THE INFLUENCE OF DIFFERENT SURFACE TREATMENTS ON THE MECHANICAL STRENGTH OF SILICON WAFERS

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ABSTRACT: The implementation of photovoltaic solar energy based on silicon is being slowed down by the shortage of raw material. In this context, the use of thinner wafers arises as a solution reducing the amount of silicon in the photovoltaic modules. On the other hand, the manufacturing process with thinner wafers can become complicated with traditional tools. The high number of damaged wafers reduces the global yield. It's known that edge and surface cracks and defects determine the mechanical strength of wafers. There are several ways of removing these defects e. g. subjecting wafers to a mechanical polishing or to a chemical etching. This paper shows a comparison between different surface treatments and their influence on the mechanical strength.
Keywords: Cost reduction, Manufacturing and Processing, Reliability

1 INTRODUCTION

The most widely used material in photovoltaic industry is monocrystalline silicon [5]. The cost increment of PV modules caused by recent lacks of raw material may stop a bigger growth of the photovoltaic industry [2, 3]. One way of reducing the cost comes with the use of thinner wafers. The main problem of the thinner wafers is that the manipulation with traditional tools increases the number of broken wafers reducing the global yield. Different studies about the mechanical properties of silicon wafers have been carried out last years [1, 2, 3, 4].

It's known that the mechanical strength of wafers is determined by the cracks and defects present in the wafer [1, 2, 3, 4, 6]. There are several ways of removing these defects. This paper presents the results of a study of the mechanical properties of monocrystalline silicon wafers. First, the steps necessary to get the strength are explained in detail. Then, the effect of reducing the thickness of wafers and the influence in the strength of different steps in the manufacturing process has been analyzed. Finally, a comparison between different methods of removing surface cracks has been carried out.

2 DIFFERENT STEPS INVOLVED IN THE STUDY

The study of the mechanical properties of wafers implies to carry out a lot of tests. Wafers with different cleavage plane orientations and with different surface treatments have been tested making possible a wide analysis of several variables. The main steps of the study are explained in detail below.

2.1 Test description

The test chosen for this study has been the four line bending test (Figure 1). The force is applied to the two supports on top of the wafer while the other two are fixed. The displacement of the supports and the force applied is recorded.

With this fracture test both surface and edge cracks and defects are contribute to failure [1, 2, 3, 4].

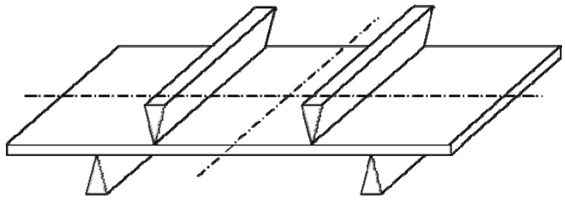

Figure 1: The four line bending test

2.2 Numerical model

In order to determine the stress state of the wafer in the fracture moment, it's necessary to develop a numerical model. Wafers in the four line bending test present a non-linear behaviour due to large displacement and contact between supports and wafer.

A Finite Element model using the commercial software ANSYS has been developed. The large displacement formulation and the sliding and friction in the contact points have been taken into account.

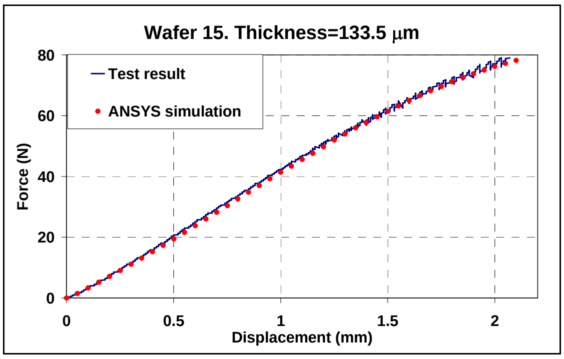

Figure 2: Fitting of test results and numerical simulation

2.3 Test results

Simulating the wafer behaviour in the test with the numerical model (Figure 2) it's possible to obtain the maximum stress in the wafer in the fracture moment. This result has been taken as the mechanical strength of the wafer [1]. Finally, wafer with the same properties have been grouped and statistical calculus has been applied in order to get a global result for each group.

3 INFLUENCE OF THE SURFACE TREATMENT IN THE MECHANICAL STRENGTH

3.1 Relation decreased thickness-mechanical strength

It's known that the mechanical strength is determined by the cracks and defects present in the wafers surface and edges [1, 2, 3, 4, 6]. Many of these cracks and defects are generated in the wire sawing process. So, an obvious way to increase the wafers strength is removing the work-affected layer. In order to study this influence, several wafers have been prepared for being tested. In table I a summary is presented with the average values for each group of wafers tested.

Table I: Summary of wafer tested

Original thickness (µm)	Decreased thickness per face (µm)	Thickness in test (µm)
355	70	215
212	0	212
212	0.6	211
211	5.6	200
210	12	186
207	17.5	172
209	24.5	160
207	28	151
209	30	149
211	43	125
206	53	100
141	0.6	140
141	5.6	130
140	12	116

Several wafers of each group have been tested. The numerical model for each wafer has been adjusted for the test result and the maximum stress at the fracture moment has been obtained. The mean value for each group is represented in the figure 3:

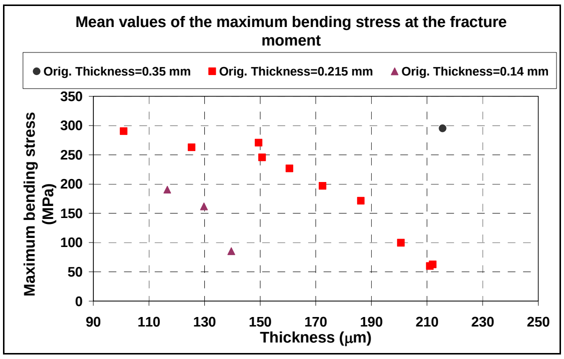

Figure 3: Maximum bending stress according to the wafer thickness

As can be seen, wafers of each group present a similar tendency in the maximum stress with the decreased thickness. They have been grouped according to the decreased thickness, independently of the thickness during the test. In the Figure 4 the bending strength with the decreased thickness per face has been represented.

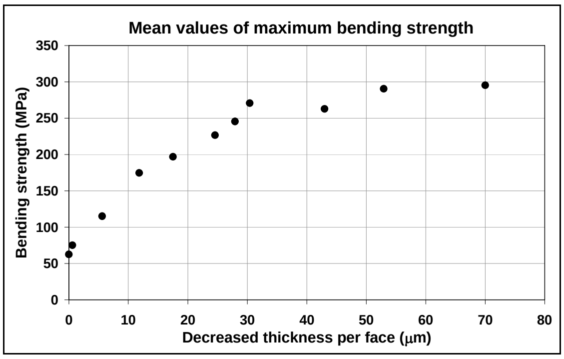

Figure 4: Bending strength versus decreased thickness

The bending strength rises linearly with the decreased thickness up to a value close to 300 MPa which corresponds with a decreased thickness of 30 µm per face. Since then, it seems that the bending strength becomes constant. So, it could be concluded that for the wafers tested the most important surface cracks reside in an approximately 30 µm thick top layer [1].

The wafers tested for this analysis have the cleavage plane orientations of 45º from the edge. Their thicknesses have been reduced by caustic soda baths of different duration.

These results have been taken as the reference for the comparison with those obtained with other methods to decrease thickness.

3.2 Influence of different steps in the solar cell manufacturing process in the mechanical strength

In a PV factory, after a wafer is cut from an ingot, there are several steps to convert the wafer in a solar cell. The influence of some of these steps in the mechanical strength has been analyzed.

The processes chosen for the analysis have been the texturing procedure and the phosphorus addition. The influence of these processes has been studied for different thicknesses of wafers. To this end, wafers subjected to caustic soda baths of different duration have been prepared previous to the analysis of the different steps. These wafers have been divided into three groups. The wafers of the first group have been tested to get a reference value. Those included in the second group have been subjected a texturing process while the wafers on the third group have been added phosphorus. Then, the last two groups have been tested and the complete process explained above has been applied (Figure 5).

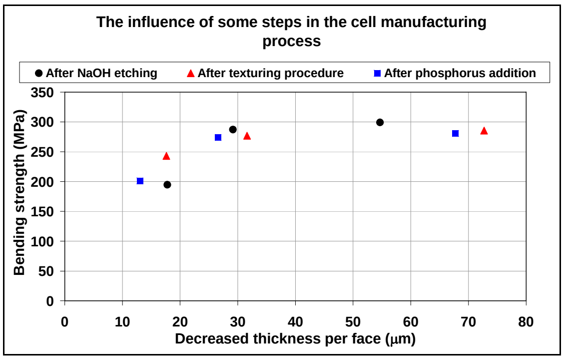

Figure 5: The influence of some steps in the mechanical strength

The wafers prepared for this study have the cleavage planes oriented 22.5º from the edge. The original thickness was 330 microns before starting any surface treatment.

It seems that the texturing process and the addition of phosphorus don't affect significantly the bending strength of the wafers.

3.3 Influence of the cleavage plane orientation in the mechanical strength

The previous results show that the two steps analyzed don't modify the mechanical strength of the silicon wafers. All these points can be grouped in a unique curve which corresponds to the relation between decreased thickness and the mechanical strength for wafers with cleavage planes oriented 22.5º from the edge. The influence of the cleavage plane orientation in the mechanical strength can be analyzed comparing the curves of decreased thickness-mechanical strength for each group or wafers (Figure 6).

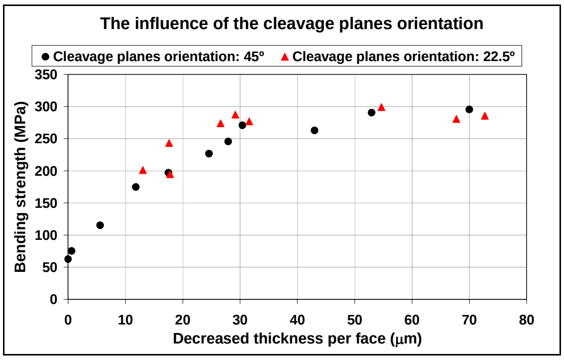

Figure 6: The influence of the cleavage planes orientation in the mechanical strength

The results show that the mechanical strength is not significantly affected by the orientation of the cleavage planes. This result confirms the conclusion drawn in [1].

4 COMPARISON BETWEEN METHODS OF DECREASING THICKNESS

4.1 Mechanical polishing

Another different way of decreasing the thickness of wafers could be the mechanical polishing. This method doesn't employ any chemical product and decreases the thickness through a physical contact.

For the study of this method, two different groups of wafers have been prepared. The original thicknesses in both cases were 210 µm approximately. Through a mechanical polishing the thickness of these wafers has been reduced to 177 µm and to 147 µm. The results are presented in Figure 7 with the reference curve shown before.

The results show that wafers subjected to a mechanical polishing present a lower mechanical strength than wafers bathed in caustic soda. It's thought that the mechanical polishing caused a surface damaged in the wafers that justifies the low values of the strength. This surface damage in the wafer may be caused by the physical contact.

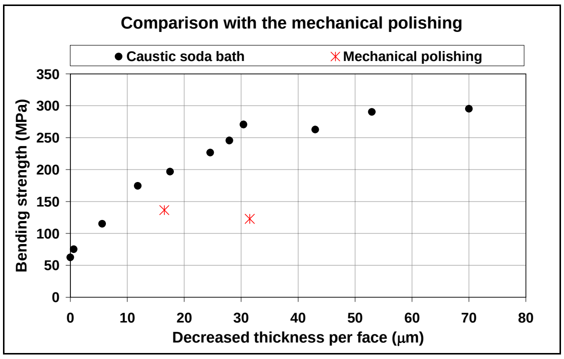

Figure 7: Comparison between the caustic soda bath and the mechanical polishing

4.2 Acid bath

The behaviour of wafers subjected to an acid bath has also been analyzed. The acid bath is more aggressive than the basic one and it's more difficult to control the decreasing thickness process.

For this study, two different groups of monocrystalline wafers with cleavage plane oriented 45º from the edge have been employed. Ones were cut with a thickness of 350 µm and the others with a thickness of 210 µm. The wafers of the second group were bathed in a solution of $HF\text{-}HNO_3$ for different duration getting several thicknesses for testing. However, the treatment for the thicker wafers was a bit different. First, the thickness was reduced through a basic bath with caustic soda. And finally, they were put into a solution of $HF\text{-}HNO_3$ during five and eight minutes, getting wafers with a decreased thickness of 60 and 70 µm per face respectively (the last two points in the right corner of the figure 8). The results of the test are plotted together with the reference in the figure below.

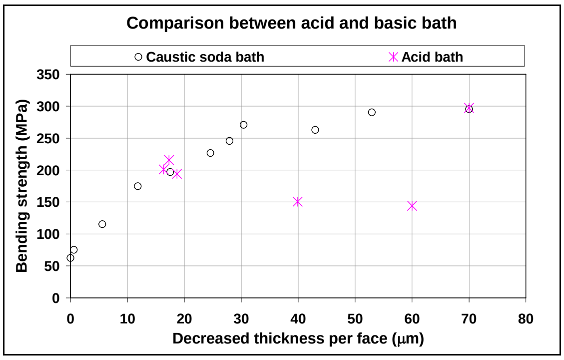

Figure 8: Comparison between the caustic soda bath and the acid bath

There are some points which have similar behaviour as in the basic bath case but there are another which are too far of the reference curve. The results obtained don't permit to draw a final conclusion at this moment. More experiments have to be carried out and further research is necessary in order to know the final state of the wafer after an acid bath.

5 SUMMARY AND CONCLUSIONS

It's well known that the surface damage caused by the multi wire sawing process reduces the maximum stress that the wafer can support. So, an obvious way of increasing the mechanical strength is removing the work-affected layers of the wafers. This paper shows an analysis of the influence of the surface treatments in the mechanical strength and a comparative study of different methods of decreasing thickness.

The main conclusions that can be drawn are:

- Decreasing thickness, the behaviour of wafers is the same despite they were cut with different thicknesses. So, the most important issue for getting a high value of mechanical strength is to eliminate the damaged layers, independently of the initial thickness.
- The mechanical strength increases linearly with the reduction of the thickness. Decreasing the thickness over 30 μm per face, the strength remains constant. However these conclusions are only valid when a caustic soda bath is used for the removal of the surface layers.
- The texturing procedure and the phosphorus addition process don't seem to affect significantly the mechanical properties.
- The orientation of the cleavage plane is not very important in the mechanical strength.
- The caustic soda bath appears as the most reliable way of reducing thickness of the methods analyzed.
- The mechanical polishing process leads to low values of mechanical strength of wafers. It could be justified by the damage caused by the physic contact.
- The acid bath results are very scattered. This way of decreasing thickness is more aggressive than the basic bath and the final state of the wafer is unknown.

Several ways are being studied to confirm the results obtained so far. First, the influence of other steps in the manufacturing solar cells process is being analyzed, as can be the addition of HF. Moreover, it's interesting to study the behaviour of wafers subjected to an acid bath. Finally, the same study for multicrystalline silicon wafers is going to be carried out.

6 ACKNOWLEDGMENTS

This work has been carried out under the sponsorship of the University and Investigation State Secretary, belonging to Spanish Ministry of Education and Science, in its contract ENE2005-09431-C03-03. The presented results have been obtained in cooperation with Institute of Solar Energy (IES) and Microelectronic Technology Institute (TIM). The authors want to thank Isofotón for providing wafers. The authors want to thank also to Philippe Nasch of HCT Shaping Systems for supplying thinner wafers and Stephan Glunz for the supply of mechanically polished wafers.

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