A SIMPLIFIED PROCESS FOR ISOTROPIC TEXTURING OF MC-SI

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ABSTRACT

Texturing of mc-Si wafers is an important field of research currently due to the increasing amount of mc-Si used by the PV industry. Different techniques are under investigation. One of the most promising techniques is isotropic etching with HF, HNO_3 and organic additives. We have found an etch consisting of only HF and HNO_3 that leads to comparable improvements in reflection and I-V characteristics, but is easier to handle and less critical during the etch process. The wafers can be etched horizontally compatible with existing in-line etch systems and the etch depth is only 5 µm from the as-cut wafer, which is beneficial for thin wafers. It is suitable not only for block-cast Si but with some adaptation also for EFG, SR, Tri-Si, and RGS. A relative efficiency gain of 7 % on cell level and 4.8 % with a 36 cell module has been reached.

1. INTRODUCTION

The share of mc-Si used by the PV industry is continuously increasing due to the lower material costs. There are two main disadvantages compared to CZ-Si: the effective bulk lifetime of the minority charge carriers is lower and the well known and widely used alkaline texture technique leading to random pyramids is largely ineffective due to the different grain orientations in mc-Si. Several texturing techniques are under investigation, but none have reached the status of mass production for standard screen printed solar cells. The mechanical texturing with a dicing saw for example is only used for the POWER (polycrystalline wafer engineering result) solar cell concept. Reactive ion etching is used at Kyocera Corp. in an extended pilot production and only the acid texturing developed by IMEC [1], [2] has been used on large batches of wafers. This method using HF, HNO_3 and some additives has shown its benefit for the solar cell efficiency, but on the other hand has several aspects which are difficult to control in mass production. Some of these problems do not occur or are easier to handle with our newly developed etching solution.

2. ETCHING SOLUTION

Compared to other acid etching solutions for Si which contain 3 or more components in addition to water, our solution consists of only 2 acids: HF and HNO_3.

This leads to the following advantages:

- very easy to mix
- lower cost of etch solution
- no organic chemicals; easier to dispose
- very little generated heat during preparation of etch solution

In addition the etching is carried out at temperatures below room temperature, which has the following benefits:

- little gas emission during etching and when the wafers are withdrawn
- little generated heat during etch process
- high stability of etch composition
- etch speed is easier to control
- less generation of toxic gases per unit time

The following advantages can not be assigned to a certain point, but are no less important:

- self limiting process; after saw damage is removed almost no further etching
- wafers may be etched horizontally; in-line system compatible
- suitable for cast mc; for EFG, SR, Tri-Si, RGS after adaptation
- small etching depth is sufficient; important for thin wafers and reduced etch time

At the moment the etching is carried out in a bath with approximately 12 l of etch solution. One carrier at a time, holding up to 20 wafers, is placed horizontally and the etching time is in the range of 3-5 min, which corresponds to an etching depth of about 5 µm. The etch bath stands in a larger ice-cooled bath, which allows etching temperatures below room temperature. For this 12 l etch solution more than 500 wafers have been etched without replenishment of chemicals and only a slight decrease in etch speed. First experiments in an in-line etching system have already been carried out. A special prototype system is scheduled.

3. OPTIMISATION OF REFLECTION

Starting with etch solutions containing 3 or 4 chemicals we reached very low mean reflectivity of the Si wafers below 10 % (see Fig. 1). This is due to a porous silicon (por-Si) layer on top of the macrotexturisation. The wafers with macrotexturisation only have mean values of reflection in the range of 23-25 % (in the range of 400 – 1100 nm), which is comparable with the results from IMEC. The processed solar cells with por-Si showed the lowest J_{sc} values despite having the lowest reflection (see Tab. 1). Therefore we conclude that the thin por-Si layer is absorbing and now this layer is removed with a short dip in a low concentration NaOH solution at room temperature. In the following we succeeded in using only HF and HNO_3 with no increase in reflection and, in addition, with easier etch conditions, as mentioned above.

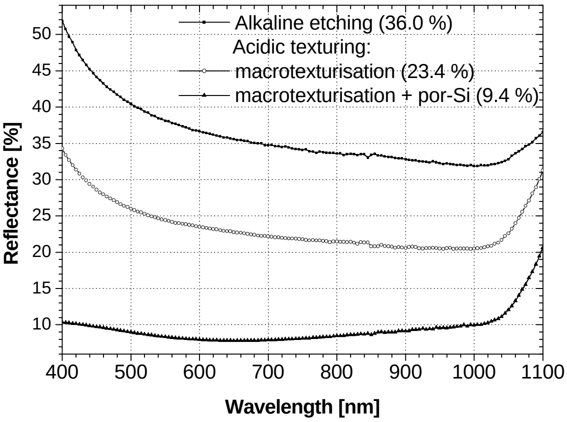

Fig 1: Reflectance curves and mean values of differently etched neighbouring mc-Si wafers. There is a large improvement with macrotexturisation. With macrotexturisation and porous silicon mean reflectance values of below 10 % have been reached.

Table 1: First solar cell results (10×10 cm²) for the textured wafers shown above. Despite the very low reflectance of the wafers with por-Si they have the lowest J_{sc} and V_{oc}.

	J_{sc} [mA/cm²]	V_{oc} [mV]
Alkaline etching	30.8	617
Macrotexturisation	31.7	608
Macrotexturisation + por-Si	26.1	590

4. OPTIMISATION FOR SOLAR CELLS

Using this 2 component etching solution we optimized several etch parameters including composition, temperature and time. The etch time has a large influence on the solar cell performance because if the saw damage is not removed totally, a layer with crystal defects remains, which lowers V_{oc} and J_{sc} (see Fig. 2, 3). If the etch time is too long, the dimension of the texture becomes too large. This causes an increase of reflection (decrease in J_{sc}) and a large increase of surface area (decrease in V_{oc}). Both effects have an optimum at nearly equal etching depths of 4–5 µm, resulting consequently in an optimum for the efficiency at the same point (see Fig. 4).

V_{oc} is still a little lower than for alkaline etched wafers, but we have narrowed this gap to a value below 2 mV (see Tab. 2). This gap in V_{oc} is due to the larger surface area which increases J_{02}. The surface enlargement is proportional to the structure height, which does not have to be very high for good reflectance. The height difference between the highest and lowest areas is in the range of 5 µm (see Fig. 5). This is advantageous for screen printing, because there are no etch steps. The height topography was calculated by a special software tool from two SEM pictures taken at different angles.

For the fill factor we even reached a higher level for the textured cells compared to NaOH etched cells because of an enlarged contact area between metalpaste and silicon.

R_s has been improved by firing optimisations for the textured wafers.

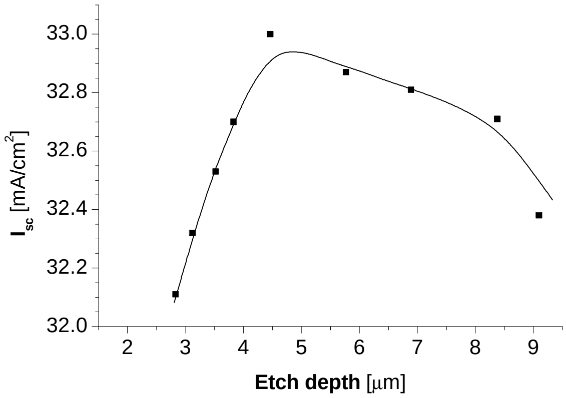

Fig 2: J_{sc} resulting from different etch depths using our acidic texturing solution.

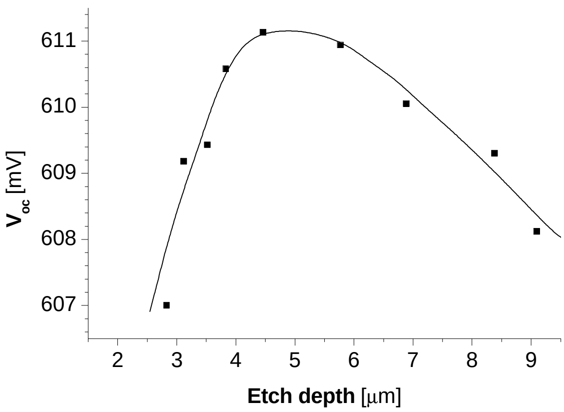

Fig 3: V_{oc} resulting from different etch depths using our acidic texturing solution

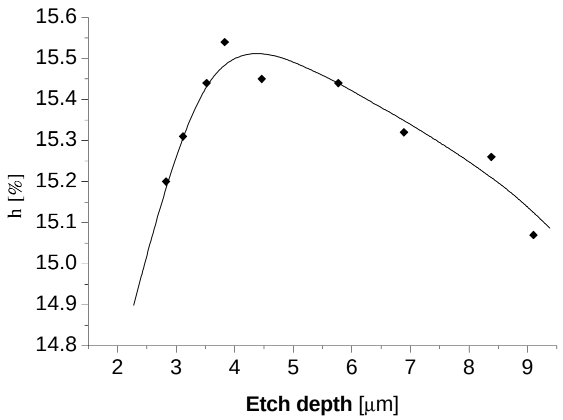

Fig 4: Cell efficiency resulting from different etch depths using our acidic texturing solution

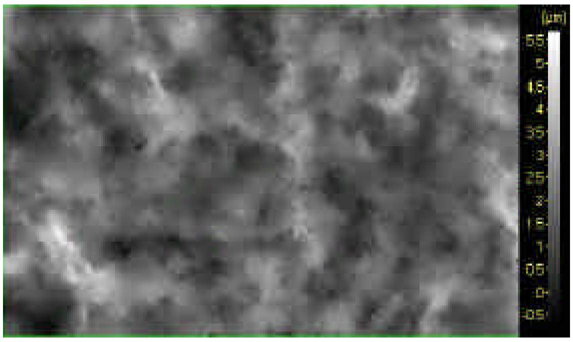

Fig 5: Height topography of an isotropic textured wafer area of app. 60×30 µm². The 3 dimensional surface was calculated from 2 electron microscope images taken at different angles.

5. GAIN UNDER ENCAPSULATION

After a large improvement on cell level compared to NaOH etched wafers has been reached, the gain through the texturing compared to alkaline etched wafers should be shown under encapsulation. Therefore a batch of 100 neighboring mc-Si wafers 12.5x12.5 cm² was split into 2 exactly comparable groups. We took the bottom of a brick, therefore the results vary from wafer 1 to wafer 50 in each group, which can be seen by J_{sc} in Fig 6.

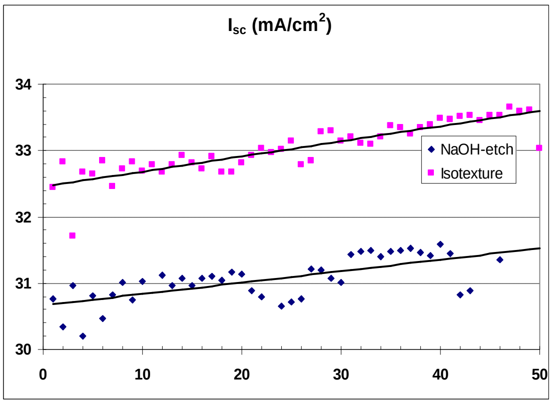

Fig 6: J_{sc} of neighbouring isotextured and alkaline etched wafers. The gain due to the texture is in the range of 2 mA/cm².

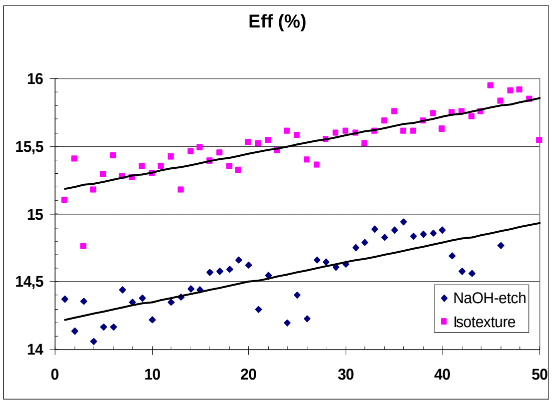

Fig 7: Efficiency of neighbouring isotextured and alkaline etched wafers. The gain due to the texture is in the range of 1 % absolute.

An increase for V_{oc} from wafer 1 to 50 was also observable; therefore we conclude that not only the doping, but also the lifetime varies. That is not beneficial to get good module results. With more homogeneous wafers the output power of the modules could have been higher than presented later on.

After the etching our standard solar cell process was performed on the two batches which means: $POCl_3$ diffusion (55 O/sq), edge isolation by plasma etching, PSG removal, PECVD-SiN deposition, screen print of front and back contacts and fire in an IR-furnace. The results of the I-V measurements show, that there is large improvement for each pair of wafers due to the texture (see Fig. 6, 7).

From these 2 groups the 36 best cells of each were taken to make modules and determine the gain of the texturing under encapsulation. In Table 2 the mean values of the IV-characteristics can be seen. The best textured cell reached 16 % efficiency. The increase in efficiency of 1 % absolute means a gain of almost 7 % relative. This result has been confirmed by measuring 2 neighboring, mean cells of each group at Fraunhofer ISE CalLab (see Tab. 3)

Table 2: I-V characteristics of the best 36 cells from Fig. 6 & 7. There is an absolute gain of 2 mA/cm² in J_{SC} and 1 % in efficiency

	FF	**J_{sc}**	**V_{oc}**	**Eta**
	%	**mA/cm²**	**mV**	**%**
NaOH	76.3	31.2	615.9	14.6
Isotexture	76.6	33.2	614.1	15.6
Gain	0.3	**2.0**	-1.8	**1.0**

Table 3: I-V characteristics of 2 neighbouring solar cells measured at Fraunhofer ISE CalLab. There is a 0.9 % increase in efficiency due to the texturing.

	FF	**J_{sc}**	**V_{oc}**	**Eta**
	%	**mA/cm²**	**mV**	**%**
NaOH	75.9	31.44	615.4	14.7
Isotexture	77.1	32.96	613.4	15.6

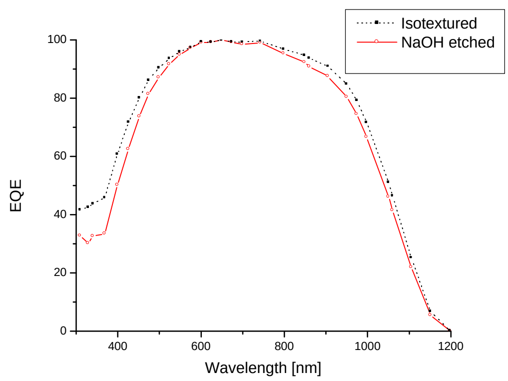

Fig 8: EQE of the 2 cells from Tab. 3 measured at Fraunhofer ISE CalLab.

BP Solar USA made 2 modules with these cells. In Fig. 8 the more homogeneous and dark appearance of the textured module compared to the standard module can be seen. The I-V measurements of these modules show that there is still a remarkable gain in both I_{sc} (4.2 %) and power (4.8 %) relative (see Tab. 4). Despite of the fact that the original material was of varying quality (see Fig. 6, 7), an output Power of 86.5 W has been reached for the textured module. This corresponds to a cell efficiency of 15.4 %, very close to the value of the unencapsulated cells (15.6 %).

After these optimizations a level has been reached which is at least comparable or even better than published by other groups. In 2001 a comparison between NaOH etched and isotextured cells on a similar batch size and with the same solar cell process has been presented. There was an increase in efficiency from 14.8 % up to 15.2 % due to the texture, which is 2.7 % relative [3].

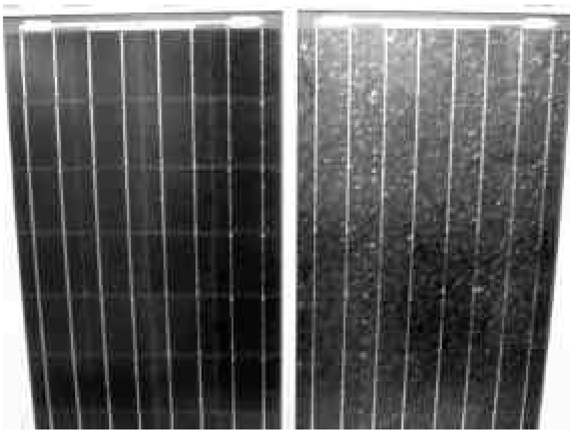

Fig 9: 36 cell modules made of neighbouring wafers.
Left: isotextured; 86.5 Watt
Right: NaOH etched. 82.5 Watt
4.8 % relative increase in efficiency

Table 4: I-V characteristics of the 2 modules shown in Fig. 9 and the calculated values of the cells.

MODULE	**FF**	**I_{SC}**	**V_{OC}**	**P**
	%	**A**	**V**	**W**
NaOH	74.5	4.98	22.2	82.5
Isotextured	75.0	5.19	22.4	86.5
CELL	**FF**	**J_{SC}**	**V_{OC}**	**Eta**
	%	**mA/cm²**	**mV**	**%**
NaOH	74.5	31.9	616.7	14.7
Isotextured	75.0	33.2	622.2	15.4
GAIN [%]	**0.6**	**4.2**	**0.9**	**4.8**

6. BURIED CONTACT SOLAR CELLS

In addition to the results on screen printed cells the process was applied to buried contact solar cells. With HEM material from BP Solar we reached a gain due to the isotexture of 1.2 % absolute in efficiency, resulting in a mean value of 15.8 % on a batch of 6 wafers. Due to problems during processing the mean FF is only 73.8 %. Nevertheless the best cell reached 16.2 % efficiency.

Table 5: Mean I-V values of buried contact solar cells (mc HEM material, 12.5x12.5 cm², 240 µm). The increase in efficiency is 1.2 % which is even higher than for screen printed cells.

BCSC	**No**	**FF**	**J_{SC}**	**V_{OC}**	**Eta**
		%	**mA/cm²**	**mV**	**%**
NaOH	4	72.8	33.1	605.9	14.6
Isotexture	6	73.8	34.9	614.3	15.8

7. SUMMARY

Etch conditions for the isotropic texturing of mc-Si have been developed resulting in a recipe containing only H_2O, HF and HNO_3 and nothing else. The omission of organic chemicals and “additives” has a lot of advantages for etch conditions, equipment design and disposal of chemicals. The resulting reflection on bare wafers is on the same level than published earlier by other groups and the gain we reached on cell level is even higher. For 2 comparable groups of 36 screen printed solar cells an increase in efficiency of 1 % absolute or 6.8 % relative was observed due to isotexturing compared to etching in NaOH. The modules made of these cells still show a gain of 4.8 % due to the texturing resulting in 86.5 W output power. This corresponds to a cell efficiency of 15.4 % which is a rather good value for the reason that the wafers showed a varying origin quality.

For buried contact solar cells even a more pronounced increase due to the texturing has been observed. On small batches of wafers (12.5x12.5 cm²) 14.6 % efficiency after NaOH etching have been reached compared to 15.8 % after isotropic texture.

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