"Study of the failure mechanism of crystalline silicon: relation between crack orientation and failure stress"

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In the PV industry, cracking of solar cells is one of the main causes of failure and demotion. Most cracks are generated in the cutting process to obtain the silicon wafers. For this reason, the characterization of the mechanism of breakage and the behaviour of strength of silicon wafers is highly important in order to minimize the fracture rate and to optimize the process steps. In this study, monocrystalline silicon UMG wafers with different orientation of cracks generated are subjected to a 4-line bending test in order to:

Visualize the moment of the break and the failure mode using a high speed camera (HSC)

Characterize the mechanical strength of the silicon wafers with different cracks orientation by means of the Weibull probabilistic model

Study the relation between the failure stress and the cracks orientation to stablish an accuracy failure criteria for silicon wafers

1. Removing sawing damage

- **Monocrystalline silicon UMG wafers**
- **156x156 mm^2** dimensions (thickness of 200 mm)
- The sawing damage has been removed by means of alkaline **NaOH solution** in all of them.
- Final thickness about **150 µm**.

2. Doing controlled cracks

- The cracks are generated with a **diamond tip**.
- The **depth and the length (10 mm)** of the crack are always the same.

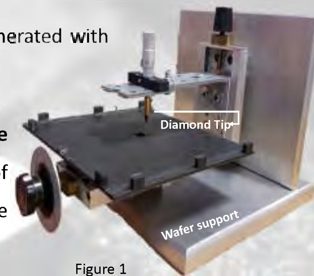


Figure 1

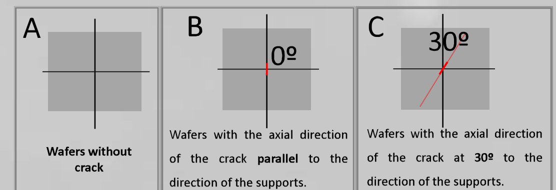


Figure 2

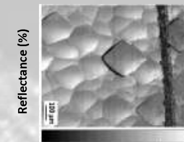


Figure 3

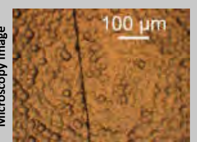


Figure 4

3. Four - line bending test and HSC study

4 – line bending system

- **HSC Photron Fastcam SA1.1**
- **Objective Samyang 135mm**
- **180 000 fps**

A In this case, the silicon wafer breaks into a thousand pieces.

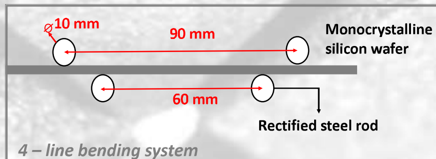


Figure 5

B As can be seen from the image, the breakage goes through the crack completely.
The wafer, at the end of the test, can be reconstructed.

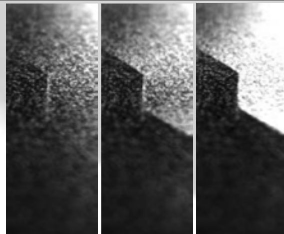


Figure 6

Final state of the wafer in the case B

Figure 7

C Similarly to the previous case, the breakage goes through the crack. However, the wafer is not divided into several pieces at the end of the test (Fig. 9)

Figure 8

Final state of the wafer in the case C

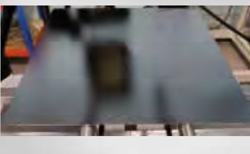
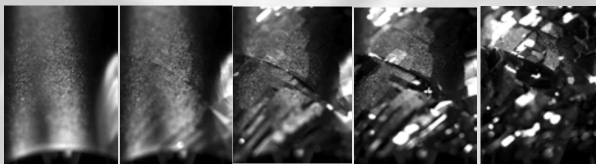


Figure 9



4. Strength characterization

- As a first step, 24 samples of set A and 24 samples of set B are prepared for the strength characterization being tested by the 4-line bending device.
- A clear **non-linear behaviour** is observed for wafers without cracks due to the large displacements during the tests (Fig. 10).
- Finite Element Models (FEM) are developed to simulate the tests (Fig.12).

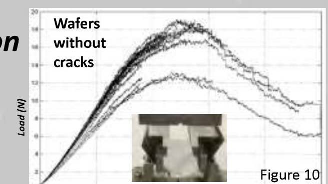


Figure 10

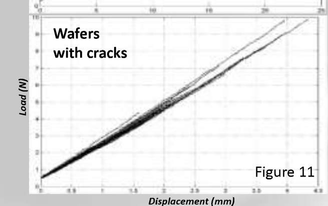


Figure 11

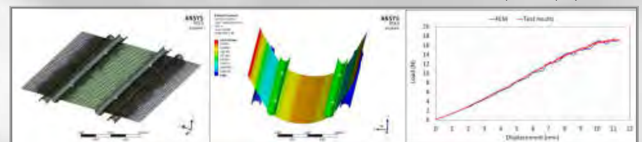


Figure 12

- The whole test is not simulated due to **convergence problems.**
- Once the stress state of all samples are obtained, results are fitted to a Weibull three-parameters distribution obtaining the strength of each set and **the relation between the crack orientation and the strength of the wafers.**

5. Conclusions

- **The images collected with HSC allow to observe how the behavior of the break is different in wafers with and without cracks.**
- **The thin wafers are very flexible, resulting in a non-linear behavior that complicates the model.**
- **Further investigations will be carried out.**

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