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The influence of holes in the mechanical properties of EWT solar cells

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Abstract

EWT back contact solar cells are manufactured from very thin silicon wafers. These wafers are drilled by means of a laser process creating a matrix of tiny holes with a density of approximately 125 holes per square centimeter. Their influence in the stiffness and mechanical strength has been studied. To this end, both wafers with and without holes have been tested with the ring on ring test. Numerical simulations of the tests have been carried out through the Finite Element Method taking into account the non-linearities present in the tests. It's shown that one may use coarse meshes without holes to simulate the test and after that sub models are used for the estimation of the stress concentration around the holes.

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Keywords: EWT solar cells; holes; stiffness; strength; stress concentration; sub-models; ring on ring test; wafers; Finite Element Method

1. Introduction

Last years, back contact silicon solar cells are gaining popularity because they present some interesting features as the high efficiencies or simpler module assembly [1]. There are several different types of back contact cells on the market like metal wrap through (MWT), emitter wrap through (EWT) or transistor wrap through (TWT). Some steps of the manufacturing processes of these cells are quite harmful with regard to the mechanical strength. The continuing tendency to reduce the wafer thickness will worsen the problem. MWT and EWT cells have holes of different size and distribution to take the electrons to the

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back side of the cell and MWT cells have grooves to improve the transistor effect. In this work the mechanical structure of the EWT back contact solar cell is studied and a way to study the stress concentration around the holes is presented.

To this end, two sets of wafers have been prepared. The first set represents the physical structure of a commercial EWT solar cell. First of all, the wafers have been chemically etched to remove any possible surface damage from wire-sawing [2]. After that, the wafers have been drilled by a laser process following an EWT pattern. The pattern consists in a matrix of tiny holes (average diameter of $40\ \mu\text{m}$) spaced with a density of 125 holes per square centimeter (Figure 1). Finally, the wafers are etched for a second time to remove any possible damage generated by the laser process. The second set of wafers serves as reference set. First, as the other set of wafers, they have been chemical etched to remove any damage from wire-sawing and after that, they have been etched ones again. This second etch process has been done to get a set as similar as possible to set one, the only difference being the holes.

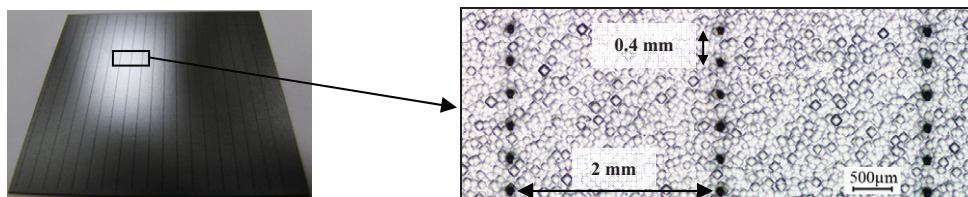


Fig. 1. (a) Sample of drilled wafer; (b) Zoom of the hole pattern

2. Sample test

In order to evaluate the damage induced by the holes, the ring on ring test has been chosen for the analysis. In this test, the wafer is supported by 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 2 shows a sketch and a photo of the test setup. Stresses inside the lower ring are much higher than in the outer part [3]. Therefore, the evaluation of the strength using this type of test takes only the damage caused by the holes into account, neglecting the influence of border cracks that might exist.



Fig. 2. (a) The ring-on-ring test; (b) A photo of one test

3. Numerical model

The test gives information about the behavior of the samples and the maximum load and displacement reached before failure takes place. However, it's also necessary to determine the attained rupture stress. The finite element method has been used for the simulation to account for both the anisotropy of monocrystalline silicon and the non-linear behavior of the sample during the test. The non-linearities present in

the test are due to large displacements and contact between the wafer and the rings. The software ANSYS has been used developing a model in which wafer and supports have been modeled with shell elements, as it's recommended in [4]. The anisotropy of the silicon is considered using the constants $c_{11} = 165.6$ GPa, $c_{12} = 63.9$ GPa and $c_{44} = 79.5$ GPa.

In general, one has to take into account the holes for the simulation of the drilled wafers. First of all, the influence of the holes in the stiffness has been analyzed. To this end, the behavior of a model with holes has been compared with the one of a model with similar mesh but without holes.

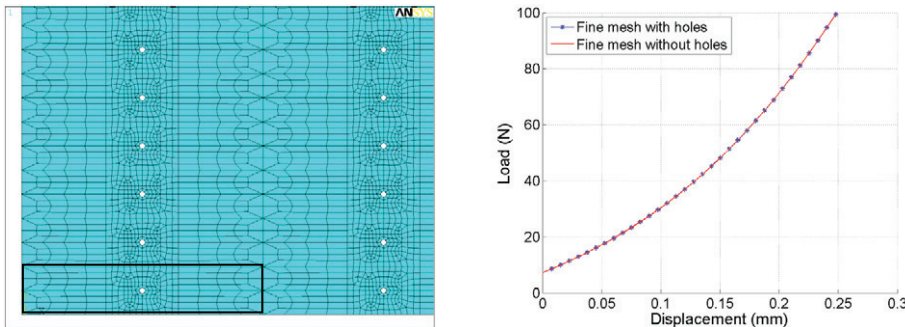


Fig. 3. (a) Mesh of the model with holes; (b) Stiffness comparison

Either of the models has more than 190000 elements and the calculation time has been higher than ten hours despite the contact between wafers and rings has not been included in the models. The load displacement curves are almost identical, as may be seen in figure 3. However, the mesh with holes is not fine enough to analyze the stress concentration around the holes, as may be derived from figure 7. The use of a finer mesh would lead to excessive calculation times.

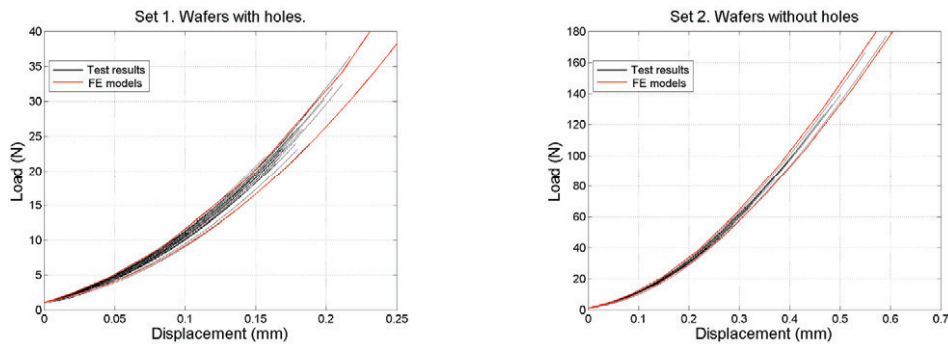


Fig. 4. (a) Set 1: Test results and FE models; (b) Set 2: Test results and FE models

The strategy followed is thus to first use a model without holes in order to obtain the displacement field, and then to use sub modeling to estimate the stress distribution. In all models developed for the test simulations the contact between wafers and the rings has been taken into account. As all samples of each set of wafers have similar thickness, only two models have been developed for each set: the model corresponding to the thinnest wafer, which behaves as the most flexible and the one corresponding to the thickest wafer (figure 4).

4. Statistical analysis

The fracture stress for all samples of each test has been obtained through a linear interpolation taking into account the elastic energy stored in the wafer before failure and its thickness. As is usual for brittle materials the Maximum Principal Stress Failure Criterion has been used. For brittle materials the Weibull distribution is commonly used to evaluate statistically the results. Therefore, results of each set of wafers are fitted to a Weibull bi-parametric distribution [5]. The probability of failure is defined as:

$$P_f = 1 - e^{-(\sigma/\sigma_0)^m} \tag{1}$$

The parameter σ_0 represents the characteristic fracture stress at which 63.2% of all samples fail. The Weibull module m informs about how scattered the results are. The adjustment is shown in figure 5 and the values are shown in Table 1.

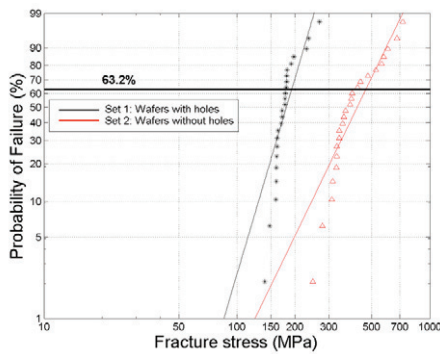


Table 1. Results of the Weibull fitting

Set	σ^0 (MPa)	m
Wafers with holes	192.1	5.69
Wafers without holes	465.6	3.48

Fig. 5. Weibull fitting

Stress values for the adjustment have been obtained by means of FE models without holes and it seems that the presence of holes in the wafers acts as a stress concentrator with a factor of 2.42.

5. Sub-model

The study of the stress concentration around holes of wafer set 1 has been carried out using the sub-modeling method which is also called cut boundary displacement method. To this end, one model with a characteristic thickness of the samples (216 μm) has been developed without holes, as previous ones showed before. The stress-displacement curve of the model is shown in figure 7a.

The sub-model developed is of size 2 mm x 0.4 mm since these are the distances between holes in the wafers. First, a mesh convergence study of the sub-model has been carried to determine the mesh size necessary to obtain accurate stress values. The first mesh size taken for this study has been the one used to compare the stiffness between wafers with and without holes marked in figure 3a. From here, keeping the dimensions of the sub-model constant, the mesh has been refined till convergence has been achieved, as shown in figure 6a. The finally chosen mesh is also shown (figure 6b).

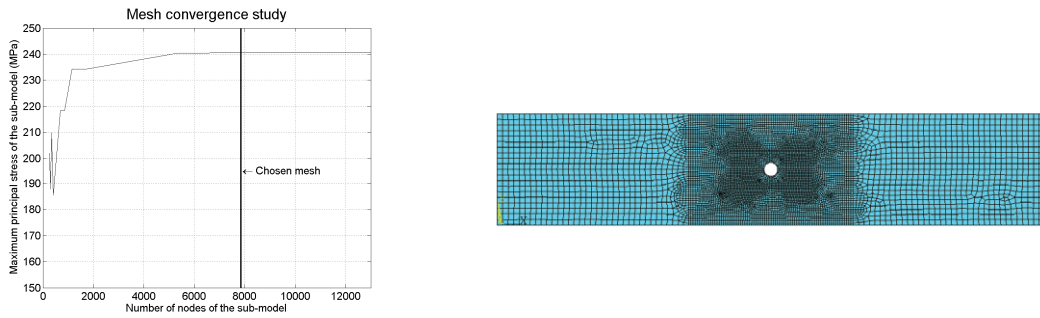


Fig. 6. (a) Mesh convergence study; (b) Chosen mesh for the sub-model

The stress distribution of the whole sample model without holes shows that the maximum stresses are found inside the lower ring. Therefore, only the holes of this zone have been analyzed. A total of 125 holes have been studied through the sub-modeling technique. The displacements at the moment of failure have been imposed at the boundary nodes of the sub-model to calculate the stress distribution. The maximum stress obtained is represented versus the displacement showing the difference with the curve obtained in the model without holes (figure 7a). In figure 7b the stress intensity factor for the different displacements imposed is shown.

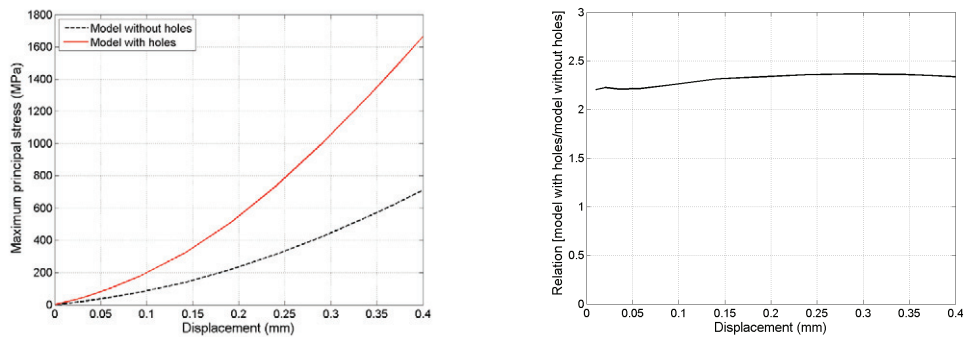


Fig. 7. (a) Stress-displacement with and without holes; (b) Stress intensity factor

It can be seen that the stress intensity factor obtained with the comparison between the coarse mesh model without holes and the analysis with sub-models of 125 holes is varying between 2.2 and 2.4, giving a very close result to the one obtained experimentally. This stress intensity factor is only valid for the model developed and before drawing general conclusions for drilled wafers, other parameters such as density and geometry of the holes or the damage caused by the drilling process have to be further examined. Moreover, the correct Weibull distribution adjustment needs to consider the size effect in order to get fully comparable values for both sets of wafers.

6. Conclusions

This paper presents the results of a study of the influence of holes in the mechanical properties of wafers for EWT back contact solar cells. These wafers are drilled by means of a laser process generating several thousands of tiny holes. The holes lead to stress concentration effects that reduce significantly the

wafers strength. To carry out the study, two set of wafers have been prepared. The first one corresponds to the commercial structure of EWT solar cells and the second one is quite similar except it doesn't have holes. Both sets have been tested by means of the ring on ring device and tests have been simulated employing the Finite Element Method.

First of all, the influence of the holes in the wafers stiffness has been analyzed showing that the holes are so small that they don't reduce significantly the stiffness of the sample. Therefore, coarse meshes without holes have been employed to simulate the test. Non-linearities present in the test have been included in the model. The maximum principal stress obtained in the models for each test has been adjusted to a Weibull distribution giving two curves, one for each set. This fitting shows that the relation between wafers with holes and wafers without holes is 2.42. This factor comes from the stress concentration around the holes and is only valid for the studied samples.

To analyze what happens around the holes, the sub-modeling technique has been employed. A sub-model of the influence zone around the hole has been developed and a mesh convergence study has been carried out to get the optimum mesh size for the sub-model. After that, a model without holes has been developed and the relation between the maximum principal stress and displacement has been obtained. Moreover, the 125 holes closer to the centre of the wafer have been studied with the sub-model. Results show that the stress is increased a factor between 2.2 and 2.4 in each load step, getting a quite constant value. This factor could be applied to all samples with holes getting an estimation of the fracture stress. However, the attained fracture stress is only part of the information needed to take into account the size effect, one also has to know the stress distribution. At the moment, further investigations are being conducted to examine the influence of parameters such as density and geometry of the holes or the damage caused by the drilling process on the stress intensity factor.

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