell of conversion efficiency 14. 12 % was fabricated with this new approach of acid texturing, which showed Isc as high as 4.96 A. Acid polished multicrystallilne silicon surface was found to be better than alkali textured whereas the surface textured with our new approach showed the best result. This texturing technique could be significant to fabricate high efficiency solar cell in large scale with low-cost, starting with multicrystalline silicon.

REFERENCES

[1] Jeffrey A. Mazer, Solar Cells: An Introduction to Crystalline potovoltaic Technology, Kluwer Academic Publishers, 1997, p.137.

[2] A. Hauser, I. Melnyk, P. Fath, S. Narayanan, S. Roberts, T. M. Bruton, 3rd world conference on Photovoltaic Energy Conversion, Osaka, Japan., May 11-18, 2003.

[3] S. W. Park and J. Kim, Journal of Korean Physical Society 43- 3 (2003) 432- 426.

[4] D. H. Macdonald, A. Cuevas, M. J. Kerr, C. Samundsett, D. Ruby, S. Winderbaum, A. Leo , Solar Energy 76 (2004) 277-283 .

[5] S. Narayanan, Solar Energy Materials & Solar Cells 74 (2002) 107- 115