Progress in machine and tool development towards the implementation of the mechanical texturization in a cr Si solar cell production line

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Abstract: New concepts for an industrial texturing machine are presented and a summary of possible applications for mechanical cell treatments in the field of solar cell processing is given. The reduced reflection and improved IQE of mechanically V-textured solar cells due to a better carrier collection leads to an increase in the short circuit current resulting in an efficiency gain. If the enhanced IQE adds the dominantly benefit, the groove angle as well as the V-texture tip radius do not have to be small. Therefore, the production of structuring tools would be easier. If the reduced reflection is the key effect, profiles with small angles and tip radius would be preferred. To optimise the texturization tool design for industrial applications, tools with different profiles have been prepared varying the V-texture angle as well ad the tip radius. Solar cells have been processed with different surface texture. Reflectance, short circuit current as well as IQE measurements are compared.
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1 Introduction

Photovoltaic production capacity will rapidly increase in the next decade and therefore high efficiencies at a high throughput in a production line is needed. A collaboration has been established between the University of Konstanz and Solarex in order to evaluate and adapt the mechanical texturization technique for a possible implementation in a multicrystalline silicon solar cell production line.

The efficiency gain of mechanically V - textured solar cells is based on the reduced reflection and better carrier collection properties. This has been shown on a laboratory scale in several publications. [1], [2]. Up to 17.2% efficiency on screenprinted multicrystalline silicon solar cells was reached by Sharp [3], whereas 16.5% has been obtained in a collaboration between the University of Konstanz and IMEC [4]. Using the buried contact approach for cell metallization 15.8% were reached by Solarex [5].

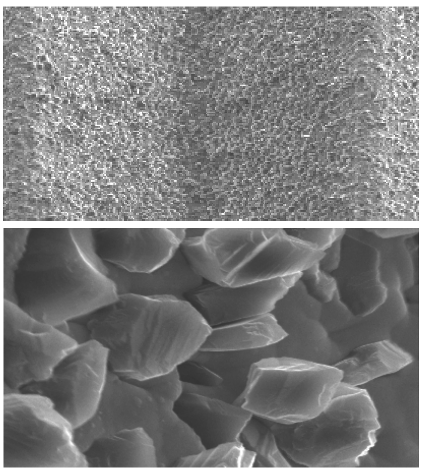

Figure 1: Electron micrographs of the abrasive layer on a texturing wheel. Clearly visible are diamond grains bound in a nickel matrix.

Within these highly efficient solar cells the wafers were textured by using a bevelled dicing blade on a conventional dicing machine. At the University of Konstanz, a mechanical texturing process using a texturing wheel is being developed [6]. The wheel consists of a metal body, which is provided with the desired profile and subsequently covered with a nickel-diamond based abrasive layer (Fig. 1).

Using such a tool complete texturization of a wafer in less than 3 seconds is possible. With this throughput a production capacity of approximately 1200 cells/hour can be reached which is required for a modern multicrystalline silicon solar cell production line. For a wheel textured screenprinted solar cell a record efficiency of 16% has recently been reached by IMEC [4].

2 Application and machine concept

For a high throughput texturing machine with a fast handling system a large number of applications in the field of solar cell processing are possible and under investigation in our institute:

- Surface texturing for efficiency enhancement of low cost multicrystalline silicon solar cells.
- Surface levelling for ribbon solar cells.
- Polishing of as-cut wafer surface to minimize defect etching time.
- Surface cleaning to reuse partly processed wafers.
- Surface texturing of substrates for thin film solar cells.
- Hole formation for electrical interconnection of solar cell front and rear side (back contact emitter wrapped through cell, semitransparent POWER cell, bifacial solar cells).
- Buried contact groove formation.
- Parasitic edge removal as an alternative for dry plasma etching.

First of all there is the well known mechanical texturization of the wafer surface to lower the reflection and enhance the IQE of low cost multicrystalline solar cells. Another application is especially interesting for ribbon silicon material as this often exhibits an uneven surface which should be levelled for easier processing. This can be done by using an untextured levelling or polishing tool. Also standard wire sawn silicon wafers could be polished by using tools with small diamond grains in the abrasive layer. The usage of such finely grained tools has the benefit of a strongly reduced subsurface damage as compared to wire-sawn surface of as-cut wafers. This can lead to a reduction of the duration and chemicals consumption of the initial defect etching step by a factor of 2. Furthermore, latest generation inline wet chemical etching systems would benefit from this fact. Within such systems the etching time at a given temperature is somewhat limited by the maximum tolerable length of the bath. The front side damage is less than 3 µm using one of our current wheels and can be further reduced. First experiments indicate that the wire saw induced damage on the back side might not influence the cell parameter in the case of using Al paste for the back side screen printed contact. The aim of this development is to be able to skip the wet etching step completely. Texturing or polishing wheels can also be used to remove electrical circuits from microelectronic wafers or contacts from old solar cells to reuse the wafer.

Microstructuring tools, currently under development at the University of Konstanz, (texture dimension <10µm) can be applied to texture substrates for thin film silicon solar cells and the thin film itself.

Holes in a silicon wafer can be obtained by the introduction of perpendicularly intersecting grooves at the front and rear side of a silicon wafer. Holes in solar cells give the possibility of new cell concepts like the back contact emitter wrapped through cell [7], the semitransparent POWER cell and bifacial solar cells [8]. Till now this simple mechanical method is the fastest method to form holes in a silicon wafer with hole generation rates of up to 100000 holes per second. As a comparison the fastest Q-switched industrial lasers can reach at best a hole generation rate of 5000 holes per second.

A further application for a mechanical texturing machine with fast handling is the contact groove formation of buried contact solar cells. The required shallow grooves (width: <25µm) can simply be cut with dicing blades. If multiple dicing blades are mounted on one flange, all grooves for a buried contact cell can be cut in one step [9]. In a tool wear experiment we found that the lifetime of a 15µm thin dicing blade was above 100,000 cuts on 12.5 cm wide SiN coated wafers at a scanning velocity of 100 mm/s.

Finally the high operational costs, limited fill factor performance especially on multi Si and the incompatibility with an inline process line of dry plasma etching stations for parasitic pn junction edge removal can be avoided by applying a mechanical alternative. It is based on the introduction of cuts at the diffused wafer periphery to separate the solar cell emitter of the front side with the p-base contact at the rear side. This mechanical approach can also be used in the underlying context to realise unconventional cell sizes and shapes.

In order to obtain the required high throughput, high scanning velocities have to be applied. Using texturing wheels scanning velocities of more than 100 mm/s are possible. Additionally a fast handling system is needed. For this application an in-line handling system can be used. The wafer are continuously loaded in front of the spindle, fixed during the texturization and unloaded after having passed the spindle.

The first tool generation was 25 mm long with typical V-texture tip radius of 90 µm and 52 mm in diameter. By optimising tool production a tip radius below 35 µm could be reached. On a new machine with a more powerful spindle it was possible to use 65 mm long tools which are 75 mm in diameter. First prototypes of 130 mm length are under preparation to find out the best method for the manufacturing of large quantities of tools. For tools of this size a more powerful and stiffer spindle than the ones in conventional dicing machines has to be used. A specially adapted machine with automated in-line handling system is currently under development and will be on the market in 1999.

3 Profile study

Various prototype structuring tools have been developed with different tool geometry. Some investigated texture profiles exhibit plateaus for the screen printed finger contacts, on others the fingers are printed directly in the groove. Printing on a plateau brings the advantage of an easier alignment of the finger in V-texture direction. This helps to avoid fingerinterruptions when the contacts cross the V-texture. Furthermore for large groove angles the fingers do not smear out like it can be seen in Fig. 4. Finally the optimisation of the screen printing and firing process step is less critical [4].

On neighbouring multicrystalline wafers, solar cells with different surface profiles were processed by using a PECVD SiN firing-through process. For texturization the wheel and single blade technique was applied to reach a wide range of profiles (Figs. 2-5). In the following discussion alkaline defect etched cells, which also show a clear increase in short circuit current by encapsulation, serve as reference. These samples are referred to as „untextured“ although they exhibit of a surface texture during the alkaline defect etching step.

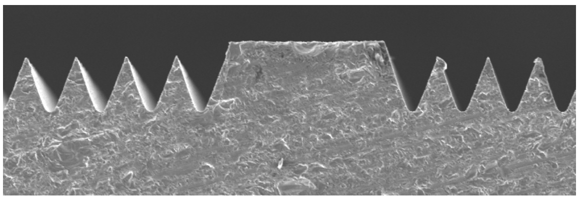

Figure 2: Profile 1, 35° angle with 220 µm wide plateaus

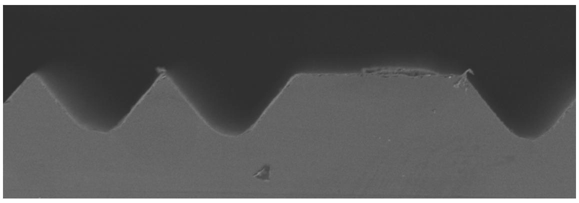

Figure 3: Profile 2, 75° angle, 220 µm wide plateau for screenprinted fingers. The contact finger is hardly visible

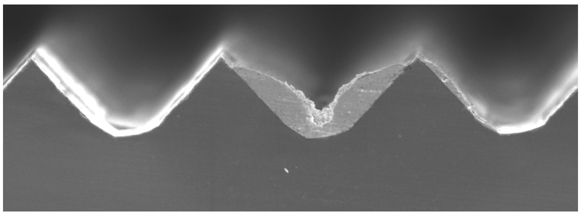

Figure 4: Profile 3, 80° angle, no plateau, screenprinted finger in the groove.

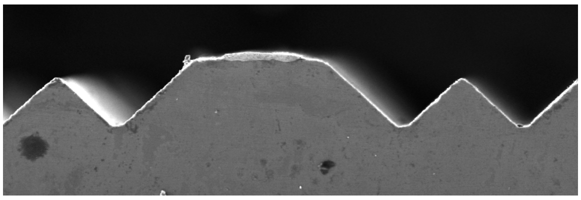

Figure 5: Profile 4, 90° angle with 220 µm wide plateau

As a first step of characterisation the reflectance without encapsulation has been measured. As the reflectance of alkaline defect etched multicrystalline cells varies for different grain orientations, measurements were taken on different crystallites. The average reflectance is shown in Fig. 6. As expected the profiles with a smaller groove angle exhibit the lowest reflectance. The higher reflectance of the profile 3 compared with profile 2 can be explained by smeared out screenprinted fingers and therefore a higher reflectance of the contact grid.

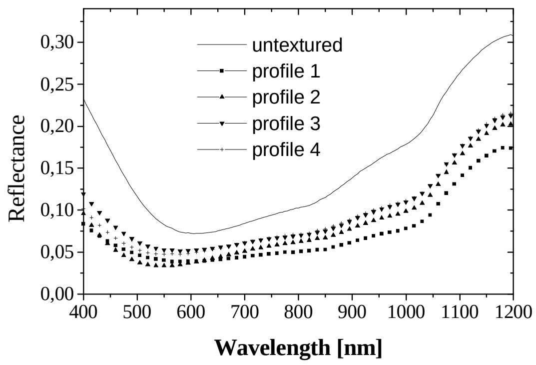

Figure 6: Measured hemispherical reflectance without encapsulation. The profiles with smaller groove angle show the lowest reflectance.

As a next step the short circuit current was measured under 100 mW/cm² AM 1.5 spectrum. To estimate the performance of encapsulated cells, the IV measurement is repeated, while isopropanol was poured onto the cell surface (Tab. 1).

The cells textured with profile 1 which exhibits the smallest groove angle and lowest reflectance give the largest increase in short circuit current with respect to the alkaline defect etched ("untextured") cell before encapsulation. But this effect is reduced after encapsulation. For profile 1, the J_{sc} increase after encapsulation is much less than before encapsulation. However for the larger angle of profile 3 (Fig. 4) and profile 4 (Fig. 5) the benefit in J_{sc} after encapsulation as compared to untextured references is higher than before encapsulation. But for cells with these large angle profiles the gain in J_{sc} is lower than for cells textured with the small angle profile. This data show that the increase of the short circuit current density J_{sc} is strongly dependent on the texture angle. Compared with previous studies the overall gain is lower, which could be due to more advantageous surface texture of the alkaline etched reference cells or the non optimal approximation of the encapsulation by measuring the cells with isopropanol on surface. [6]

Table 1: Measured short circuit current density without encapsulation and with isopropanol on the cell surface to approximate an encapsulation. The increase in short circuit current refers to alkaline defect etched ("untextured") cells.

Surface	J_{sc} before encaps. [mA/cm²]	increase [%]	encapsulated (isopropanol) J_{sc} [mA/cm²]	increase [%]
untextured	27.8	-	29.5	-
Profile 1	30.7	9.4	31.1	5.1
Profile 2	29.2	5.0	30.6	3.7
Profile 3	28.5	2.5	30.3	2.6
Profile 4	28.1	1.1	29.9	1.4

Beside a lower reflectance an enhanced IQE for mechanically textured cells can be observed. Due to the macroscopic texture carriers which are generated in the bulk near the grooves can be collected more effectively at the emitter surface. Therefore the collection probability of macroscopically textured solar cells is higher than for untextured ones. This effect increases in the long wavelength IQE and is especially visible for material with a low diffusion length. An effect of better light trapping for long wavelength photons is usually not significant for low cost solar cells.

On multicrystalline material, the diffusion length varies with different grains. To see an effect on the IQE, several grains have to be measured. This method leads to the problem, that the spectral response has to be measured on the same grain as the reflectance. In Fig. 7 a measurement on a grain with a long diffusion length well above 250 µm is shown. All cells show the same curve shape and no difference between textured and untextured cells can be found.

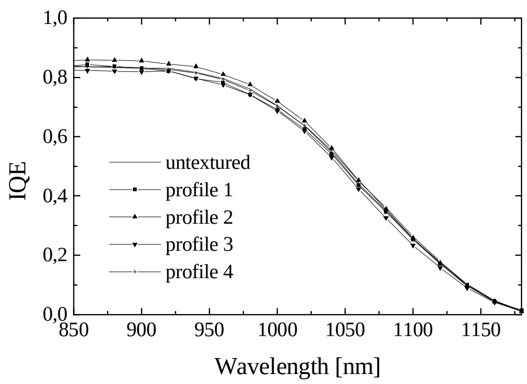

Figure 7: Long wavelength IQE of a grain with high diffusion length, the IQE of all cells is nearly the same.

Fig. 8 shows the long wavelength IQE measured on a grain with a lower diffusion length. Here one can see a variation of the curve shapes. The fact that all textured cells exhibit higher IQE indicates that this is an effect of the better collection properties due to the macroscopic texture.

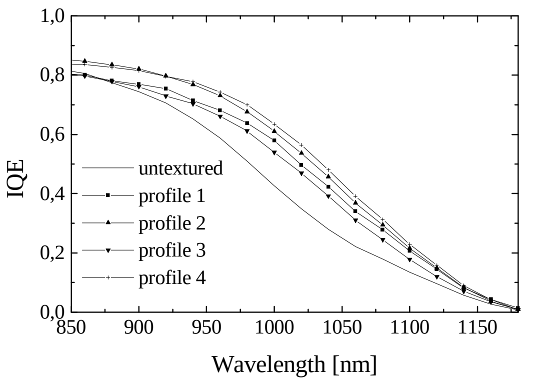

Figure 8: Long wavelength IQE of a grain with poor diffusion length. The untextured cell exhibits the poorest shape which indicates the effect of the texture.

4 Conclusion

In this paper recent progress on machine and tool development was described showing a wide range of applications of the mechanical abrasion technology in the field of solar cell processing. A texturing machine with a fast in-line handling is under construction and will be on the market in 1999. With this machine a throughput of 1200 wafer/h can be reached. On the laboratory level record efficiencies of 16.5 % (confirmed by Fraunhofer ISE) and 16 % were recently reached by IMEC [4] on multicrystalline solar cells textured at the University of Konstanz with the single blade and wheel method respectively. To simplify the implementation of the mechanical texturization in an industrial environment and to avoid the smearing out of screenprinted fingers, profiles with plateaus have been developed. An increase in short circuit current due to mechanical texturization of 9.4 % relative compared to alkaline defect etched reference cells was reached before encapsulation. Approximating cell encapsulation by isopropanol poured on cell surface during the measurement the gain is 5.1%. Structuring tools with small V-texture angle enable a higher short circuit current gain but are more difficult to manufacture.

The effect of an IQE enhancement can only be seen on grains with comparatively low diffusion length. For multicrystalline cc material with good starting quality most grains exhibit high diffusion lengths after a PECVD SiN firing through process. This indicates that for high quality multicrystalline material the key effect for current gain of mechanically textured solar cells is the reduced reflection.

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