Measuring Stress in Si Ingots Using Linear Birefringence

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INTRODUCTION

The cost of Si material is one of the most significant cost factors in the production of Si solar panels. Material losses of up to several percent occur throughout the manufacturing process, mostly due to stress and defects that arise during the crystal growth process. Stress in Si crystals remains undetected long into the fabrication process, until ultimately the end product fails, or its performance is severely compromised. We report measuring stress birefringence in Si crystal ingots early in production before subsequent processing costs are incurred.

INSTRUMENT AND WORKING PRINCIPLE

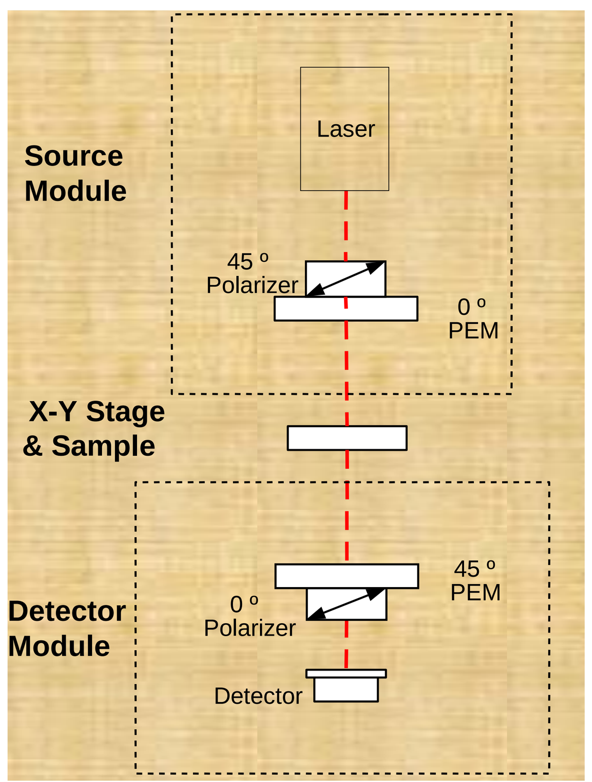

Fig.:1 Block diagram of a NIR Exicor stress birefringence polarimeter.

Retardation:

$$\delta = \tan^{-1}\left(\sqrt{\left(\frac{R_1}{R_3}\right)^2 + \left(\frac{R_2}{R_3}\right)^2}\right)$$

$$\rho = \frac{1}{2}\tan^{-1}\left[\frac{R_2}{R_1}\right]$$

Differential stress:

$$\sigma = \frac{\delta}{t \cdot C_B}$$

High repeatability

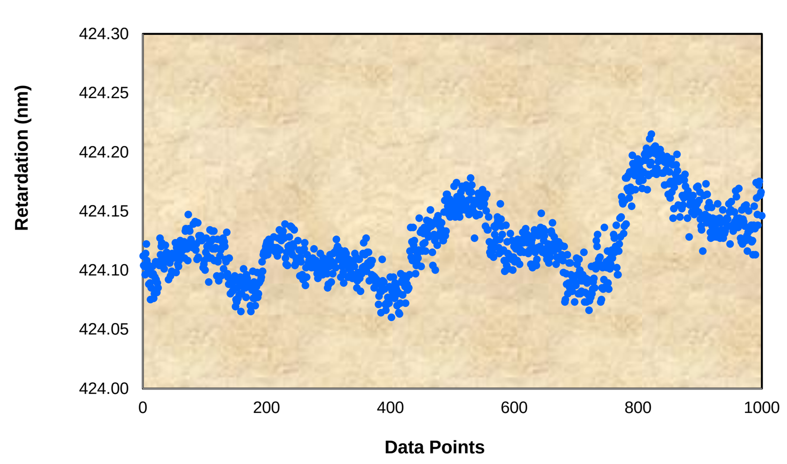

Fig. 2. A typical data set representing instrumental repeatability, mean: 424.12 nm; standard deviation of 0.03 nm; measuring wavelength: 1310 nm.

Low noise

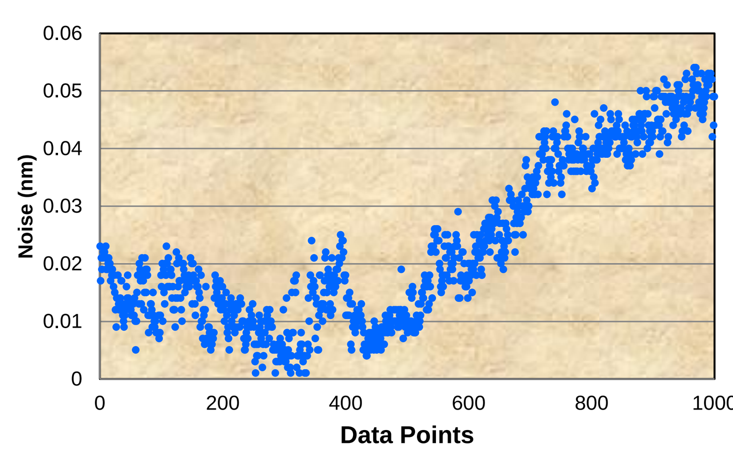

Fig. 3. A typical data set representing instrumental noise level; standard deviation of 0.02 nm; measuring wavelength: 1310 nm.

High accuracy

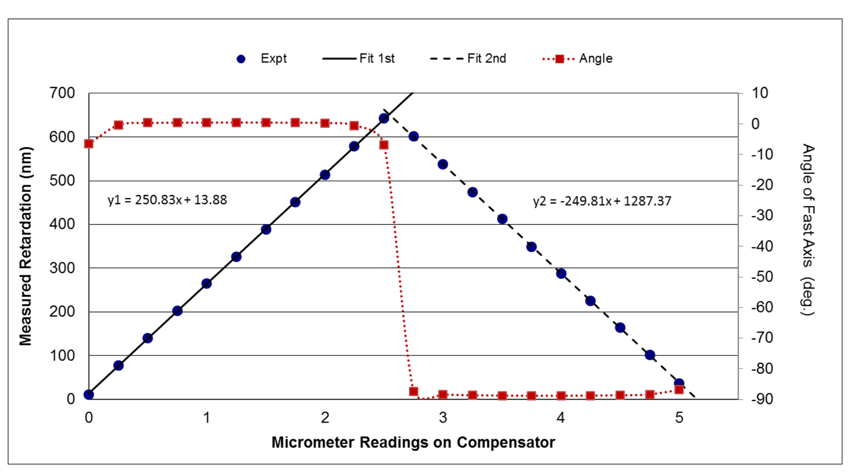

Fig. 4. Accuracy test data at 1310 nm using a Soleil-Babinet compensator (blue dots: measured values for retardation; red squares: measured angles of fast axis; linear fit for the first half: solid line; linear fit for the second half: dashed line).

Si Ingots, Squared, various lengths

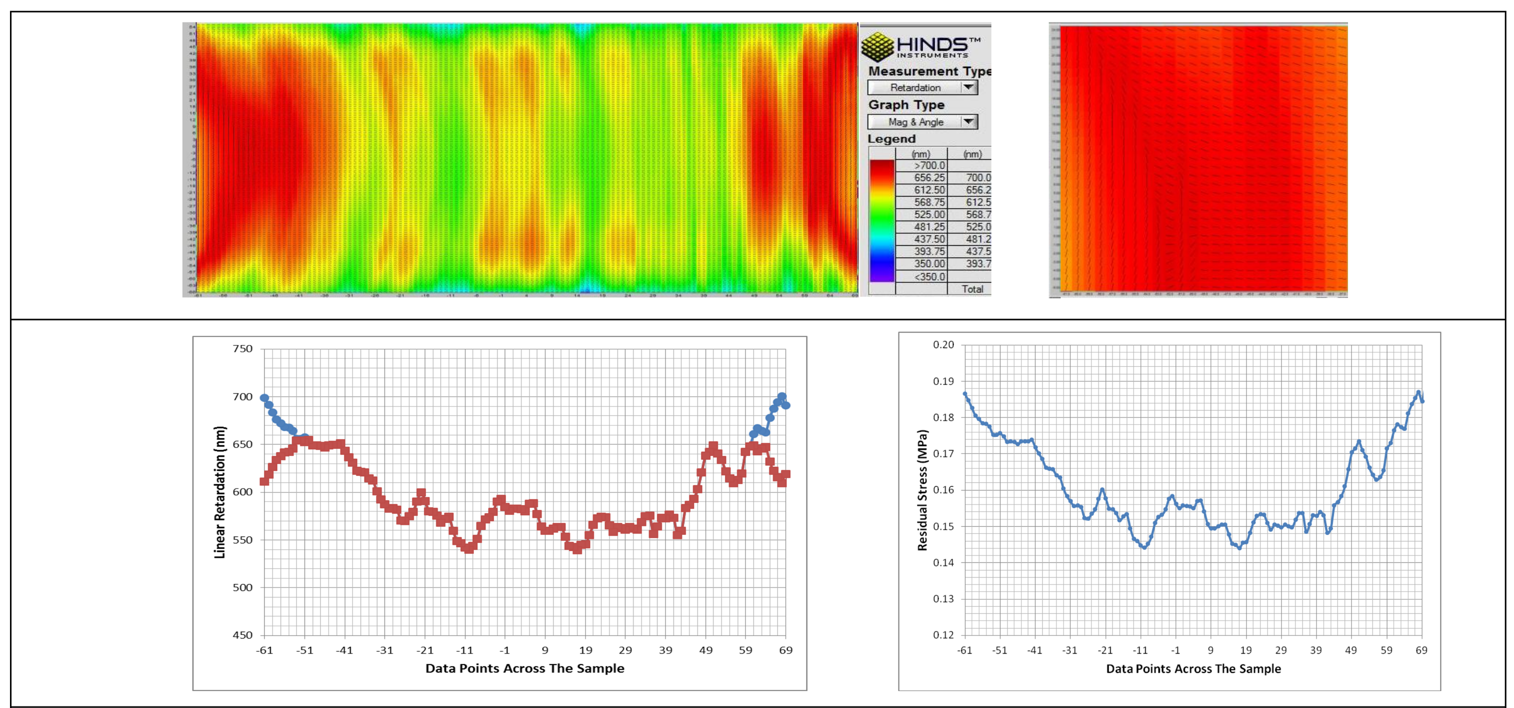

Fig. 5. (a. top-left) 2D linear retardation map of a squared Si ingot; (b. top-right) an expanded portion of the left end of 5a to show the 90º shift in measured fast axis when retardation is above half-wave; (c. bottom-left) numerical values of measured (squares) and corrected (dots) linear retardation for a line of data from the 2D map; (d. bottom-right) numerical values of calculated stress for the corrected data.

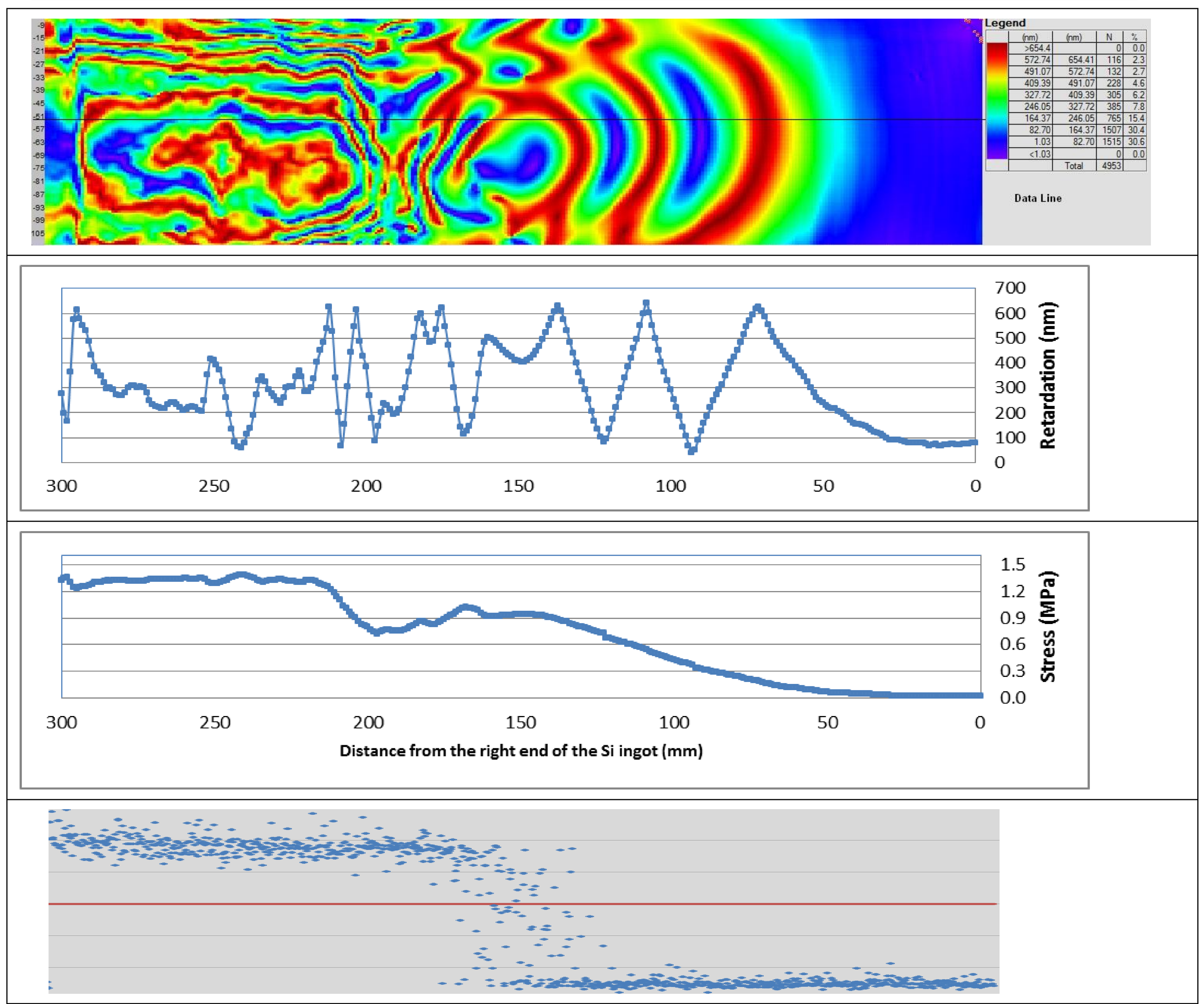

Fig. 6: Top to bottom: a. 2D linear retardation map of stressed Si ingot; b. line data for measured linear retardation (The right end of the Si ingot is labeled "0" on the horizontal axis. Each data point represents a 1 mm spacing.); c. calculated stress; and d. bowing of Si wafers produced from the same ingot.

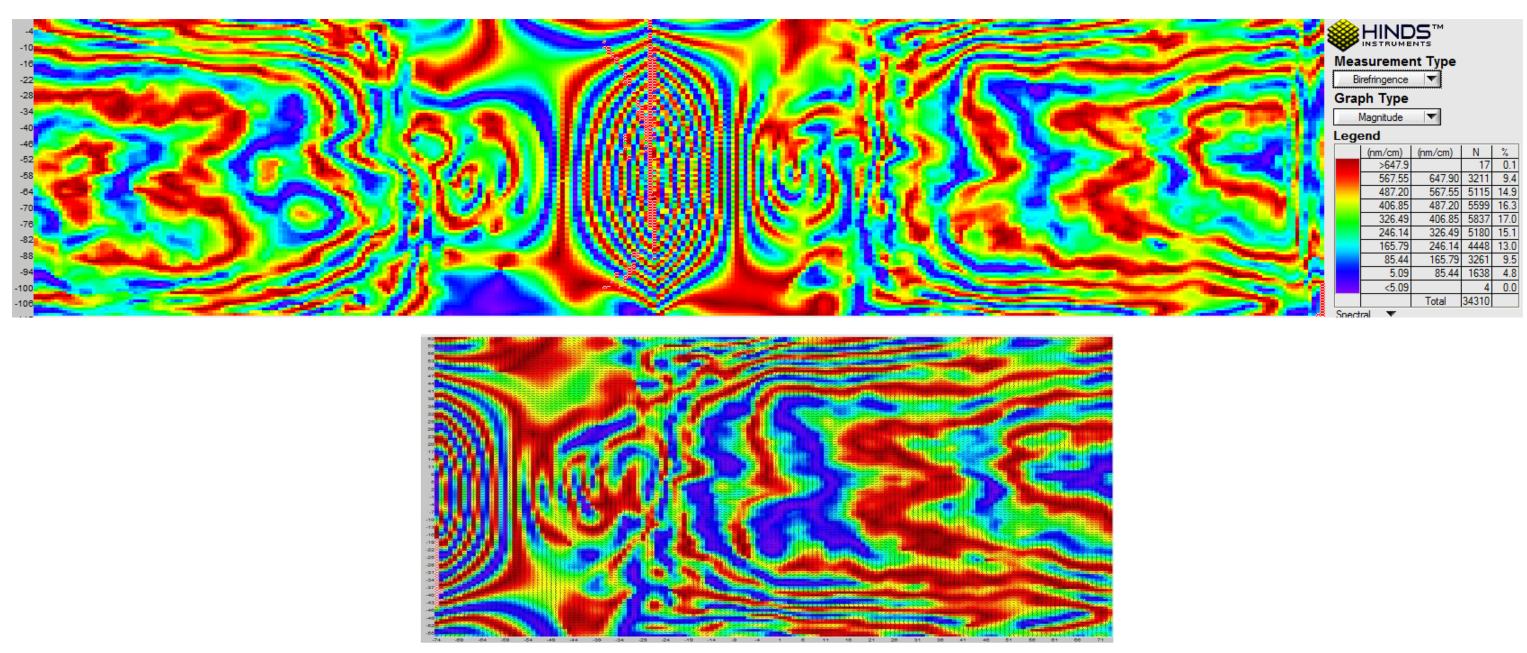

Fig. 7. (a. top) 2D retardation map of two Si segments joined together by adhesive; (b. bottom) 2D retardation map of the right Si segment after removing the adhesive.

CONCLUSIONS:

Mapping of stress birefringence is a promising technique to measure stress in CZ-grown Si ingots. The linear birefringence measurement system can be employed as both a quality control tool for Si ingots and a laboratory research instrument for production process improvement. Our data suggests that stress above 0.5 MPa in Si ingots could result in strong wafer bow.

Acknowledgments

BW thanks Andy Breninger, Bob Lakanen, Chad Mansfield, John Freudenthal, Doug Mark, Hugh Runyan, Jacob Wolf, Linda Hirschy and other colleagues at Hinds for their help.

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SiliconPV 2013, Hamelin, Germany