Handling of Thin Silicon Wafers in PV Manufacturing

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Introduction

- Need for thin (100-250 µm) and ultra-thin (< 100 µm) crystalline silicon wafers driven by PV and semiconductor industry.

- Decreasing wafer thickness and increasing wafer size present significant challenges to handling during cell/module processing.
Thin Wafer Handling Issues

- Fragility: breaks easily under conventional handling/gripping forces
- Lack of rigidity: bow and warp under handling/thermal/device stresses
- Sags under gravity, flutters in slightest airflow
- Very sharp edges: can easily cut through soft materials
Potential Solutions

- Re-design/optimization of existing wafer holding devices/techniques through modeling and analysis

- Minimize wafer handling/transfer via design of integrated wafer processing equipment and/or “palletized” wafer transfer systems

- Develop non-contact handling methods e.g. air conveyors
Research Objectives

Investigate influence of gripper and wafer characteristics on wafer stresses, distortion and breakage. Bernoulli, Vacuum and Mechanical grippers will be studied.

Investigate interaction of process induced residual stresses with handling stresses.

Optimize gripper variables to minimize breakage and hence improve yield of thin crystalline silicon wafers in solar cell fabrication.
Approach (1)

Static and dynamic wafer handling experiments for different wafer types and wafer thickness (100~250\,\mu\text{m})

Modeling and analysis of wafer deformation and stresses due to handling forces

Develop gripper optimization models to maximize yield
Approach (2)

Methodology for understanding the impact of handling and residual stresses on wafer breakage

Wafer Processing

Measure residual stresses in the wafer

Polariscope-based residual stress measurement system

Calculate handling stresses

Pressure and Deformation models

Superpose residual and handling stresses

Compare with breakage stress

Fracture strength Data
Experimental Setup (1)
Instrumented Bernoulli gripper mounted on 4-axis Adept SCARA Robot

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Sample Results (1)

Volumetric flow rate influence

20% ↑ in V
£ 118% ↑ in D
(for T=202 μm & H = ‘-’)

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Sample Results (2)

Thickness influence

43% ↓ in T
50% ↑ in D
(for V= 39.1 lpm & H=‘-’)

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Sample Results (3): EFG Wafer
Methodology for modeling and analysis of deformation and stresses in thin wafer held by Bernoulli gripper

- Volumetric flow air
- Gripper geometry

Pressure distribution model

- Pressure distribution
- Wafer characteristics

Finite Element model

- Wafer deformation
- Handling stresses

Unstable handling due to excessive stresses or vibration

\[ p(r) - p_a = \frac{1}{2} \rho \left( v_0^2 - v(r)^2 \right) + Ef(r) \]

\[ Ef(r) = \int_r^{r_0} dEf(r) dr \]

\[ dEf(r) = \frac{6 \rho Q \nu}{\pi} \times \frac{1}{r h(r)^3} \sqrt{1 + \frac{K^2 Q}{8 \pi \nu} \times \frac{h(r)}{r^2}} \]
Predicted deformation (0.20mm max.) of 202µm EFG wafer compared to measured deformation (0.39mm max.) at Q= 30 lpm

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Predicted Mises stresses of a 202µm EFG wafer at Q= 30 lpm

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Predicted vs. measured maximum EFG wafer deformation

- **T = 202 μm**
- **T = 315 μm**
- **T = 353 μm**

- Measured deformation
- Predicted deformation

**Volumetric flow rate (lpm)**
Summary

Research focus on developing fundamental understanding of thin wafer handling issues

Evaluate capabilities and limitations of current handling devices for thin silicon wafers e.g. Bernoulli, vacuum, mechanical grippers

Analyze interaction of residual stresses and handling stresses

Develop physics-based models for thin wafer handling optimization to minimize breakage
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