STUDY OF THE MECHANICAL STRENGTH IMPROVEMENT OF WAFERS FOR EWT SOLAR CELLS BY CHEMICAL ETCHING AFTER THE DRILLING PROCESS

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ABSTRACT: Mechanical stability of EWT solar cells deteriorates when holes are created in the wafer. Nevertheless, the chemical etching after the hole generation process improves the mechanical strength by removing part of the damage produced in the drilling process. Several sets of wafers with alkaline baths of different duration have been prepared. The mechanical strength has been measured by the ring on ring bending test and the failure stresses have been obtained through a FE simulation of the test. This paper shows the comparison of these groups of wafers in order to obtain an optimum value of the decreased thickness produced by the chemical etching.

Keywords: Mechanical strength, Back contact, Chemical etching

1 INTRODUCTION

Although the silicon shortage suffered last years has been overcome, solar cell companies have been forced to improve manipulation tools, develop less harmful processes and mount crack detection tools in the manufacturing line to remove damaged wafers from the process.

In comparison to conventional designs back contact cells ([1]) present some interesting properties for the photovoltaic industry. Nevertheless, their manufacturing processes are harmful in some of their steps causing a reduction in the wafer’s mechanical strength. In the last years, the studies about the influence of the holes on the mechanical strength of these wafers are becoming very popular. ([2], [3])

This study is focused on emitter wrap through (EWT) solar cells which present more holes and tinier ones than metal wrap through (MWT) solar cells. The presence of holes implies stress concentration and thus a reduction of wafer strength. Moreover, the laser drilling process generates surface damage around the holes which reduces even more the mechanical strength. The current tendency of manufacturing thinner wafers and cells will emphasize even more the role and importance of this damage with respect to the mechanical behaviour of solar cells.

The damage produced during the drilling process can be reduced by an alkaline bath decreasing the thickness of the wafer. Previous studies by the group have shown that a bath of two minutes increases more than 40% the strength of the wafers ([3]).

The main target of the paper is to evaluate the strength of wafers subjected to wet chemical etching procedures of different duration after the drilling process, trying to get an optimum from a mechanical point of view.

2 PREPARATION OF SAMPLES

In this work 5 groups of wafers with identical EWT structure than the ones of the previous study have been prepared. All samples are 52.5 mm x 52.5 mm mono-crystalline silicon wafers.

The hole pattern has a density of 100 holes/cm\textsuperscript{2} in which each hole has an average diameter of 50 \( \mu \text{m} \) in the front side and 30 \( \mu \text{m} \) in the back side. This distribution is shown in Figure 1.

![Figure 1: Holes size and distribution in a EWT structure.](image)

All the samples were subjected to a preliminary etching before the wafer drilling to remove any possible surface damage from wire-sawing. Then, they were drilled following the described EWT pattern. Finally, the wafers were etched again to remove part of the possible damage produced by the laser. This second bath is the object of study of this paper and its duration is the element which differences each set from the other ones.

The main characteristics of the groups of samples included in this study are shown in Table 1.

Table 1: Samples tested

<table>
<thead>
<tr>
<th>Set</th>
<th>Bath duration (min)</th>
<th>Mean value of thickness (( \mu \text{m} ))</th>
<th>Mean value of decreased thickness (( \mu \text{m} / \text{face} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0:00</td>
<td>195.8</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>1:45</td>
<td>187.5</td>
<td>4.8</td>
</tr>
<tr>
<td>3</td>
<td>2:40</td>
<td>182.6</td>
<td>7.3</td>
</tr>
<tr>
<td>4</td>
<td>3:30</td>
<td>174.7</td>
<td>9.4</td>
</tr>
<tr>
<td>5</td>
<td>4:25</td>
<td>173.0</td>
<td>11.8</td>
</tr>
</tbody>
</table>

3 RING ON RING TEST

In order to evaluate the surface damage, wafers were tested by means of the ring-on-ring bending test. In this test, the wafer is supported on a ring of 20 mm of diameter. The load is applied on the front side of the wafer by an upper ring of 10 mm of diameter. Figure 2 schematizes the test.
The stresses produced inside the lower ring are much higher than in the outer part. Therefore, the evaluation of the strength using this configuration neglects the influence of edge cracks of the wafers but takes into account any surface damage like the holes or the effect of the drilling process.

The force transducer has a range of 0-200 N. The displacement of the top ring is imposed and both the force and the displacement are recorded. The velocity employed is 0.2 mm/min. This value has been chosen to get a quasi-static test. In order to avoid buckling, adequate dimensions of the samples and the rings have been chosen. A photograph of one test just after the failure of a wafer is shown in Figure 3.

The test provides the displacement and the load reached before the failure. Nevertheless, to characterize the material it’s necessary to know the stress that causes the failure.

To this end a numerical model to simulate the test has been developed. Analytical methods are inappropriate to obtain the stresses because of the nonlinear behaviour of the test due to large displacements and contact between the wafer and the rings during the test.

The model has been developed through the Finite Element Method using the commercial package ANSYS. The anisotropy of the mono-crystalline silicon is taken into account using the following constants:

- $c_{11}=165.6$ GPa
- $c_{12}=63.9$ GPa
- $c_{44}=79.5$ GPa

The wafer as well as the rings is modelled with shell elements. The nonlinearity due to large deflection is also taken into account in the model. In Figure 4 a zoom of the contact zone is shown.

The range of variation of thickness in each set of wafers is limited. In order to reduce the calculations, only
two wafers of each group are simulated; those associated with the thinnest and the thickest samples of each set. In Figure 7 the adjustment of the numerical model to one set of wafers is shown.

![Figure 7](image)

**Figure 7** – Test results (black lines) and FE models (red lines) of wafers of Set 3.

5 RESULTS

5.1 Statistical evaluation

The model provides information about the stresses during the test just until the failure. Using the results corresponding to the two limit cases of each set and taking into account the elastic energy stored in the wafer before the failure as well as its thickness, the stresses have been obtained by linear interpolation. The maximum principal stress in the wafer has been considered as the fracture stress of the sample.

When all the stresses are obtained, a statistical study is carried out. The values are fitted to a two-parameter Weibull distribution [4], commonly used to characterize brittle materials. The probability of failure is defined as:

\[ P_f = 1 - \exp\left(-\frac{\sigma}{\sigma_\theta}\right)^m \]

The parameter \(\sigma_\theta\) represents the characteristic fracture stress at which the 63.2% of all samples fail. The Weibull module \(m\) informs about the scattering of the results. The adjustment of the five sets of wafers to a Weibull distribution is shown in Figure 8.

![Figure 8](image)

**Figure 8** – Estimated Weibull distributions.

5.2 Results comparison

The results of the study are summarized on Table 2:

<table>
<thead>
<tr>
<th>Set</th>
<th>Bath duration (min)</th>
<th>(\sigma_\theta) (MPa)</th>
<th>(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>130.5</td>
<td>7.42</td>
</tr>
<tr>
<td>2</td>
<td>1:45</td>
<td>196.4</td>
<td>7.27</td>
</tr>
<tr>
<td>3</td>
<td>2:40</td>
<td>205.0</td>
<td>5.71</td>
</tr>
<tr>
<td>4</td>
<td>3:30</td>
<td>233.5</td>
<td>7.14</td>
</tr>
<tr>
<td>5</td>
<td>4:25</td>
<td>212.8</td>
<td>4.54</td>
</tr>
</tbody>
</table>

These results confirm the general opinion that an increment in the duration of the chemical etching improves the mechanical strength of wafers. However, this improvement reaches a maximum value. At the first glance, decreasing the thickness by 11.8 microns per face does not imply an increase of wafer strength like in the other groups, as can be observed in Figure 9. However, at this point it is not clear whether this should be interpreted as turning point being the scatter quite considerable.

![Figure 9](image)

**Figure 9** – Characteristic fracture stress (\(\sigma_\theta\)) versus decreased thickness per face

During the chemical etching process material is removed from all surfaces. As a consequence, it is observed that the removal of the damage produced in the drilling process modifies the hole dimensions. Before the chemical bath the holes have an average diameter in the front side of 50µm and in the back side of 30µm. After a reduction of thickness less than 5µm per face, the holes diameters are 60µm on the front side and 40µm on the back. Figure 10 shows photographs of a hole before and after the chemical etching on both sides of the wafer.

![Figure 10](image)

**Figure 10** - a) Hole on the front before etching, b) hole on the back before etching, c) hole on the front after etching, d) hole on the back after etching
6 SUMMARY AND CONCLUSIONS

In this paper the influence of the duration of the chemical etching after the drilling process of EWT wafers has been studied. With this aim five sets of wafers subjected to baths of different duration have been prepared.

All the samples were tested by the Ring on Ring test. This kind of device is chosen because the higher stresses produced in the central part of the wafer are suitable to evaluate the stress concentrations due to surface cracks or holes neglecting the influence of edge cracks. A numerical model is developed to simulate the test in order to obtain the stresses just before the wafer failure. This simulation takes into account the non-linearities presented in the test due to large displacements and contact between the wafer and the rings. The holes have not been included in the FE model. Finally, a statistical study is carried out by fitting the failure stresses to a two-parameter Weibull distribution.

As a result of this study, it is observed that an extension of the etching time significantly increases the mechanical strength of these wafers by removing part of the damaged produced by the drilling process. Further studies are undertaken focusing on the stress concentration in the proximity of the holes and the variation of the hole diameter during the chemical etching process.

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8 REFERENCES