Strength of Si Wafers with Microcracks: A Theoretical Model

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Introduction

- Production yield losses resulting from wafer breakage can be as high as 5%–10% in a typical manufacturing facility.
- Fracture strength becomes even more important when the new thinner and large-area wafers are manufactured.
- To successfully reduce silicon usage and maintain high production yield, one needs to understand the fracture behavior of silicon wafers.

Objective

Develop model for the strength of photovoltaic (PV) wafers.

- Analytical description
- Numerical simulation

Identify the features which limit the wafer strength

- Effect of micro-cracks generated during wafer sawing
- Optimize handling and processing to improve production yield

- How to increase wafer strength?
- How to handle fragile wafers?

Classical strength modeling

Weibull distribution

Classical Weibull equation describes the probability $F_\alpha(\sigma)$ that the brittle specimen survives load $\sigma$.

$$F_\alpha(\sigma) = \exp\left\{-\frac{(\sigma - \gamma_v)^{\alpha_v}}{\alpha_v}\right\} dV$$

where $\gamma_v$, $\alpha_v$, and $\alpha_v$ are the three parameters of the Weibull distribution.

In the case of the multiaxial stress state, $\sigma$ represents position-dependent effective stress.

Decomposition into three modes of failure

Monte Carlo simulation for strength of PV wafer

Calculation procedure:

We generate a set of 100 virtual wafers. Each wafer contains 100 randomly distributed and oriented surface cracks.

The maximum load for each wafer is calculated using the fracture-mechanics methods and the weakest-link principle.

Statistical analyses of the results for all 100 wafers are performed to obtain the strength distribution.

We determine if the Weibull distribution can accurately fit the obtained results.

Comparison with experiment

- In our virtual experiment, the strength of wafers varied from 100 to 125 MPa.
- The most probable strength value was 106 MPa.
- The obtained distribution can be accurately fitted by the Weibull equation.
- The predicted distribution compares well with the available experimental results from the literature.
- The strength distribution predicted in this study fits between experimental distributions for the as-sawn and 5-μm etched wafers.

Discussion

1) A new analytical expression that takes into account the surface, edge, and bulk properties of a wafer has been proposed to describe the strength of the brittle materials.
2) A new proposed fracture-mechanics numerical simulation successfully predicted the strength of the cast silicon wafers.
3) It has been shown that the predicted wafer strength distribution agrees well with the available experimental results.

Conclusions and Acknowledgments

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