OPTIMIZING THE DENSITY OF HOLES OF EWT SOLAR CELLS TAKING INTO CONSIDERATION MECHANICAL ASPECTS

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ABSTRACT: EWT solar cells start from drilled wafers with approximately 100 holes/cm^2. These holes act as stress concentrators leading to a reduction in the mechanical strength of this type of wafers. The viability of cells with higher density of holes has been studied. To this end, sets of wafers with different density of holes have been characterized. The ring on ring test has been employed and FE models have been developed to simulate the test. The statistical evaluation permits to draw conclusions about the reduction of the strength depending on the density of holes. Moreover, the stress concentration around the holes has been studied by means of the FE method employing the sub-modeling technique. The maximum principal stress of EWT wafers with twice the density of holes of commercial ones is almost the same. However, the mutual interaction between the stress concentration effects around neighboring holes is only observed for wafers with a density of 200 holes/cm^2.
Keywords: Back Contact, Experimental Methods, Simulation, Stress Concentration

1 INTRODUCTION

In the 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 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. MWT and EWT cells have holes of different size and distribution to take the electrons to the back side of the cell and MWT cells have grooves to improve the transistor effect.

This study is focused on EWT solar cells. In this context it is quite common to use drilled wafers with approximately 100 holes per square centimeter. These holes act as stress concentrators reducing the mechanical strength [2], [3]. Increasing the density of holes may cause an overlapping of the stress concentration areas of different holes decreasing the mechanical strength. This effect has been studied characterizing several sets of wafers with different density of holes and studying the stress concentration in a numerical way through the Finite Element Method.

2 TEST

2.1 Preparation of samples

Three sets of samples have been prepared to study the influence of different densities of holes. First of all the monocrystalline pseudo-square silicon wafers have been chemically etched to remove any surface damage caused by the wire sawing process. After that, two of the sets have been drilled with a laser following two different patterns of holes while the third set has been kept without holes in order to have a reference set. Finally, the three sets of wafers have been etched again to remove any possible damage caused by the laser drilling [4]. In order to get more samples, wafers have been cut in four pieces of 52.5 mm x 52.5 mm by means of a laser cutting process. The influence of any possible damage caused in this step can be neglected because the ring on ring test has been chosen for the analysis and failure in this type of test is usually caused by surface cracks located at some distance from the wafer edges.

The hole patterns consist of two different arrays of tiny holes with densities of approximately 100 and 200 holes per square centimeter. Concentration of holes in one direction was higher than in the other one 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. Therefore, a separation of 2.5 mm has been kept for all the patterns in one direction and the difference between sets comes from the separation in the other direction. Holes have been made approximately each 400 μm and 200 μm for the sets with densities of 100 and 200 holes per square centimeter, respectively.

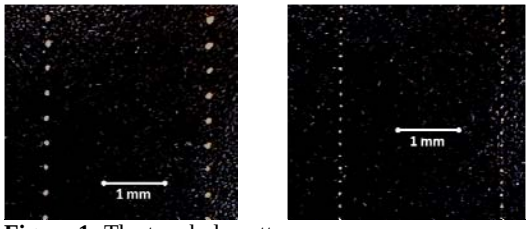

Figure 1: The two hole patterns

2.2 Ring on ring test

The ring on ring test has been chosen in order to evaluate the mechanical strength of the drilled wafers. The diameters of the rings are 20 mm and 10 mm, respectively. In figure 2 a photograph of the test setup is shown:

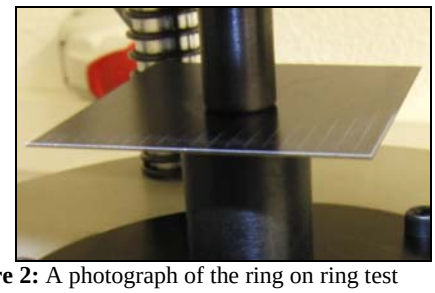
Figure 2: A photograph of the ring on ring test

3 NUMERICAL MODEL

The Finite Element Method has been chosen for the analysis to adequately simulate the non-linearities like contact situations and big displacements ([2], [3], [4]).

In the model developed, wafer and supports have been modeled with shell elements. The anisotropy of the silicon is considered using the following material constants:

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

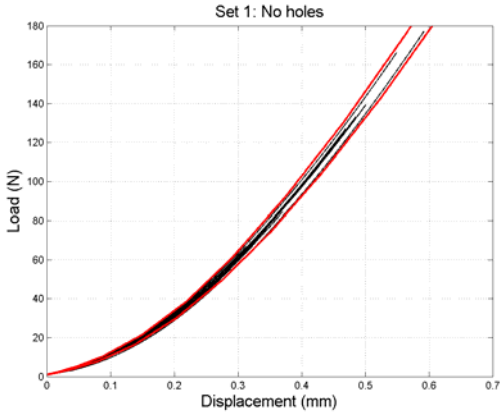

Figure 3: Test results and FE models of wafers of Set 1.

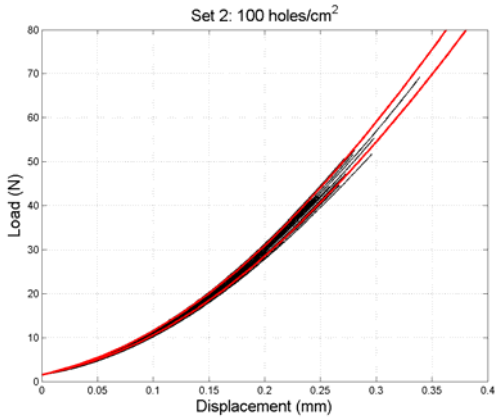

Figure 4: Test results and FE models of wafers of Set 2.

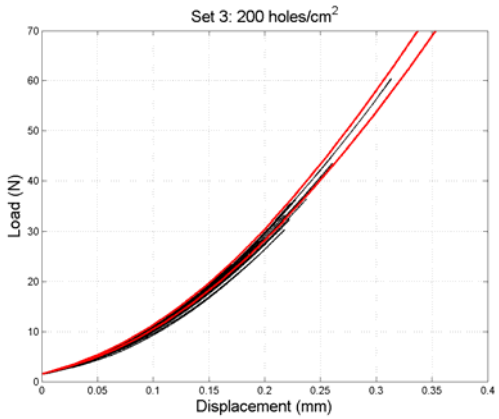

Figure 5: Test results and FE models of wafers of Set 3.

The models developed for the simulation of the drilled wafers do not include the holes! It has been demonstrated in previous studies ([2]) that the influence of the holes in the stiffness of the wafers can be neglected. Therefore, two models without holes have been developed for each set: the model corresponding to the thinnest wafer and the one corresponding to the thickest wafer. Test results and the models developed for each set can be seen in figures 3, 4 and 5.

A good fit of the numerical models and the tests of each wafer set can be observed. 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. It has been considered that the maximum principal stress is the failure stress.

4 STATITISCAL EVALUATION

Once the stress states of all wafers have been obtained, the resulting values for each set have been fitted to a three-parameter Weibull distribution. This cumulative distribution function describes the failure probability of a uni-axially tensioned area ΔA. The failure probability for a uni-axially tension area Aeq different from ΔA can be expressed [5]:

$$P_{f,Aeq}(\sigma) = 1 - \exp\left[-\frac{Aeq}{\Delta A}\left(\frac{\sigma-\lambda}{\delta}\right)^{\beta}\right]$$

Where λ is known as the location parameter representing a threshold stress, δ is the scale parameter and β is the shape parameter.

By definition, a specimen having the equivalent area that is subjected in a tensile test to the maximum stress observed in the ring on ring test, results in the same probability of failure. Although the definition of the equivalent area requires that the specimen is subjected to a tensile test, we have considered in the finite element model that each element is subjected to a tensile test i.e. the maximum principal stress because it's the failure criterion as it has been mentioned before. Therefore, assuming that the rupture strength follows a three-parameter Weibull distribution, the equivalent area of each test can be calculated with the following expression:

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

The integral of the whole model requires knowing the principal stress at each Gauss point, the area associated to this point, the maximum principal stress of the model and the location and shape parameters of the Weibull distribution.

It is important to note that the equivalent area of each specimen depends on the parameters of the Weibull distribution. That means that an iterative process has to be employed in order to estimate the parameters of the Weibull distribution. A proposal for such an iterative procedure may be found in [6]. In figure 6, the Weibull cumulative curves are shown for each set referred to a ΔA = 4.8 e-5 m^2.

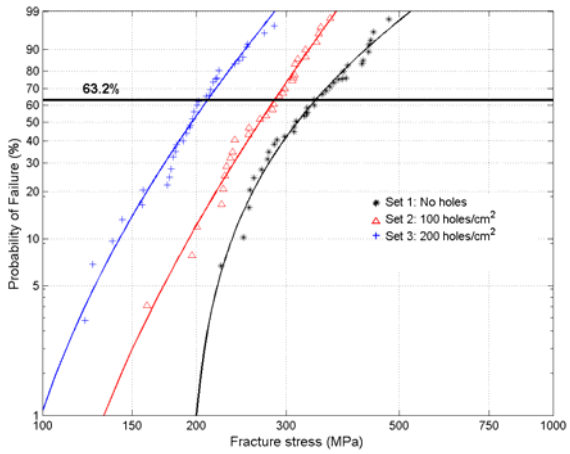

Figure 6: Weibull distribution for each set

Results are summarized in Table I. In addition to the Weibull parameters, the characteristic fracture stress σ_θ, that represents the stress at which 63.2% of all samples fail, is presented.

Table I: Results of the study

Set	Holes density	λ (MPa)	δ (MPa)	β	σ_θ (MPa)
1	No holes	191.2	153	1.84	344.2
2	100	72.6	212.8	4.06	285.4
3	200	67.1	144.1	3.47	211.2

Results show a clear influence of the density of holes in the characteristic fracture stress. One aspect that helps to explain the different stress values is the mutual interaction between the stress concentration effects of neighboring holes in wafers with a density of 200 holes/cm^2.

5 STRESS CONCENTRATION

The study of the stress concentration around holes has been carried out using the sub-modeling technique 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 models used in the simulation of the tests. Details of the mesh size are displayed in in figure 7.

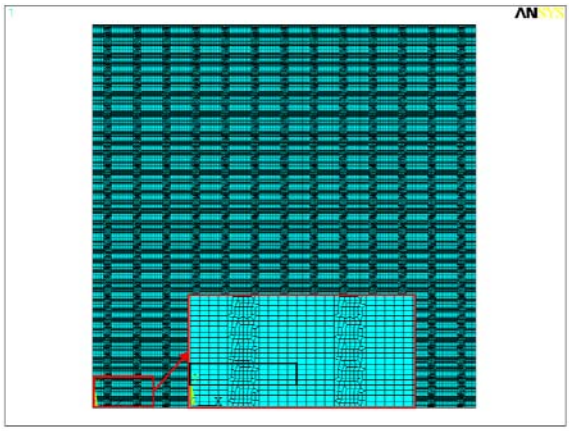

Figure 7: Model without holes

Moreover, two different sub-models of the zone around holes have been developed simulating the two different types of wafers with densities of 100 and 200 holes per square centimeter. The zone around a hole is marked in figure 7 with a black rectangle. The sub-models have the dimensions of the black rectangle but the mesh is much finer to get accurate values close to the holes, as can be seen in figures 8 and 9.

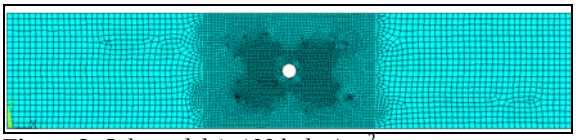

Figure 8: Sub-model 1: 100 holes/cm^2

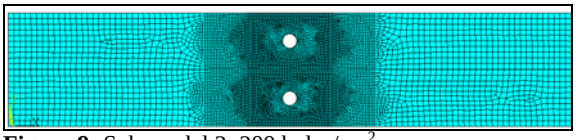

Figure 9: Sub-model 2: 200 holes/cm^2

The displacements field of the zone around the central hole in one load step of the whole model is imposed at the boundary of both sub-models and the stress state is compared in order to determine the stress concentration around the holes. Results are shown in figures 10 and 11.

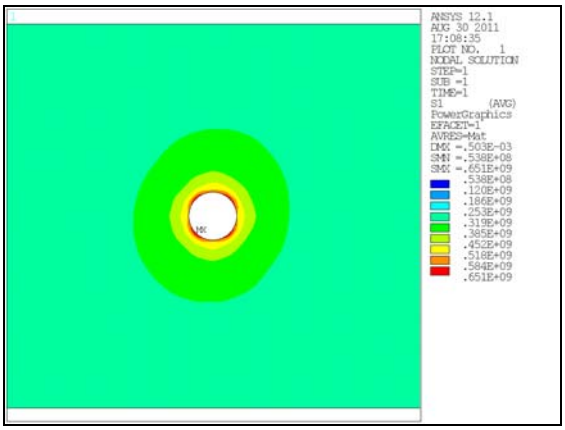

Figure 10: Stress state for sub-model 1

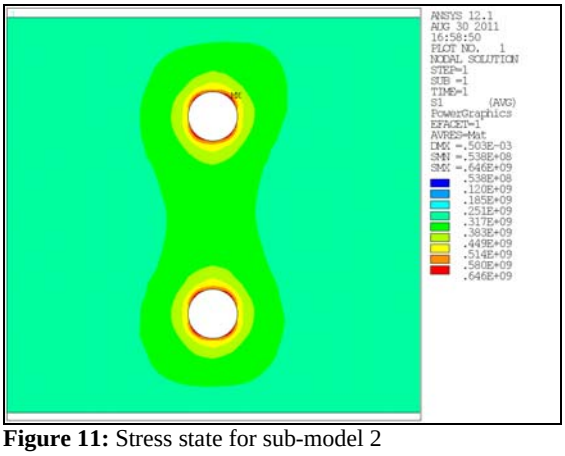

Figure 11: Stress state for sub-model 2

It can be seen that the maximum stress is quite similar in both models. The effect of the anisotropy of silicon is also observed as the maximum stress occurs at

an angle of 45º.

Although the maximum stress is not significantly affected by the mutual interaction in sub-model 2, it can be observed that a greater part of the surface is subjected a higher stresses. This effect is more visible if the sub-models include more holes. Joining three of the sub-models presented in figures 8 and 9 leads to the following stress distribution:

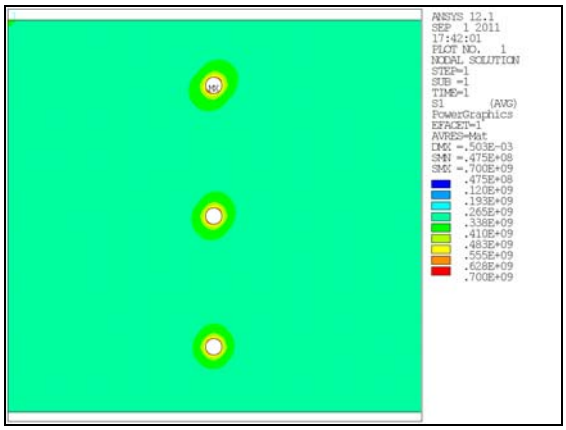

Figure 12: Stress state for 3 sub-models 1 together

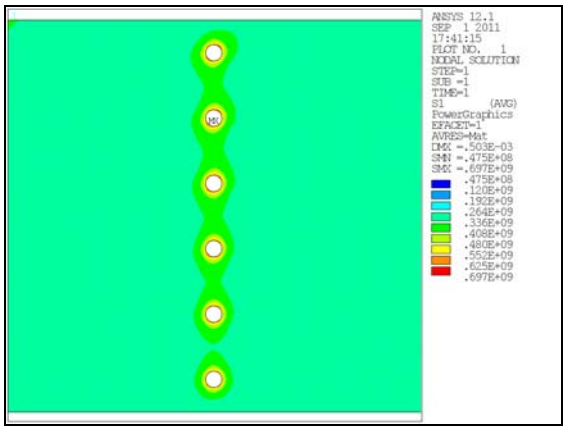

Figure 13: Stress state for 3 sub-models 2 together

The overlapping of stresses with high values (a half of the maximum) is clear for wafers with density of 200 holes/cm^2. Therefore, as a greater part of the surface is subjected a higher stresses the probability of failure is also higher. This effect, apart from the fact that a higher density of holes results in more regions with stress concentrations, is thought to contribute to the difference between wafers with density of 100 and 200 holes/cm^2.

6 SUMMARY AND CONCLUSIONS

This paper presents the results of a study of the influence of the density 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, three sets of wafers have been prepared. The first one corresponds to the reference set without holes. The second one represents the commercial structure of EWT solar cells; the corresponding wafers have a density of approximately 100 holes/cm^2. Finally, the third set contains wafers with a density of 200 holes/cm^2.

All sets have been tested by means of the ring on ring device and tests have been simulated employing the Finite Element Method using models without holes.

Results for each set in terms of stresses have been fitted to a three-parameter Weibull distribution taking into account the correction by size-effect. Wafers with a density of 100 holes/cm^2 show a characteristic fracture stress that is reduced by almost 20% with respect to wafers without holes. In the case of wafers with a density of 200 holes/cm^2 this reduction is even higher, almost 40% .

The stress concentration effects have been studied by means of the sub-modeling technique. For the investigated density values, the maximum principal stresses around the holes can be considered as independent of the density of holes.

A mutual interaction between the stress concentration effects around neighboring holes is only observed in the sub-model corresponding to wafers with a density of 200 holes/cm^2.

7 ACKNOWLEDGEMENTS

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7 REFERENCES

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