MECHANICAL STABILITY IN CRYSTALLINE SILICON SOLAR CELLS

Eneko Cereceda[1], Josu Barredo[2], José Rubén Gutiérrez[1], Juan Carlos Jimeno[1]
[1]TIM, Instituto de Tecnología Microelectrónica, Tecnologia Mikrolektronikaren Institutua
Technological Park, Building 105 - 48170 Zamudio-Bizkaia, Spain
[2]Department of Structural Mechanics and Industrial Constructions, Polytechnical University of Madrid, c/ José Gutiérrez Abascal 2, 28006 Madrid, Spain.
email: ecereceda001@ikasle.ehu.es

ABSTRACT: Mechanical stability of back contact solar cells deteriorates when holes (MWT, EWT) or grooves (TWT) are created in the wafer. These operations are essential for these structures so we found necessary to quantify the magnitude of this damage. A set of wafers with the EWT structure was produced and its mechanical strength measured by the Ring on Ring bending test. Other two sets of wafers with similar processes were prepared and tested to compare the effect of different fabrication steps on mechanical strength of the wafer. A numeric model was developed to analyse the data from the Ring on Ring test and a statistical study was carried out.
Keywords: Mechanical strength, Back contact, Laser processing.

1 INTRODUCTION

Silicon shortage suffered in the last few years involved a quick reduction in wafer thickness for solar cell production. Nowadays this shortage has been overcome but wafer thickness remains in values around 200µm and cost reduction policies will push this dimension to lower values.

Solar cell companies have been forced to manage this rapid decrease in wafer's thickness in order to get competitive products. Consequently, they improved manipulation tools, developed less harmful processes and mounted crack detection tools in the manufacturing line to remove damaged wafers from the process [1].

Nevertheless, there is a special kind of solar cells in whose manufacturing process are particularly harmful but essential steps. These are back contact solar cells like metal wrap through (MWT), emitter wrap through (EWT) or transistor wrap through (TWT). In these solar cells the physical structure of the wafer must be modified and these modifications affect its mechanical strength.

Nowadays back contact solar cells are thick enough to support this kind of processes and the damage they produce but, with the current tendency of manufacturing thinner wafers and cells, this damage could have a more important role in the mechanical behaviour. The aim of this work is to understand the effect of developing a back contact structure on the mechanical strength of a solar cell.

2 PREPARATION OF SAMPLES

Back contact solar cell structures have different physical geometries that affect their mechanical behaviour. MWT and EWT cells have holes with different sizes and distribution to take the electrons to the back side of the cell and the TWT cell has grooves to improve the transistor effect. In this research we studied the mechanical structure of the EWT back contact solar cell.

We prepared three sets of 52.5 mm x 52.5 mm monocrystalline silicon wafers which underwent different processes.

The first set of wafers represented the physical structure of a commercial EWT solar cell. First of all they were chemically etched to remove any possible surface damage from wire-sawing [2]. Then they were drilled with a laser process following an EWT pattern. Finally, the wafers were etched for a second time to remove any possible damage generated by the laser process.

The process over the second set of wafers was similar to the previous one. First they were etched to remove any surface damage and then drilled with laser. In this case, the second etching process was omitted, leaving the laser damage on them. Comparing this set of wafers with the first one we could learn the effect of laser damage removal on the mechanical strength of the wafer.

The third set of wafers would give us the reference as undamaged wafers. First, similarly to the other sets of wafers, they were chemically etched to remove any damage from wire-sawing and afterwards they were etched once again as done with the wafers from set one. This second etch process was done to get a set as similar as possible to set one, with the only difference in the lack of holes. Figure 1 shows the different processes of each set of wafers.

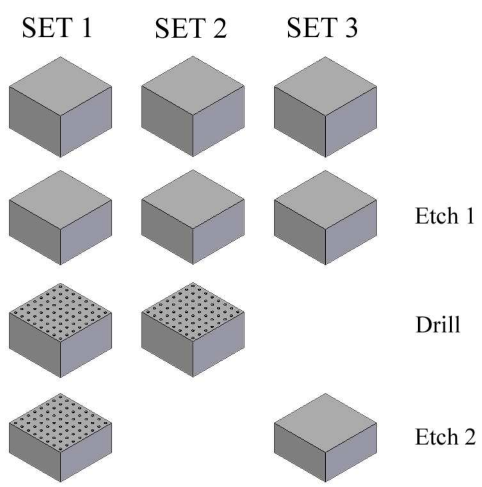

Figure 1: Processes over the three set of wafers

2.1 Hole drilling

The laser drilling process was performed with a Q-switched fiber laser from EOLITE Systems (France), which generates pulses of 10ns, working in three wavelengths (λ_1=1030nm, λ_2=515 nm and λ_3=343nm).

The equipment has a high speed x-y galvano-mechanical beam positioner which allows to scan samples in a 160mm·160mm platform. For this porpuse, the 515nm laser was chosen, working at 234µJ peak energy.

The hole pattern consisted of a matrix of tiny holes with a density of approximately 100 holes per square centimetre. Concentration of holes in one direction was higher than in the other because, in a EWT solar cell, metallic contacts for the base and for the emitter are both at the back of the cell. The emitter contacts are under the line of holes, and the base contacts are placed in the space between them. Figure 2 shows the distribution of our EWT pattern.

The holes had an average diameter of 50µm in the front side and of 30µm in the back side. A hole in the front and back sides of the wafer can be seen in figures 3a and 3b respectively.

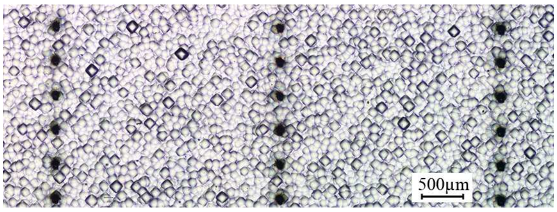

Figure 2: Holes size and distribution in an EWT structure.

The latter etching process improved the appearance of the holes removing the damage from the laser drilling. This was a brief process which removed less than 5µm per face. After that, the holes diameters were 60µm in the front side and 40µm in the back. Figures 3c and 3d represent a hole after the second etching process in the front and back sides respectively.

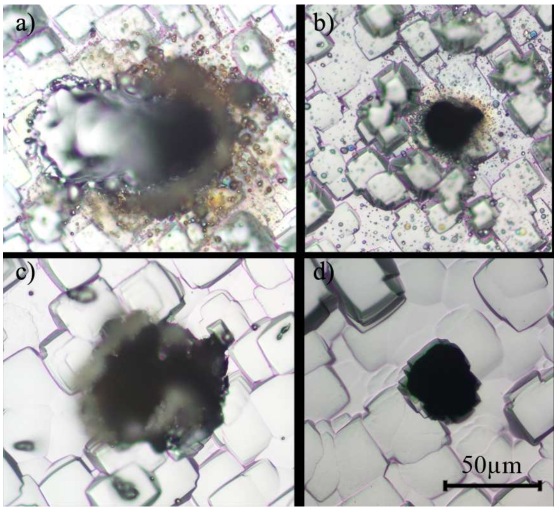

Figure 3: a) Hole in the front before etching, b) hole in the back before etching, c) hole in the front after etching, d) hole in the back after etching

3 RING ON RING TEST

In order to evaluate the surface damage induced by the holes, the Ring on Ring bending test was chosen for the analysis. In this test, the wafer is supported on a ring (20 mm of diameter) and the load is applied on the other side of the wafer by means of a ring of smaller diameter (10 mm). Figure 4 schematizes the test.

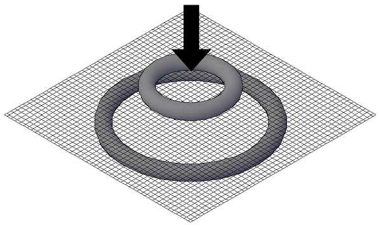

Figure 4: The ring on ring test

Stresses inside the lower ring are much higher than in the outer part [4], [5]. Therefore, the evaluation of the strength using this type of test takes into account only the damage caused by the holes, neglecting the influence of the edge cracks of the wafers.

The force transducer has a capability up to 200 N. The displacement of the top ring is imposed and both the force and the displacement are recorded. The velocity is very low in order to get a quasi-static test. In this research a value of 0.2 mm/min was employed. The dimensions of the samples and the test set up were chosen to avoid buckling. A photograph of one test just after failure is shown in figure 5.

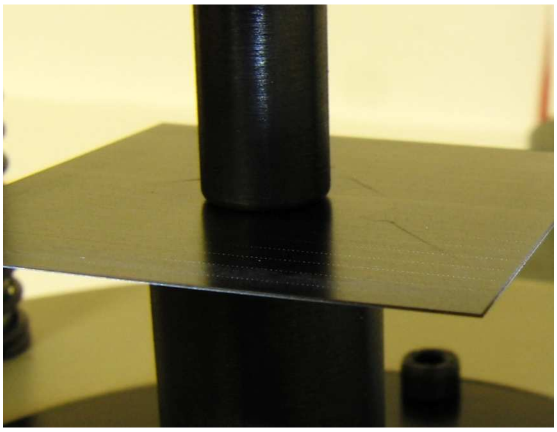

Figure 5: Photograph of one test just after failure

4 NUMERICAL MODEL

The test gives information about the behaviour of the samples and the maximum load and displacement that it reaches before the failure; nonetheless, it's necessary to know the stress that causes the failure.

Analytical methods are inappropriate for this objective since the anisotropic behaviour of the wafer and the non-linearities present in the test, due to large displacements and contact between the wafer and the rings, are not taken into account. Therefore, the finite element method was used for the simulation using the commercial package ANSYS.

In the model developed, both the wafer and the supports were modelled with shell elements. The anisotropy of silicon was considered using the following constants:

$c11=165.6$ GPa
$c12=63.9$ GPa
$c44=79.5$ GPa

The stress evaluation of the model shows that the zone under maximum stress is located under the upper ring.

In order to reduce the calculations, only the thinner and the thicker samples of each set were simulated [4]. In figures 6, 7 and 8, the adjustment of the numerical model to each set of wafers are shown.

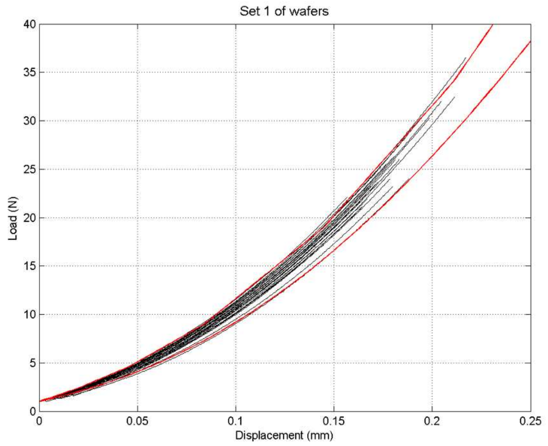

Figure 6: Test results (black lines) and FE models (red lines) of wafers of Set 1: Etching + Drilling + Etching

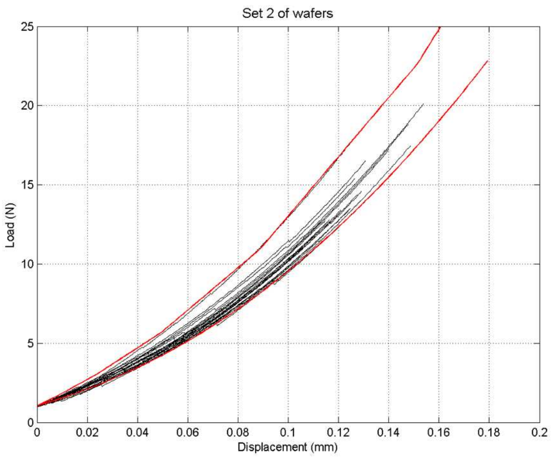

Figure 7: Test results (black lines) and FE models (red lines) of wafers of Set 2: Etching + Drilling

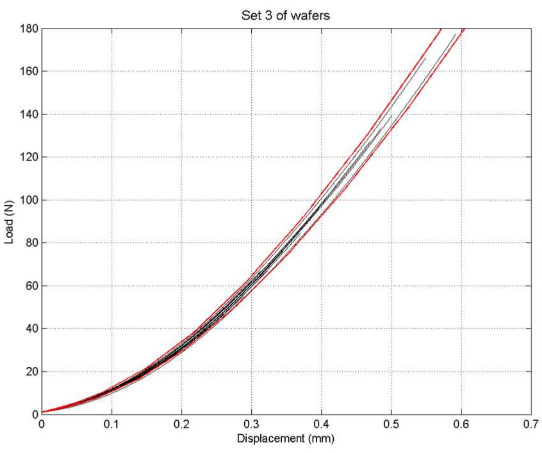

Figure 8: Test results (black lines) and FE models (red lines) of wafers of Set 3: Etching + Etching

The non-linear behaviour of wafers during the test can be clearly observed. Moreover, the good fitting of the numerical model and the test of thinner and thicker wafers of each set is also shown.

The fracture stress for all samples of each test was obtained through a linear interpolation taking into account the elastic energy stored in the wafer before failure and its thickness.

5 RESULTS

5.1 Statistical evaluation

When all fracture stresses were obtained, a statistical study was carried out. For brittle materials the Weibull distribution is commonly used to evaluate statistically the results. Therefore, results of each set of wafers were fitted to a Weibull bi-parametric distribution [3]. The probability of failure is defined as:

$$P_f = 1 - e^{-(\sigma/\sigma_\theta)^m}$$

The parameter σ_θ represents the characteristic fracture stress at which 63.2% of all samples fail. The Weibull module m informs about how scattered the results are. In figure 9, the adjustment of the three sets of wafers to a Weibull distribution is shown.

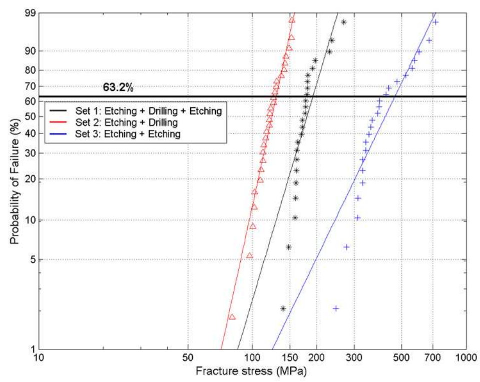

Figure 9: Weibull adjustment

5.2 Results comparison

Results of the study are summarized in Table I:

Table I: Results of the study

Set	Wafers treatments	σ_θ (MPa)	m
1	Etch 1 + Drill + Etch 2	191.8	5.69
2	Etch 1 + Drill	129.2	7.77
3	Etch 1 + Etch 2	464.1	3.49

It is clear that wafers without holes present a higher fracture stress than the other ones. The comparison between sets 1 and 3 shows that the drilling process implies a reduction of more than 50% of the strength of silicon wafers falling the characteristic fracture stress from 464.1MPa to 191.8MPa. It's thought that the reduction in strength is due to the stress concentration near the holes. Further investigations are being carried out in order to evaluate this stress concentration.

On the other hand, the comparison between sets 1 and 2 shows that the second etching process improves the mechanical strength increasing characteristic fracture stress from 129.2MPa to 191.8MPa. It seems that the drilling process leads to cracks near the holes which are removed during the second etching process.

6 SUMMARY AND CONCLUSIONS

In this work the mechanical influence of the hole drilling process of back contact solar cells on the wafer has been studied. With this aim three sets of wafers were prepared. The first set underwent an etching process, then the hole drilling and finally another etching process. The second set also had an etching process just followed by the hole drilling. The third set only underwent the two etching processes.

These sets of wafers were tested by the Ring on Ring bending test which evaluates the inner area neglecting any peripheral damage. A numeric model was developed to get the fracture strength values taking into account the non-linearities present in the test due to large displacements and contact between the wafer and the rings. Then a statistical study was carried out adjusting fracture strengths of each set of wafers to a bi-parametric Weibull distribution.

As a result of this study it was observed that the presence of holes in the wafers causes a severe reduction in the mechanical strength of silicon wafers. Also it was observed that the etching process after drilling removes laser damage, increasing significantly the mechanical strength of the wafer.

Future efforts will be focused on analysing the stress concentration in the proximity of the holes and optimizing the etching process after the laser drilling to enhance the mechanical strength of the wafer. Moreover, other back contact cell technologies like MWT and TWT will be analysed.

7 ACKNOWLEDGEMENTS

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