RESIDUAL STRESS MEASUREMENTS USING POLARISCOPY AND CRACK DETECTION AND ANALYSES USING RESONANCE ULTRASONIC VIBRATIONS IN CRYSTALLINE SILICON WAFERS

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ABSTRACT

This research addresses the non-destructive measurement of in-plane residual stresses and crack detection in thin, flat single and multi-crystalline silicon wafers. A specialized polariscopy system and technique has been designed and built and stress maps are being made by the transmission and detection of near infrared radiation. A crack detection system utilizing resonant ultrasonic vibrations has been designed and built and edge cracks are being measured. Close cooperation has been established with the major sheet silicon manufacturers.

1. Objectives

The objective of this research are to identify and eliminate sources of residual stresses and mechanical defects such as periphery cracks leading to the loss of wafer integrity and ultimate breakage of as-grown and processed Si wafers and cells. The problem is increased as the wafer thickness is reduced down to 100 microns with a parallel increase of size up to 210 mm. It is recognized that the development of non-destructive methods for fast non-contact stress measurements and in-line crack detection is required for all crystalline Si technologies, including Czochralski (Cz), cast and ribbon. This report summarizes our crack detection work [1] and [2] while ref. 3 documents the work on in-plane residual stresses.

2. Results and Accomplishments

(a) Mode analyses. In Figure 1 we show a full-range RUV f-scan on a 156 mm x 156 mm cast wafers with 240 μm thickness. The scan shows a number of sharp RUV peaks, four of which are identified with particular vibration modes using Finite Element Analyses (FEA) in an ANSYS program. In Table 1 experimental and calculated resonance frequencies are compared. To further confirm the mode identification, we performed periphery line scans of each vibration mode to establish a profile of the vibration amplitude. The results shown in Figure 2 for vibration mode #2 with the peak position at 45 kHz are consistent with ANSYS results and calculated mode shape.

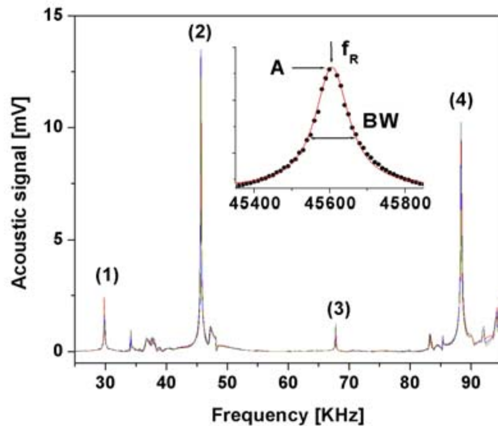

Fig. 1. Full range ultrasonic frequency scan on four similar 156mm x 156mm cast Si wafers. Four principal resonance modes are replicated in the f-scan. The insert shows the experimental data of the second mode at 46.8kHz (points) and its Lorentzian fit (solid line).

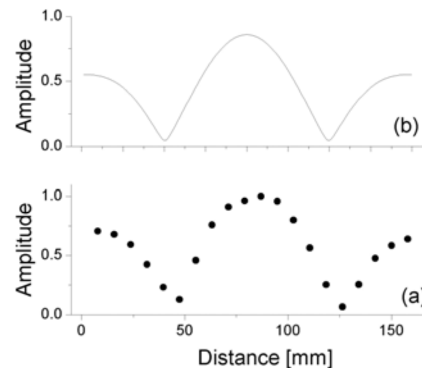

Fig. 2. Periphery line scans of the vibration amplitude of the 45 kHz RUV mode on the square 156 mm x 156 mm wafer: (a) experiment, (b) FEA modeling.

Table 1. Experimental and calculated resonance frequencies of 4 vibration modes [Hz] in 156 mm x 156 mm silicon wafers.

Mode number	(1)	(2)	(3)	(4)
ANSYS	31,461	45,980	68,089	89,334
Experiment	29,800	45,800	67,800	87,500

(b) Crack detection. A set of identical 125mm x 125mm pseudo-square shaped (100) oriented Cz-Si wafers were chosen for the initial crack study. All wafers were initially screened using a Scanning Acoustic Microscope (SAM) for structural integrity. Using the RUV technique, frequency scans of the longitudinal vibrations from 20 to 90 kHz were measured and one of the resonance modes (A-mode) at $f=49,930\pm20Hz$ was selected. We *introduced* cracks with different sizes oriented along <110> directions by scribing the wafer edge with a diamond pin. The length of each crack has been measured using SAM with a 10 μm resolution. In Figure 3, we demonstrate the A-mode spectra in wafers with different crack sizes.

Clearly, the A-mode frequency decreases with increasing crack length. In addition, the mode bandwidth (BW) increases with the crack length.

We were able to clearly detect mm-size cracks by assessing A-mode peak shift and line broadening. We estimate that the RUV approach offers sub-millimeter crack length sensitivity in Cz-Si wafers.

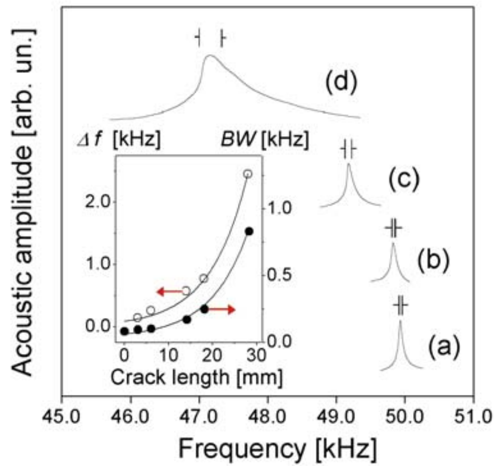

Fig. 3. The A-mode spectra of a non-cracked Cz-Si wafer (1), and wafers with different <110> crack lengths: (2) 3.0 mm, (3) 18 mm and (4) 28 mm. The insert shows the dependence of resonant frequency shift and bandwidth variation of the A-mode versus crack length.

In the next step, RUV measurements were performed on a set of 125 mm x 125 mm cast Si wafers with 220 micron thickness. All wafers show consistency in the RUV peak parameters (Figure 4). The wafer #11 was subjected to the crack indentation, which immediately responded to substantial variation of all three RUV parameters. We suggest that assessing all three parameters of the resonance peak using RUV approach substantially increases the sensitivity of the crack detection in cast wafers reducing the number of false positives in the RUV.

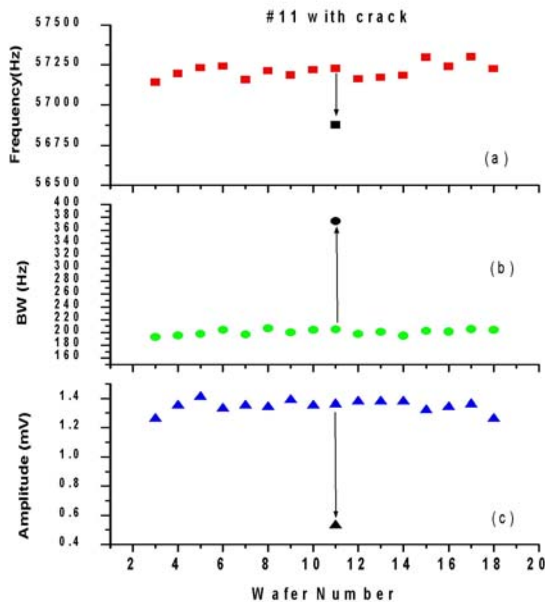

Fig. 4. RUV data on a set of 125 mm x 125 mm (220 microns thick) cast wafers. 10 mm crack in the wafer #11 is identified by (a) peak shift to the lower frequency, (b) increase of the bandwidth, and (c) reduction of the peak amplitude.

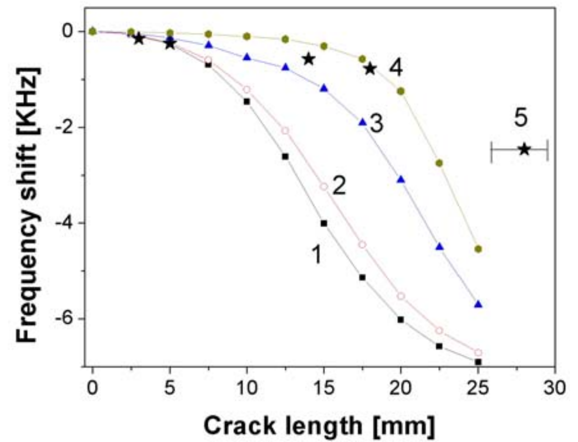

Fig. 5. ANSYS calculated downward shift of the resonance frequency for 51,052 Hz mode as a function of spring element stiffness parameter [dn/cm^2]: (1) – 0, (2) -1e10, (3) – 1e11, (4) – 1e13, (5) – experiment.

3. Conclusions

The observed decrease of the RUV mode frequency and its dependence on crack length are consistent with FEA analysis. We concentrated on the frequency shift of the vibration mode at f_0=51,052 Hz, which is closest to the experimental vibration A-mode. The FEA shows a decrease in frequency shift with increased crack length, which supports our experiment (Fig. 5). We introduced into FEA modeling a spring damping element with variable stiffness which is a fitting parameter in the calculations. In Figure 5, we present a set of curves for Δf_R shift versus crack length at different spring stiffness along with experimental data. Though FEA calculations are consistent with experimental data, we recognize a noticeable deviation for a large crack length (28 mm crack). Further development of the FEA model is in progress. We may conclude that experimentally observed downward frequency shift in wafers with crack is a consequence of the reduced stiffness of the wafer caused by the peripheral crack.

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