MECHANICAL MICROTEXTURIZATION FOR MULTICRYSTALLINE SI SOLAR CELLS

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ABSTRACT: One major concern of the silicon solar cell industry is an efficient surface texturisation technology for multicrystalline and ribbon silicon. Therefore, the University of Konstanz (UKN) started developing a mechanical texturisation technique in 1991 which is now ready for implementation in a production line. A fully automatic texturing system is commercially available and first tests show good performance. Efficiencies up to 15.6 %. on mechanically V – textured multicrystalline silicon solar cells have been reached applying a PECVD SiN firing through process developed at UKN.
As some manufacturers want to use thinner wafers (e.g. ≤ 200µm), we have developed a new tool generation and are now able to create a texture in the range of a few microns. Applying this texture the cell has a more homogeneous appearance, a higher current and the etching duration can be reduced as compared to as cut samples. Manufacturing of first microtextured screen printed multicrystalline silicon solar cells leads to a current gain of 2.5% relative.
Keywords: Texturisation - 1: Multi-Crystalline - 2; Screen Printing –3

1 TEXTURISATION OF MULTICRYSTALLINE SI SOLAR CELLS

There are three different kinds of texturisation techniques for multicrystalline silicon solar cells which are currently under investigation for implementation in a production line:

- Reactive ion etching,
- Acid texturisation,
- Mechanical texturisation.

Reactive ion etching creates a needle-like surface, on which screen printing is difficult, but this problem can be overcome by an additional wet chemical etching step [1]. However, the additional alkaline etching step brings the disadvantage of a reduced gain in reflectance. Acid texturisation based on HF and HNO_3 increases chemical waste in production and temperature as well as composition has to be controlled [2]. At University of Kontanz we focussed our work on mechanical texturisation. A new system with automated handling designed for mechanical texturisation is now available [3].

2 MECHANICAL TEXTURING SYSTEM

For a mechanical texturing system the following applications in the field of solar cell processing are possible and under investigation at our institute:

- Surface texturing for efficiency enhancement of low cost multicrystalline silicon solar cells,
- Surface levelling for ribbon silicon solar cells [4],
- Polishing of as-cut wafer surfaces to minimise 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) [5,6],
- Buried contact groove formation [7],
- Parasitic junction isolation as an alternative to dry plasma etching.

Our in house machine, which was developed and manufactured by DISCO Corp. Japan, is capable of handling up to 15 x 15 cm² wafer from stack to cassette or cassette to cassette. Belt to belt handling is available on request. To ensure a high operation reliability bernoulli pads or vacuum pick up arms are used depending on the task. Each handling step is being monitored by sensors to detect a broken wafer or a handling malfunction immediately and avoid damaging of succeeding wafers.

For screen easy printing on a mechanical V-textured surface the contact fingers have to be parallel to the grooves. In the currently used texturing profile plateaus are left untextured for the fingers (see Fig. 1). As there is currently no optical alignment system available, which is able to detect the surface structure of a wafer automatically, the alignment before the texturing and printing step has to be made at a specified wafer edge. On our texturing system the wafer is aligned by pushers to ensure that the distance from the wafer edge to the first plateau is kept constant for all wafers.

Special effort has been undertaken to optimise the vacuum chuck, as insufficient wafer clamping was identified as reason for enhanced wafer breakage during texturing. Different designs based on steel and porous ceramic were tested. The best performance is reached with a steel chuck incorporating vacuum piping for wafer fixing and separate water and air blow piping for wafer release.

Tests aiming at an optimisation of the texturing process and the yield during cutting have been carried out showing a yield of 99% at pilot line level. If the wafer exhibits a wavy surface caused by imperfect wiresawing, a strong correlation between breakage and cutting direction could be observed. To investigate the mechanical and electrical yield large batches of mechanically textured solar wafers will be processed in a production environment within the EC ASCEMUS project.

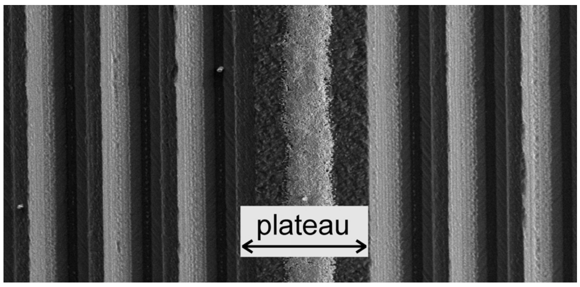

Fig 1: Screen printed finger on a 260 µm wide plateau.

3 PROCESSING OF MECHANICALLY V–TEXTURED SOLAR CELLS AT UKN

On multicrystalline silicon screen printed solar cells, the highest efficiencies have been reached applying mechanical single blade V-texturing [8,9]. Due to the macroscopic texturisation the carrier collection efficiency is higher in the V–tips. This has been shown theoretically by simulation and can be seen experimentally on LBIC measurements as described in Fig. 2 [4, 10]. Solar cells made of material with moderate diffusion length such as ribbon silicon benefit even more from the macroscopic mechanical texturisation than standard multicrystalline solar cells.

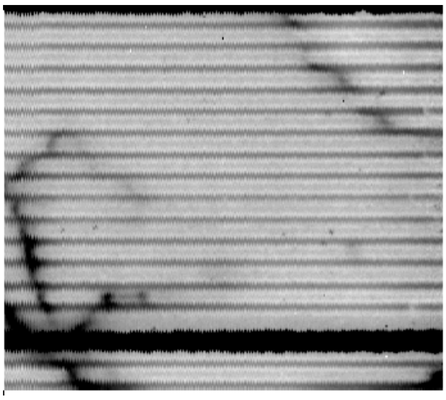

Fig 2: LBIC scan of an macroscopically textured industrial solar cell. The regions of high current generation are bright and low current generation dark. The higher current generation in the V-tips compared to the groove bottoms is clearly visible.

To reach a high throughput for industrial application of mechanical texturing a tool has been developed. The texturisation tool consists of a cylindrically profiled body coated with a diamond based abrasive layer. As body materials, brass, CuBe, ceramic and steel were investigated. Brass has the advantage of an easy profile formation, but is not hard enough for a production environment. As the lifetime of the abrasive layer is estimated to be well above 50,000 cuts, about 250 wafer will break during texturing assuming a yield of 99.5 %. The very hard silicon pieces which occur sometimes when a wafer breaks can damage a brass body. CuBe has a comparable hardness to steel, but is more difficult to manufacture and more expensive. Ceramics would be a ideal tool material, because it is very hard and resistant against deformation, but the needed fine profile for mechanical texturisation could not be created in a ceramic body. Therefore, steel is the state of the art tool material, as it exhibits a sufficient hardness and the needed profile can be formed (see Fig. 3).

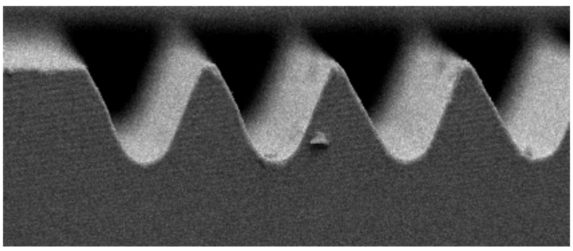

Fig. 3: Cutting profile of a steel tool. For the screen-printed contact a plateau is left untextured to ensure easy printing.

With the texture geometry shown in Fig. 3 an efficiency gain of 5% relative after encapsulation can be reached for multicrystalline solar cells.

4 SOLAR CELL PROCESS

For all solar cells presented in this paper the following industrial process was applied:
1. Mechanical texturisation (texturing tool),
2. Alkaline defect etching,
3. $POCl_3$ diffusion (35 Ω/□),
4. PECVD SiN deposition,
5. Isolation by dicing in the cell rear side,
6. Screen printed contacts (Ag front, Al rear).

The isolation by dicing in the rear side of the cell between edge and rear contact gives the same excellent results than completely cutting off the edge. Furthermore, the rear side emitter causes a higher current generation at the edge as can be seen with LBIC (see fig. 4) measurements and the cell area is kept constant.

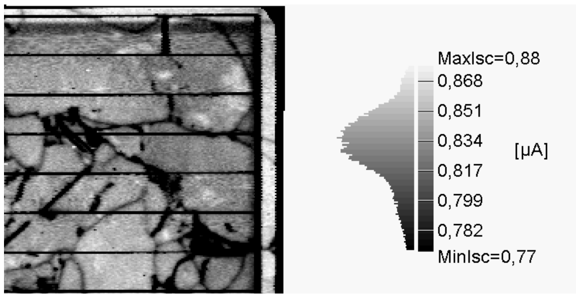

Fig 4: LBIC scan of an untextured solar cell Clearly visible is the higher current generation at the cell edge which is caused by the rear side emitter.

Applying this process, multicrystalline silicon solar cells have been manufactured using Baysix material (cell area: 100 cm², wafer starting thickness: 350 µm). The best cell results so far obtained are summarised in Table I.

Table I: Best cell results obtained on Baysix material (cell area: 100 cm², wafer starting thickness: 350 µm)

FF [%]	Jsc [mA/cm²]	Voc [mV]	η [%]	Texture
75.7	32.1	618	15.0	microtextured
76.9	32.9	615	15.6	V-textured (tool)

5 MECHANICAL MICROTEXTURING

To texture thin wafers (≤200 µm) the texture depths should be in the range of < 10 µm, which can be reached applying mechanical microtexturing, a new texturing method under development at the University of Konstanz. Although there is a kind of texturisation due to anisotropic etching behaviour of the alkaline etching solution (NaOH or KOH) in the following those wafers are referred to as "untextured".

As demonstrated by the mechanically V - textured solar cells, the microscopic textured solar cells exhibits a more homogeneous appearance, nearly like monocrystalline cells when encapsulated in a module. To calculate the maximum current gain due to reflection reduction, the IQE of an untextured cell was measured. The short circuit current was calculated using first the measured reflection of an encapsulated untextured cell with single ARC and than te reflection of an optimum textured encapsulated cell. The extracted maximum efficiency gain due to reflection reduction was about 3% for an encapsulated cell, which can be reached applying mechanical microtexturing, RIE or acid texturing, assuming that other cell parameters are constant. For macroscopic mechanical texturisation the gain can be 5% due to better carrier collection in the V-tips, which can be seen in the LBIC scan of Fig. 2.

Besides an efficiency gain and the more homogeneous optical appearance, the defect etching time can be shortened. The saw damage caused by microtexturing is lower than from wire saw wafering. As a consequence chemical waste can be reduced. Additionally, all wafers have a specific thickness after mechanical texturing. Therefore, wafers having wedge like thickness variation as well as uneven ribbon material can be levelled. So in production problems with wafers of uneven surfaces can be avoided.

As a further development one could think of combining the mechanical treatment with the slurry cleaning process. Wafer could be textured by the wafer manufacturer directly after cutting from the ingot. In this case a guarantee of well defined wafer thickness could be given. An other application is the recycling of partly processed wafers. This will even become more important with growing production capacities as the number of unusable cells or removed cells from old or defect modules will also increase. With this technique the contacts or coatings on front or rear side can be removed and the wafer reprocessed.

6 MECHANICALLY MICROTEXTURED SOLAR CELLS

Adjacent wafer have been divided into ten groups of five cells. Six groups have been textured with a microtexturing tool and 4 groups are left as references (Group c1 – c4). The wafers are etched in an alkaline solution at 80°C by varying the time. The etching depth was measured by weighing the wafers before and after etching. The mechanical treatment causes a damaged region on the surface which is microcrystalline and exhibits a large number of defects. This layer is fastly removed by the etching solution as can be seen from the slope of the curve in Fig. 5.

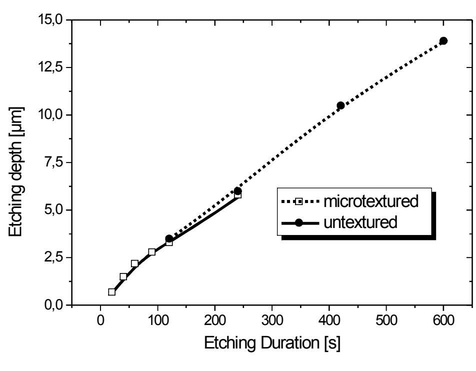

Fig 5.: Etching depth of the different groups. It can be seen, that the slope is higher for the first 50 s in which the highly damaged region is removed.

After processing applying the SiN firing through process the IV–curves are measured and open circuit voltage as well as short circuit current density are compared in Fig. 6 and 7.

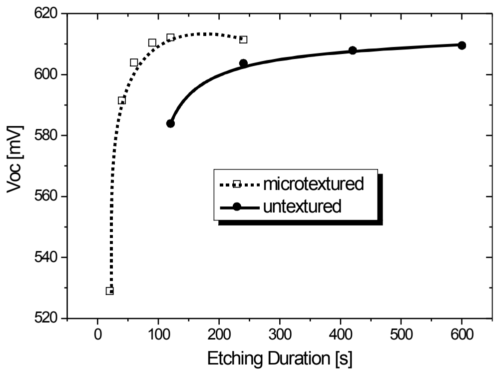

Fig. 6: Open circuit voltage V_{OC} [mV] of cells microtextured and untextured cells as a function of the etching time.

The saturation of open circuit voltage indicates the needed etching duration, because crystal defects lowerV_{OC}. The microtextured cells reach the same saturation level as untextured cells after 90s whereas the minimum etching duration for untextured cells is about 500s.

The microtextured cells show a clear increase in short circuit current density of about 2.5% related to the untextured reference group. It can be seen that there is an optimum etching duration between 90 s and 150 s. For longer etching duration the texture is flattened by the alkaline etching resulting in the observed decrease in the

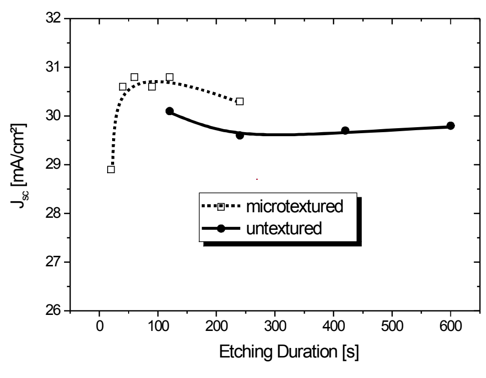

Fig. 7: Short circuit current density J_{sc} [mA/cm²] of microtextured and untextured cells as a function of the etching time.

current density. In case of the untextured cells first the current decreases down to a saturation level, which can be explained by the increase of the reflection when an as cut surface becomes more flat during etching.

7 COST CALCULATION

The texturing costs were analysed based of the experience with the full automatic system. Assuming a 3 shift production the costs are in the range of 0.05 to 0.10 Euro / wafer. The cost range is because yield and tool wear can only be roughly estimated. Experiments with very large batches of wafers are necessary to get reliable data.

Similar to the texturing costs the financial benefit per wafer can be calculated, as efficiency gain and module prices are well known. The financial benefit per watt peak B_{Wp} depends on the module price per watt peak P_{Wp} and the efficiency gain $\Delta\eta$:

$$B_{Wp} = P_{Wp} \cdot \frac{\Delta\eta}{100}$$

The benefit per wafer B_{Wafer} is additionally dependent on the cell area A the absolute efficiency η and the incident light power p:

$$B_{Wafer} = P_{Wp} \cdot \frac{\Delta\eta}{100} \cdot \frac{\eta}{100} \cdot p \cdot A$$

For example assuming typical values of:

module price	P_{Wp}	= 4.5 Euro/Wp,
cell efficiency	η	= 13%
efficiency gain	$\Delta\eta$	= 4% relative
cell area	A	= 156 cm²
incident light power	p	= 1000 W/m²

the financial benefit per wafer B_{Wp} is 0.36 Euro which is more than the expected costs. The further benefit of a reduced etching duration of mechanically texured wafers can be estimated to 0.02 to 0.03 Euro.

8 CONCLUSION

By texturing a multicrystalline solar cell a reduction in reflection is reached. This effect can result in an increase in short circuit current of maximum 3 % for industrial type multicrystalline solar cells if the other cell parameters are kept constant. First results of microtextured solar cells show an increase in short circuit currents of about 2.5 %. To reach a higher increase in efficiency a further parameter has to be improved. In the case of macroscopic mechanically textured solar cells the IQE is additionally enhanced because the carrier collection probability in the V-tips is higher than on untextured cells. As a result an efficiency gain of 5 % relative can be reached.

Additionally to the efficiency gain of microtextured solar cells the etching duration can be shortened resulting in a reduction of chemical waste. Furthermore, mechanically textured multicrystalline solar cells have a more homogeneous optical appearance, which is needed to meet the requirements of some customers e.g. for applications in facades.

9 OUTLOOK

The tools of the mechanical microtexturing process will be further optimised and the encapsulated gain investigated. Additionally tests will be carried out to combine the microscopic mechanical texturisation with the slurry cleaning process after cutting the ingot into wafer. Regarding the macroscopic V-texturing the tool wear will be further analysed and large batches will be processed in an industrial production line aiming to investigate yield and efficiency distribution.

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REFERENCES

[1] A. R. Burgers, C.J.J. Tool, J.D. Hylton, A.W. Weeber, A. G. B. J. Verholen, J.G.E. Gardeniers, M. J. de Boer, M. C. Elwenspoek,. Proc. 2nd WPVSC, pp 1531 FF.

[2] R. Einhaus, E Vaszonyi, F. Duerincks, J. Horzel, E. Van Kerschaver, J. Szlufcik, J. Nijs, R. Mertens,. Proc. 2nd WPVSC, pp 1630 FF.

[3] P.Fath, N. Ohmia, R. Busch, G. Willeke, K.H. Priewasser, H. Shiomi, E. Bucher. Presentation at 11th PVSEC, Sapporo 1999.

[4] G. Hahn, C. Zechner, M. Spiegel, W. Jooss, P. Fath, G. Willeke, E. Bucher, Proc. 2nd WPVSC, pp 1840 FF

[5] R. Kühn, A. Boueke, M. Wibral, P. Fath, G. Willeke, E. Bucher, Proc. 2nd WPVSC, pp 2415 FF

[6] A. Kress, P. Fath, G. Willeke, E. Bucher, Proc. 2nd WPVSC, pp 1547 FF

[7] R. Kühn, P. Fath, M. Spiegel, G. Willeke, E. Bucher, T.M. Bruton, N.B. Mason, R. Russel, Proc. 14th EUPVSEC 1997, pp 672 FF

[8] H. Nakaya, M. Nisida, Y. Takeda, S. Moriuchi, T. Tonegawa, T. Machida T. Nunoi, Sol. Energy Mater. Solar Cells 34, 219 (1994)

[9] F. Duerinckx, J Szlufcik, J. Nijs, R. Mertens, C. Gerhards, C. Marckmann, P. Fath, G. Willeke, Proc. 2nd WPVSC, pp 1248 FF

[10] C. Zechner, P. Fath, G. Willeke, E. Bucher, Sol. En. Mat. Sol. Cells 51, pp. 255-267, 1998