PINHOLE DETECTION IN Si SOLAR CELLS USING RESONANCE ULTRASONIC VIBRATIONS

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ABSTRACT

Resonance Ultrasonic Vibrations (RUV) methodology was developed to accurately and automatically detect mechanically unstable wafers and cells with millimeter-length cracks. It was observed by cell producers that other mechanical problems possess a high probability of wafer/cell breakage in production. A small, sub-millimeter diameter "pinhole" represents a seed point defect which dramatically reduces the cell strength and ultimately leads to breakage and yield reduction. To address this production problem, we designed a new cell inspection protocol to identify the wafers and cells with pinholes using an addition to the RUV system called the Activation Station. Pinholes were introduced by indentation in a commercial grade single- or multi-crystalline Silicon solar cells and revealed by a high resolution Scanning Acoustic Microscopy (SAM) and in further details by Scanning Electron Microscopy combined with Focused Ion Beam with cross section capability. It was established that after the indentation, a pinhole gives rise to sub-millimeter length seed cracks which elongate in the form of cross-cracks in Cz-Si cells, and lead to cell fracture. To observe and screen out cells with this type of flaws the RUV system was upgraded with the Activation Station. A new RUV-AS cell inspection protocol was realized. Our tests show that pinholes located at the central area of the cell are covered with 100% accuracy.

INTRODUCTION

The silicon wafer is a large contributor to the overall cost of the solar cell. To reduce production cost, solar Si wafers are sliced thinner with thicknesses down to 150-200 microns with a target of 100 microns. In parallel, wafer areas have also been increased with typical size of 156x156 mm. These technological trends make Si wafer handling in production more challenging and reduce the yield of solar cell lines due to increased wafer and cell breakage. In-line wafer breakage also reduces equipment throughput as a result of down time. Resonance Ultrasonic Vibrations (RUV) methodology was developed to accurately and automatically detect mechanically unstable wafers and cells with millimeter-length cracks. A fundamental concept of the RUV method is briefly described below and detailed elsewhere [1-3]. RUV technique was developed for off-line and in-line (24/7) non-destructive crack detection in full-size silicon wafers and solar cells. The RUV technology allows (1) rejection of mechanically unstable Si wafers after ingot cutting before they are introduced into further cell processing, (2) identification of wafers with mechanical defects (such as cracks) during production to avoid their in-line breakage, (3) detection of cracked cells before they will be laminated into modules to avoid panel efficiency reduction and product return from the field.

RUV FUNDAMENTALS

The RUV methodology relies on deviation of the resonance frequency response curve measured on a wafer with peripheral or bulk millimeter-length crack from identical non-cracked wafers. Through a resonance frequency curve selected from a broad range (20 - 100 kHz) the RUV method enables crack detection with simple criteria for wafer or cell rejection. A crack introduced into the Si wafer alters the RUV peak parameters: amplitude, bandwidth and peak position. This is illustrated in Figure 1 for two identical Cz-Si wafers. Specifically, the crack in the wafer shows the following features: (1) a frequency shift of the peak position; (2) an increase of the bandwidth, and (3) a reduction of the amplitude. Therefore, the RUV approach is based on a fast measurement and analyses of a specific resonance peak and rejection of the wafer if peak characteristics deviate from the normal non-cracked wafers. In Figure 2 a schematic of the RUV system layout is shown.

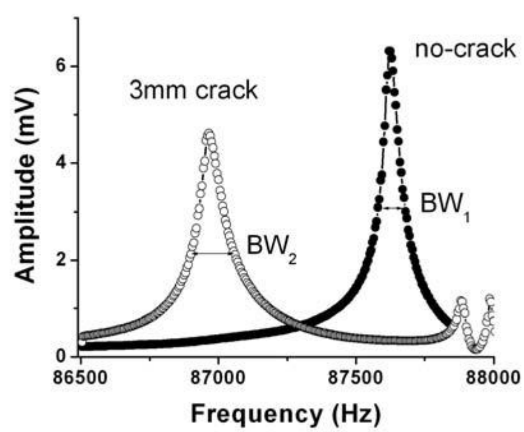


Figure 1 Deviations of peak parameters caused by a crack.

The sensitivity of RUV system, which refers to the length of the cracks, is adjustable to the needs of the user. The rejection algorithm is based on a statistical approach. In case studies the accuracy of the RUV method was between 91 - 95% [1]. It means that after RUV inspection the breakage caused by cracked wafers or cells is reduced by a factor of 10 or more.

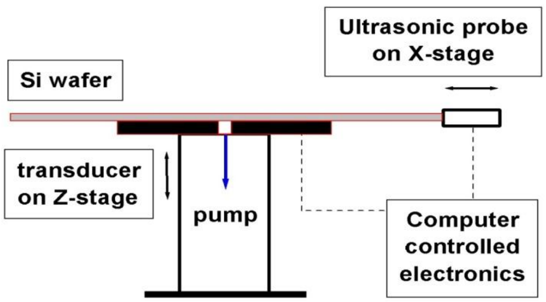
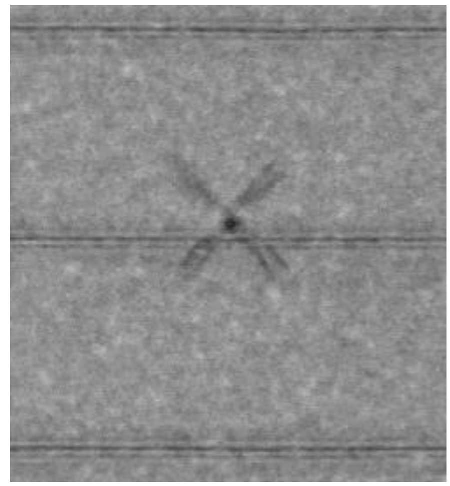


Figure 2 RUV system schematic

In terms of in-line application, the RUV-2.2 system throughput rate is close to 2.0 sec per wafer and limited only by moving mechanical parts. Standard solution with split-line configuration allows cycle time reduction down to 1.0 sec per wafer which matches to state-of-the-art automatic solar cell lines.

PINHOLE DETECTION

It was indicated by cell producers that other mechanical problems possess a high probability of wafer/cell breakage in production. A small, sub-millimeter diameter "pinhole" represents a seed point defect which dramatically reduces the cell strength and ultimately leads to product breakage and yield reduction. The illustrative high-resolution Scanning Acoustic Microscopy image of the pinhole is presented in Figure 3. To address this production problem, we designed a new cell inspection protocol to identify the wafers and cells with pinholes using an addition to the RUV system called the Activation Station (AS). In this study the pinholes were introduced by indentation in a commercial grade single- or multi-crystalline Silicon solar cells and revealed by a high resolution Scanning Acoustic Microscopy (SAM) and in further details by Scanning Electron Microscopy (SEM) combined with Focused Ion Beam with cross section capability. Illustrative SEM image of the crack's cross section is presented in Figure 4. It was established using SAM/SEM techniques after the indentation a pinhole gives rise to sub-millimeter length seed cracks which elongate in a form of cross-cracks in Cz-Si cells, and lead eventually to the cell fracture. Using a twist test technique it was established that the cell with a pinhole flaw has a breakage force below 1 N compared to 5-7 N breakage force of the identical cell without the pinhole defects. To observe and screen out cells with this type of flaws the RUV system was upgraded with the Activation Station. The following cell inspection protocol was realized: prior to RUV testing the cell is passing through the AS with settings defined by cell type. After activation, the cell is automatically transferred to the RUV system and analyzed using the upgraded software as well as using the standard RUV statistical algorithm. Some heavily damaged cells are broken during the activation step and eliminated by the hardware. The technique was successfully implemented on single-crystalline (Cz) and multi-crystalline (cast) Si cells. Our tests show that pinholes located at the central area of the cell are covered with 100% accuracy. We performed FEA calculations that justify the concept of pinhole detection using the modified RUV approach.



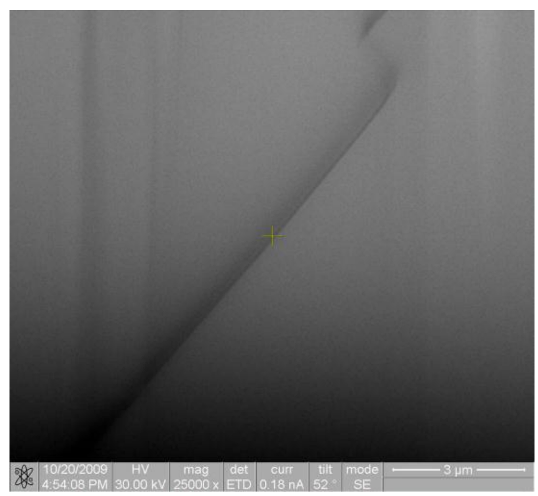


Figure 4 SEM cross-section of the silicon cell across propagated crack, image size is 9.5 x 11 microns.
Figure 3 SAM image of 3.6 x 3.6 mm map with sub-millimeter pinhole. Note that unopened cross cracks provide cleavage directions when the cell is broken.

In Figure 5 we show Finite Element Analyses results of stress pattern applied to the isotropic silicon plate using four suction cups.

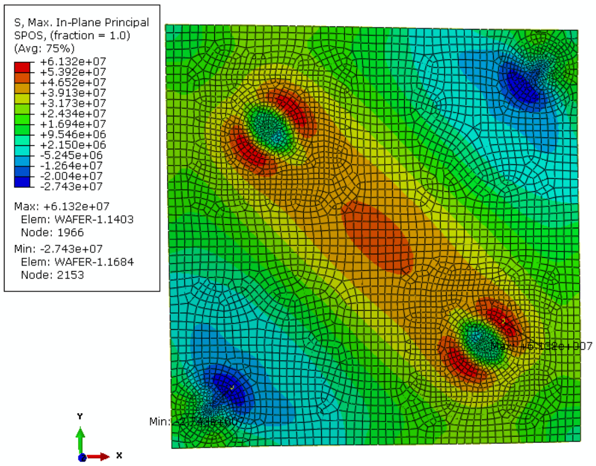


Figure 5 FEA calculation of stress profile under 5 mm wafer deflection using proposed AS procedure (front surface). Maximum stress of 61.3MPa is in the contact regions of suction cups and wafer.

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