PROCESSING AND CHARACTERISATION OF ISOTROPICALLY, ALKALINE AND MECHANICALLY TEXTURED MC-Si BURIED CONTACT SOLAR CELLS: A COMPARATIVE STUDY

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ABSTRACT: The mechanical, optical and electrical properties of isotropically, alkaline and mechanically textured Buried Contact Solar Cells (BCSC) are discussed in this work. The mechanical stability of isotropically textured wafers and BCSCs are studied using a twist tester and the wafer stability is analysed in terms of wafer fracture force and wafer flexibility. The increased stability of wafers after isotropically texturing is maintained throughout the BCSC process, even after different high temperature processes. The optical properties are investigated using the optical transmission and reflection measurements analysis. The optical path length of isotextured wafers is analysed by means of simulated transmission curve using the absorption coefficient extracted from transmission measurement of an alkaline textured wafer. The isotextured cells exhibit lower reflectance in the high wavelength range whereas the mechanically textured cells exhibit lower reflectance in the short wavelength region. Higher short circuit current density has been measured on mechanically textured BCSC in comparison to isotropically textured and alkaline textured BCSC that could be attributed to the light trapping in the short wavelength range.

Keywords: Multi Crystalline Silicon, Texturisation, Buried Contact Solar Cells.

1 INTRODUCTION

The Buried Contact Solar Cell (BCSC) invented at the University of New South Wales has the features to attain high efficiencies as compared to conventional screen printed silicon solar cells [1]. The higher efficiency in a BCSC is mainly due to the increase in short circuit current density. In this context surface texturing in multicrystalline silicon solar cells plays a vital role in light trapping to enhance the short circuit current and hence to attain higher efficiencies. Various surface texturisation schemes such as alkaline etching, reactive ion etching, isotropic texturing, mechanical texturing etc. are available for multicrystalline silicon (mc-Si) solar cells [2, 3]. Commonly used alkaline solutions like NaOH or KOH exhibits anisotropic etch rates in different crystal directions and because of this reason alkaline etching on crystal planes {100} and {111} orientation produces randomly distributed pyramids of intersecting {111} planes are formed on the wafer surface. The draw back of alkaline texture in mc-Si is that it etches only the planes close to {100} and the others still exhibit relatively higher reflectivity, i.e. alkaline texturing is strongly dependent on the orientation of the crystal planes. The acidic isotropic etching with an acidic solution of HF, HNO_3 and H_2O overcomes the above mentioned problem to some extent. In isotropic etching the surfaces are formed with grooves or trenches all over the mc-Si wafer surface. The texturing process is isotropic and the light trapping property of the isotextured wafers are higher than alkaline etched wafers. In mechanical texturing the groves or trenches are formed by using a dicing blade or dicing wheel mounted on a dicing saw. This kind of texture is purely independent of grain orientation and the light trapping properties of mechanically textured surfaces are quite close to the isotextured surfaces.

This work addresses the mechanical, optical and electrical properties of alkaline, isotropically and mechanically textured mc-Si buried contact solar cells.

2 EXPERIMENTAL

2.1 Wafer texturing

The wafers used throughout in this investigation are directionally solidified multicrystalline silicon wafers of size 125 x 125 mm², thickness 330 µm and bulk resistivity about 1.5 Ωcm. The texturing of the wafers was carried out using the following methods: isotropic texturing in an industrially feasible inline system developed by the University of Konstanz and RENA. The etching bath contains HNO_3, HF and H_2O. The topography of the textured wafer surface is captured using Atomic Force Microscopy (AFM). Corresponding pictures of the textured surfaces are given in Figure 1. The AFM analysis reveals that the trenches or grooves present on the isotextured surface are approximately 5 to 8 µm deep. The conventional alkaline anisotropic texturing was carried out to produce randomly distributed pyramid structures on the wafer surface. According to the AFM analysis, the pyramid height formed on the {100} direction is in the range of 5 to 6 µm. Using the single blade, V- grooves of depth 50 to 60 µm and angle 60° were opened on the wafer surface. In the case of dicing wheel texture the wafer surface is grinded using the wheel to produce surface irregularity. The AFM analysis shows that the depth of the grooves or trenches found on surfaces with maximum irregularity is approximately in the order of 5 µm.

2.2 BCSC processing

The cell processing starts with saw damage etch in alkaline solution and acidic cleaning followed by a light $POCl_3$ emitter diffusion of sheet resistance 100 Ω/sq. Silicon nitride (SiN_x) anti reflective coating is carried out on front side in a next step using Low Pressure Chemical Vapour Deposition (LPCVD) process. Contact grooves sized 50 µm are formed on the front side by mechanical cutting. A selective emitter with a sheet resistance of 10 Ω/sq is diffused inside the grooves. Full aluminium (Al) Back Surface Field (BSF) is formed on the rear side by screen printing Al and a belt furnace alloying process.

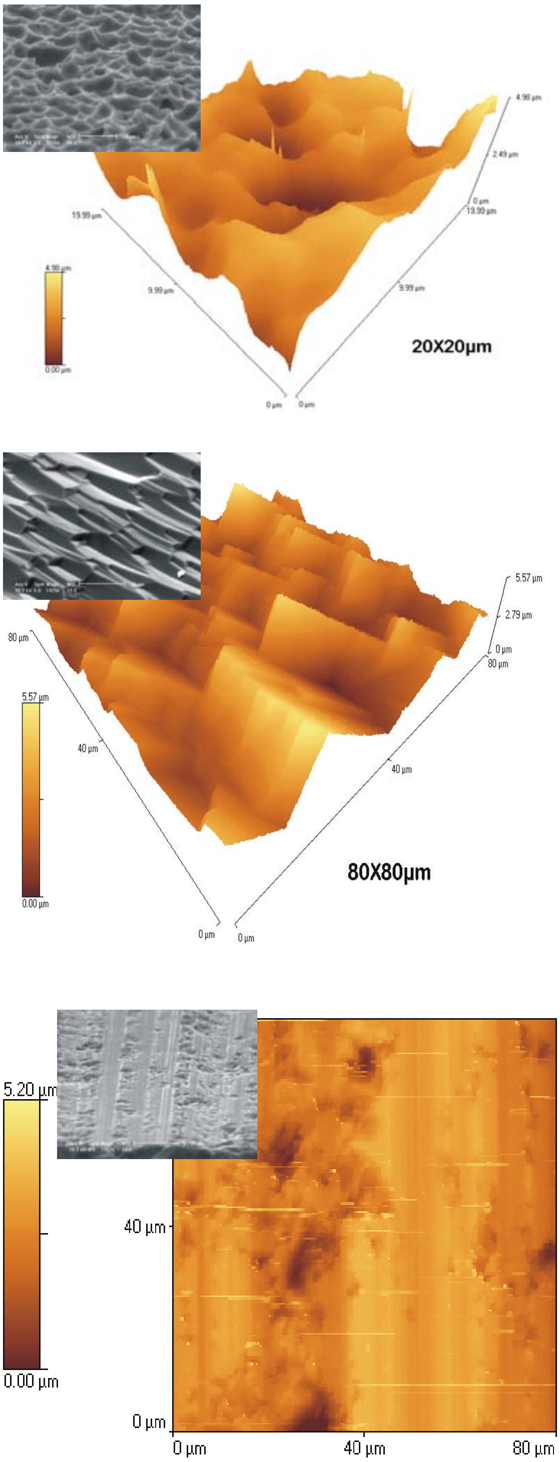

Figure 1: AFM and SEM picture of isotropic (top), alkaline (middle) and mechanical (bottom) textured surfaces (see text for details).

Bulk hydrogen passivation is carried out using a Microwave Induced Remote Hydrogen Plasma (MIRHP) source. In a next step aluminium is evaporated on the rear side followed by electroless metallisation of nickel and copper. Finally the edge isolation is carried out using a dicing saw. More detailed description of BCSC process step is described in literature [4].

2.3 Mechanical stability tests

The mechanical properties of mc-Si wafer in terms of wafer fracture force and wafer flexibility was investigated by a mechanical stability tester, called twist-tester, developed by A. Schneider et al [5]. For testing, the wafers are placed on two pins fixed diagonally opposite on a rectangular platform. The external force is applied from top using two movable pins that are perpendicular to the fixed pins on the platform. This force displaces the wafer downwards from its original position and finally leading to wafer destruction. By this way the fracture force leading to wafer breakage is determined. The mechanical characterisation was performed with as cut wafers, isotextured and mechanically textured wafers using a dicing wheel. In order to investigate the influence of temperature on mechanical stability wafer fracture force was determined after important high temperature process steps in BCSC fabrication. The investigated process steps were: after phosphorous gettering at 820°C, p-gettered with SiN_x and p- gettered + SiN_x + heavy diffusion. The above mentioned high temperature steps are important process steps of buried contact solar cell fabrication. In each category 8 neighbouring wafers were used for characterisation.

3 RESULTS AND DISCUSSION

3.1 Mechanical properties

Figure 2 shows the change of fracture force of isotextured mc Si wafers after three high temperature process stages of the BCSC fabrication.

The force of the isotextured wafers were found to be increased by more than 30% relative and the improved strength is maintained throughout the BCSC process. A similar increase in strength of isotextured wafers was reported by A. Schneider et al [5]. From Figure 2, it can be noted that the strength of isotextured BCSCs with grooves are slightly reduced as compared to isotextured wafers. This could be due to the presence of contact grooves of depth 50 to 60 µm present in the wafers. Interestingly, the fracture force is still higher than the fracture force of the as cut wafers. As expected, the fracture force of dicing wheel textured wafers is reduced considerably. This indicates that considerable wafer breakage may occur during the solar cell process. It should be noted that by mechanical texturing wafer surface irregularities – for example cracks - are produced by removing a considerable amount of silicon from wafer surface and hence the wafer strength, in our experiment, is reduced to 60% relative as compared to as cut wafers.

In our present BCSC fabrication process no wafer breakage was observed during the cell process for isotextured wafers. However, a considerable number of mechanically textured wafers broke during the high temperature process. This could be explained by the expansion of micro cracks produced during texturing. The high temperature process step produces thermal shocks on the micro cracks. Following extension during high temperature treatment leads to wafer breakage [7].

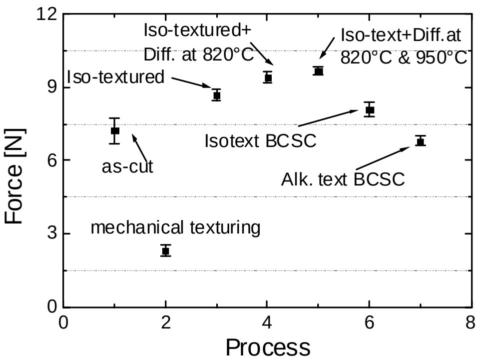

Figure 2: Influence of fracture force of isotextured and mechanically textured wafers after different BCSC process steps. The isotropically textured wafers maintain the improved mechanical stability throughout the cell process.

The twist testing is applied up to wafer breakage. The applied force bends the wafer downwards and this wafer downward bending is a measure of wafer flexibility. The wafer flexibility of isotextured wafers in BCSC process is shown in Figure 3. An increase in wafer flexibility can be observed for isotextured wafers as compared to as cut wafers. This increase in wafer flexibility is consistent with multi and mono crystalline silicon and is possibly due to the saw damage removal of the wafer by texturing [5].

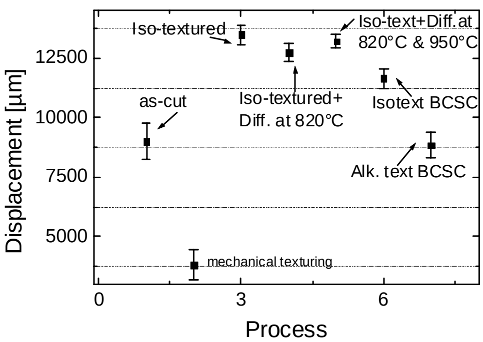

Figure 3: Wafer flexibility after various BCSC process steps.

It is not necessary that wafer thinning can not bring wafer stability and it is clear in the case of mechanically textured wafers. Here texturing causes a considerable amount of loss in silicon and reduces the fracture force and wafer flexibility. The dependence of wafer thickness and fracture force or wafer flexibility can be found in [6].

3.2 Optical properties

Figure 4 shows the optical transmission spectra of alkaline textured and isotropically textured wafers (wafer thickness for both types is 270 µm). In order to calculate the optical path length of isotropically textured silicon as compared to alkaline textured silicon, the absorption coefficient (α) was calculated from the transmission curve of an alkaline textured wafer and using the above α value a transmission curve is that exactly matches with the transmission curve of isotropically textured wafer. The fitted value shows that the optical path length of isotropically textured wafer (540 µm) is two times higher compared to alkaline etched silicon wafers.

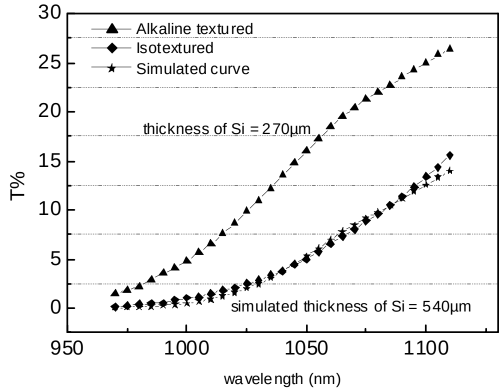

Figure 4: Optical transmission spectra of alkaline, isotropically textured (wafer thickness is 270 µm for both types) and simulated curve for silicon of thickness 540 µm (see text for details).

The optical reflectance of BCSC is shown in Figure 5. Considering the reflectance in the short wavelength range, the mechanically textured BCSCs have lowest reflectance and hence they could take advantage from the high energy photons. For this reason a higher short circuit current density could be expected from the mechanically textured BCSCs. While the alkaline textured BCSC has highest reflection losses in the short wavelength region the isotropically textured BCSCs have lower reflection losses.

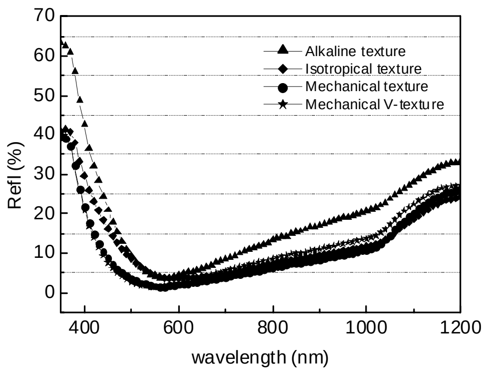

Figure 5: The reflectance variation of alkaline, mechanical and isotropically textured BCSC.

3.3 Electrical Properties

The best solar cell parameters of BCSC with four different kinds of texturing are indicated in Table I. The alkaline textured BCSC is taken as reference cell to asses the advantage of other texturing processes. As compared to the alkaline textured BCSC the isotropically textured cells have 1 mA/cm² absolute increase in short circuit current density. The mechanically textured BCSC have more than 1 mA/cm² absolute increase in short circuit current as compared to isotropically textured BCSC.

Texturing method	FF [%]	J_{sc} [mA/cm²]	V_{oc} [mV]	Eta [%]
Alkaline	77.9	32.8	597.0	15.3
Isotropic	77.0	33.9	582.6	15.2
Mechanical – Dicing wheel	77.5	35.3	587.8	16.1
Mechanical – Single blade	76.4	35.2	588.3	15.8

Table I: Comparison of cell parameters of textured BCSC.

The higher current density in mechanically textured wafer is mainly arising due to the increased light trapping in short wavelength range. As compared to mechanically textured BCSC the isotropically textured BCSC has slight reduction in short circuit current density. This could be explained due to the slight reduction in light trapping in the short wavelength range. The same explanation suits in the case of alkaline textured BCSC as well. Relatively higher open circuit voltage of alkaline textured BCSC could be due to lower dark current in comparison with isotropically textured and mechanically textured BCSC.

4 SUMMARY AND CONCLUSION

The flexibility of as cut wafers increases after isotropical texturing. The wafer fracture force is significantly increased after isotropical texturing. Increased strength of wafers is maintained and throughout the BCSC process. The reflection losses are lower for mechanically textured wafers in the short wavelength range and for isotropically textured wafers it is lower in the long wavelength range. The short circuit current density of mechanically textured wafers is found to be higher as compared to other texturing methods. The wafer stability of dicing wheel textured wafers could be increased by applying mechanical polishing of the edges. In order to combine the benefits of isotropical texturing and mechanical texturing a combination of isotropical and mechanical texturing of wafers could improve the performance and stability of dicing wheel textured wafers. This is a topic for future analysis.

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