DAMAGE REDUCTION OF THE LASER DRILLING PROCESS ON BACK CONTACT SOLAR CELLS BY CHEMICAL TREATMENT

Eneko Cereceda[1], Josu Barredo[2], José Rubén Gutiérrez[1], Juan Carlos Jimeno[1], Alberto Fraile[3] and Lutz Hermanns[3]
[1]Instituto de Tecnología Microelectrónica (TiM), University of the Basque Country UPV/EHU
Technological Park of Zamudio, Building 105, Zamudio, Spain
email: eneko.cereceda@ehu.es
[2]Centre for Modeling in Mechanical Engineering (CEMIM-F2I2), Madrid, Spain
[3]Department of Structural Mechanics and Industrial Constructions, UPM, Madrid, Spain

ABSTRACT: Production of back contact solar cells requires holes generations on the wafers to keep both positive and negative contacts on the back side of the cell. This drilling process weakens the wafer mechanically due to the presence of the holes and the damage introduced during the process as microcracks. In this study, several chemical processes have been applied to drilled wafers in order to eliminate or reduce the damage generated during this fabrication step. The treatments analyzed are the followings: alkaline etching during 1, 3 and 5 minutes, acid etching for 2 and 4 minutes and alkaline texturisation. To determine mechanical strength of the samples a common mechanical study has been carried out testing the samples by the Ring on Ring bending test and obtaining the stress state in the moment of failure by FE simulation. Finally the results obtained for each treatment were fitted to a three parameter Weibull distribution.
Keywords: Damage Reduction, Back Contact, Laser Processing, Etching, Texturisation

1 INTRODUCTION

Principal advantage of back contact solar cells like Emitter Wrap Through (EWT) and Metal Wrap Through (MWT) is that both positive and negative contacts are placed on the rear side of the wafer. This location of the contacts permits maximizing of the exposed surface to the light and an easier interconnecting of the cells in the module. To achieve this purpose it is necessary to create via holes to interconnect one of the contacts placed on the back side to the emitter that is placed in the front side of the wafer.

The generation of these via holes affects mechanical stability of the wafer in two ways. On the one hand the presence of a hole in a plate creates a stress concentration area around it when the plate is tensioned. On the other hand, the process of generation holes by laser induces additional damage as residual stress or microcracks on holes perimeter.

The reduction on mechanical strength increases the breakage ratio in the cell production line, therefore studies concerning the influence of the holes in the mechanical strength are more common [1-7].

The stress concentration around the holes is inherent in the hole. To reduce it, we can only make the holes as small as possible [4] and distance them to avoid overlapping of stress concentration areas. [5]

The damage generated during the laser drilling process can be reduced by chemical attacks. In previous works a NaOH based alkaline etching has been studied and its efficiency has been probed [6].

In this work, three different chemical procedures have been applied to drilled wafers in order to compare their ability to reduce the damage generated during laser drilling process. First recipe is a common alkaline etching process based on NaOH. The second one is an acid etching process based on nitric-hydrofluoric reaction. The last process is based on a common alkaline texturisation recipe.

2 PREPARATION OF SAMPLES

To carry out this study seven sets of monocrystalline silicon wafers are prepared. All the sets of wafers are processed in the same way with the only difference of the last chemical process after the creation of the holes.

First of all, the wafers are etched in a NaOH based chemical bath. This process removes 17.5µm per face with the aim of eliminating the damage induced during the wire-sawing of the ingot.

After this initial etching the wafers are laser drilled. The hole pattern has a density of 25 holes/cm^2 and the holes has a diameter of 50µm on the front side and 20µm on the rear side. With this pattern the minimal distance between holes is 2mm, far enough to avoid overlapping of stress concentration areas.

This process is performed with a Q-switched fiber laser from EOLITE Systems (France), which generates pulses of 10ns, working in 515nm wavelength at 234µJ peak energy.

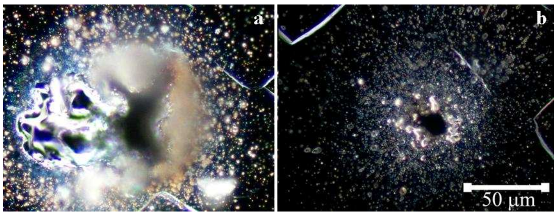

Figure 1: Hole on the front (a) and back (b) side of the wafer before chemical treatment.

The process over the first set of samples, named SET 0, is finished. This set will be used as reference to quantify the benefit that the different chemical treatments provide to the wafers. Fig.1 shows a hole appearance on the front and back side of the wafer just after drilling. It can be seen debris and rests of melted material on the surface of the wafer.

Sets 1, 2 and 3 are processed in an alkaline etching bath based on NaOH. The duration of the chemical process is different for each set; SET 1 is in the bath for 1 minute long, removing 1.7µm per face. Bath duration for

SET 2 is 3 minutes and the decreased thickness is 6.6µm per face. For SET 3, the duration of the bath is 5 minutes and 11.3µm per face is removed. Pictures in Fig. 2 show the final appearance of the holes after this process. In the pictures on the left side it can be seen that debris is eliminated with only a minute of processing. With longer processing times the anisotropy of this treatment is revealed.

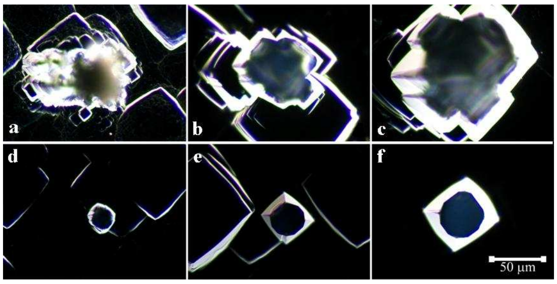

Figure 2: Holes on the front (a,b,c) and back (d,e,f) side of the samples after 1 minute (a,d), 3 minutes (b,e) and 5 minutes (c,f) of alkaline etching.

Sets 4 and 5 are etched in an acid-based etching bath. This isotropic etching is carried out by the solution consisting of hydrofluoric acid (HF) and nitric acid (HNO_3). Treatment durations are 2 minutes for SET 4 and 4 minutes for SET 5, removing 6.1µm and 9.1µm per face respectively. Results of this process can be seen in Fig. 3.

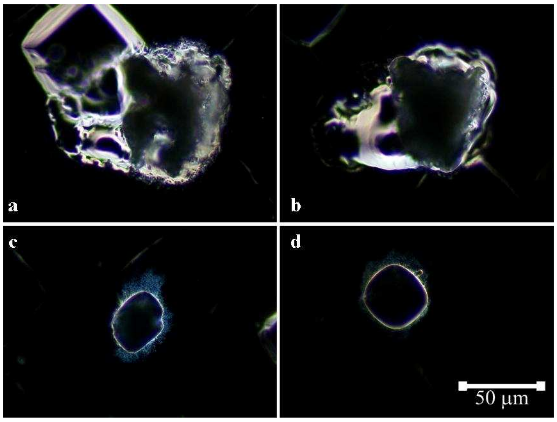

Figure 3: Holes appearance on the front (a,b) and back (c,d) side of the samples after 2 minutes (a,c) and 4 minutes (b,d) of acid etching.

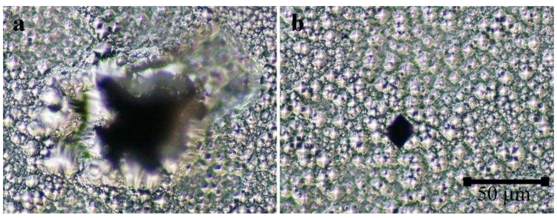

Figure 4: Holes appearance after 40 minutes of Texturisation on the front (a) and back (b) side of the sample.

Set number 6 is processed with a texturisation recipe during 40 minutes. This anisotropic treatment is very common in the industry to create a surface in the wafer covered by small pyramids. The decreased thickness with this treatment has a mean value of 6.3µm per face. Fig. 4 shows the hole appearance after this treatment. It also can be observed the result of texturisation on the surface of the wafer.

Table I summarized the chemical treatments on the different sets of samples after the laser drilling process.

Table I: Summary of the last process on each set

Set	Treatment	Bath Duration	Mean value of decreased thickness
0	None	0 min.	0 µm
1	Alk. etch	1 min.	1.7 µm
2	Alk. etch	3 min.	6.6 µm
3	Alk. etch	5 min.	11.3 µm
4	Acid etch	2 min.	6.1 µm
5	Acid etch.	4 min.	9.1 µm
6	Text.	40 min.	6.3 µm

Finally, all the wafers are cut by laser in order to get 9 samples of 34mm x 34mm from each wafer for mechanical testing. Figure 5 shows the final dimensions of the samples to be tested.

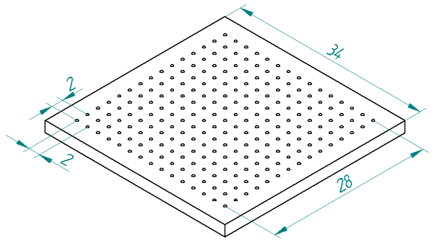

Figure 5: Dimensions of the samples (mm).

3 STRENGTH MEASUREMENT

3.1 Ring on Ring bending test

To evaluate the surface damage induced by the creation of the holes the Ring on Ring bending test is chosen. In this test, the wafer is supported on a 20mm diameter ring and a controlled load is applied by an upper ring of 10mm of diameter.

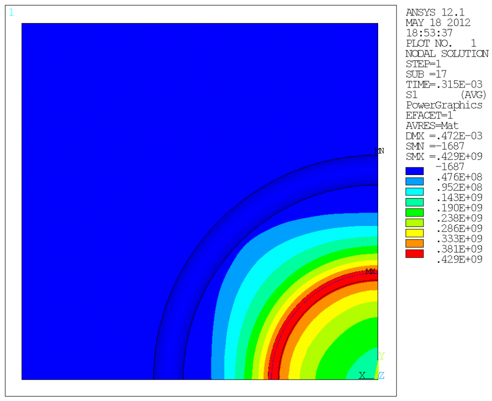

Figure 6: Stress distribution on a quarter of a sample under the Ring on Ring bending test

As it can be observed in Fig. 6, the stress distribution over the sample is much higher in the area inside the inner ring than in the outer part. Therefore, the Ring on Ring test is adequate for this study because the failure is caused by defects in the surface of the sample rather than in the edges.

From the Ring on Ring test we obtain information about the behavior of sample represented on a load-displacement curve (Fig. 7). However, we need to know the stress distribution in the sample before the failure. To this end, analytical methods are no valid due to the non linear behavior of the samples during the test. The large displacements and the contact between the samples and the rings are the reasons of this behavior.

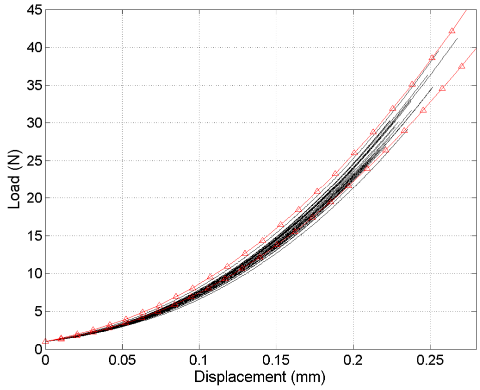

Figure 7: Test results (black lines) and FE simulation (red lines) of wafers of SET 1 (1 min. of alkaline etching)

3.2 Numerical model

In order to get to know the stress distribution in the wafer in the moment of failure a numerical model is needed to simulate the test. This model is developed with the Finite Element Method which makes possible to simulate the test considering the non linearities described above and including the special features of the material, i.e. the anisotropic behavior of crystalline silicon.

Wafer and supports are modeled with shell elements. The holes are not included in the models since their influence in the stiffness can be neglected [7] and the main target of the study is to compare the overall strength of each set more that the stress concentration around the holes. Therefore, two models without holes are developed for each set: one model corresponds to the thinnest sample and the other model corresponds to the thickest one. The fracture stress for the rest of the samples is obtained through a linear interpolation taking into account the elastic energy stored in the wafer before the failure and its thickness.

3.3 Statistical analysis of the measures

The silicon crystal is a brittle material so the fracture mechanics approaches are used to characterize its strength. It's usual to employ the Weibull distribution as the probabilistic model characterizing the failure of silicon wafers. The most general expression of the failure probability according to the Weibull model [8] is given in (1) where it's shown the failure probability of a sample subjected to a uniform stress:

$$P_f(\sigma) = 1 - \exp\left(-\int_A \left(\frac{\sigma-\lambda}{\delta}\right)^\beta dA\right) \qquad (1)$$

The material parameters have the following meaning: λ [MPa] is the location parameter representing a threshold stress, δ [MPa x (area)$^{1/\beta}$] is the scale parameter and β [dimensionless] is the shape parameter which gives information about the scattering of the samples. This function depends on the size of the loaded area and this dependence is known as the size effect. It takes into account that greater size of the sample implies lower strength values.

The probability of failure of an infinitesimal area ΔA under uni-axial and uniform tension (σ) is shown in (2).

$$\begin{aligned} P_{f,\Delta A}(\sigma) &= 1 - \exp\left(-\Delta A\left(\frac{\sigma-\lambda}{\delta}\right)^\beta\right) \\ &= 1 - \exp\left(-\left(\frac{\sigma-\lambda}{\delta_\theta}\right)^\beta\right) \end{aligned} \qquad (2)$$

$\delta_\theta = \delta\,(\Delta A)^{-1/\beta}$ is the scale parameter for the area ΔA. It has stress dimensions and the addition with the location parameter results in the characteristic fracture stress (σ_θ) at which 63.2% of all samples of area ΔA will fail.

As each test has its own stressed area, it's necessary to make a correction to obtain the failure probability of each test according to the material parameters. To this end, it's defined the equivalent area as the area subjected in a tensile test to the maximum stress observed in the sample in the moment of failure resulting in the same probability of failure (3).

$$A_{eq} = \int_{dA|\sigma>\lambda} \left(\frac{\sigma_i - \lambda}{\sigma_{\max} - \lambda}\right)^\beta dA \qquad (3)$$

As the Weibull model is based on the weakest link theory, the probability of failure of a sample of a material with parameters λ, δ_θ and β (referred to an infinitesimal area ΔA) defining its strength and subjected to a uni-axial stress field is:

$$P_{f,A}(\sigma) = 1 - \exp\left(-\frac{A_{eq}}{\Delta A}\left(\frac{\sigma-\lambda}{\delta_\theta}\right)^\beta\right) \qquad (4)$$

The calculation of the equivalent area of each test requires the knowledge of the Weibull parameters values. Therefore, it's necessary an iterative procedure [9] to fit the test results to the Weibull distribution.

Finally, in order to take into account the multi-axial stress field existing in the ring on ring test, the Principle of Independent Actions (PIA) has been applied in this study.

4 RESULTS

Results of the fitting for an infinitesimal area $\Delta A=20mm^2$ are shown in Fig. 8 and summarized in table II.

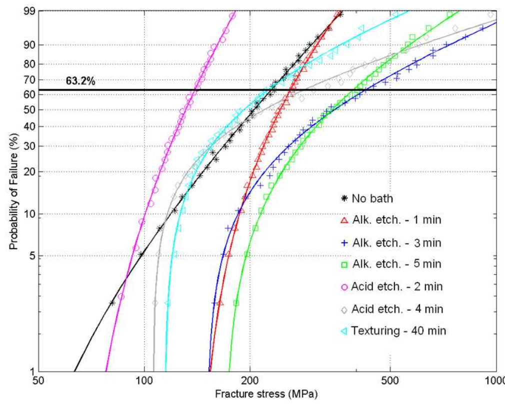

Figure 8: Weibull fitting of the 7 sets of wafers.

Table II: Parameters of Weibull fitting

Set	λ (MPa)	δ (Mpa)	β	σ_θ (MPa)
0	33.62	197.06	2.75	230.68
1	140.40	120.47	2.40	260.87
2	150.50	278.99	1.10	429.49
3	168.23	226.52	1.44	394.75
4	61.65	77.84	3.32	139.50
5	106.08	181.82	0.80	287.90
6	114.34	112.29	1.04	226.63

Looking at the characteristic fracture stress (σ_θ) we can say that the appropriate process to reduce the drilling damage is an alkaline etching. This etching can improve mechanical strength of the wafer up to 85%. The fact that characteristic fracture stress increases in shorter baths and then begins to fall in longer processes was seen in previous studies [6]. Acid etching shows not only no significant improvement of mechanical strength in long bath but also important deterioration for short treatments. Texturisation process does not present significant changes on characteristic fracture stress.

Regarding to the location parameter, set 0 (no bath) has the lowest value and alkaline etching has the highest values of the study. The possible reasons of these results are discussed below.

The shape parameter β gives information about the scattering of the samples. A smaller value of β implies a higher dispersion of the measurements. Higher values of β are shown on sets 0 and 4 (short acid etching), which also have lowest values of λ and σ_θ.

5 DISCUSSION

By a mechanical point of view it is clear that the best process to remove laser induced damage during the drilling process is the alkaline etching. Even if this process is very short, the improvement obtained is higher than with other treatments. Best improvement is obtained with a process time of 3 minutes.

The location parameter λ represents a threshold stress above which no fracture will occur. In this case, we could say that the dimensions of critical defects on set 0 are very large and an acid etching or a texturisation process doesn't reduce significantly this damage resulting in the lowest λ values. On the contrary an alkaline etching, even a shorter one, reduces dramatically the dimension of these critical defects.

Our impression is that those critical defects are the microcracks generated by the drilling process, and the alkaline etching has the ability of rounding the tips of these microcracks, avoiding their propagation.

Regarding to the dispersion of the measurements, lower dispersions are obtained in sets with lower location parameters. This shows that the failure of sets 0 (no bath) and set 4 (short acid etching) is clearly caused by the presence of cracks. Low dispersion is also show in set 1 (short alkaline etching) indicating that 1 minute of this treatment is not enough to repair completely the defects. Higher values of dispersions seen in longer alkaline etching sets, shows that damage is mostly eliminated and failure is caused by the structure of the samples.

6 AKNOWLEDGEMENTS

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