Detection of cracks in single crystalline silicon wafers using Impact test and Endurance test

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Abstract - *In the present investigation is about detection of cracks in single-crystalline silicon wafers by using a vibration method in the form of an impact test. The aim is to detect cracks from vibration measurements introduced by striking the silicon wafer with an impact hammer. Such a method would reduce costs in the production of solar cells. A hammer is used as the actuator and a microphone as the response sensor. A signal analyzer is used to collect the data and to compute frequency response. Parameters of interest are audible natural frequencies, peak magnitudes, damping ratio and coherence. In the present work, is to make the impact hammer automated instead of manually hitting the hammer. This would facilitate a quicker repeatable test process possibly suitable for in-line production use. A non-automated impact test takes about 15-30 seconds. If automated this could be reduced to a few seconds. Different crack lengths should be investigated to establish a quantitative sensitivity limit for the millimeter size cracks. In this present work, the crack lengths investigate were less than 8 mm or larger than 38-55 mm. Also, explore further tests to different crack locations could be studied. It is also to develop an endurance test to investigate how many impacts can be applied on the cracked wafer with a critical length of 1 cm before it breaks. This would represent an endurance is applicable or not.*

Key Words: *Silicon Wafer, Impact Hammer, Signal Analyser, Actuator, Microphone, Vibration measuring parameter.*

1. INTRODUCTION

The renewable energy market is growing and so are the photovoltaic industries. The thought of using the sun's power for generation of electricity is not new. The concept dates back to the industrial revolution. Crystalline Silicon is the most common material used in the photovoltaic market with over 95% market share. The reason that the photovoltaic cell is not more widespread is cost, particularly cost of cell production. During crystal growth and processing of silicon wafers, imperfections (such as cracks, residual stresses and sub-surface damage) are introduced. Breakage during production due to defects is currently 6-15%, but the industry wants to get this down to 1%, in this thesis to detect the cracks could help facilitate this goal. There is a need for fast in-line mechanical quality control methods to detect these imperfections during the production of silicon solar cells. This could reduce the further processing of defective products and reduce overall costs. This thesis focuses on vibration impact testing of wafers for crack detection.

1.2 Specifications of Single crystalline silicon wafers

Type:	P
Dopant:	Boron
Resistivity:	1.0-3(ohm.cm)
Dimension:	127 x 127±0.5 (mm)
Thickness:	200±20 (μm)
Oxygen Content:	≤1 x 10^{18}
Carbon Content:	≤5x 10^{16}
Minority Carrier Lifetime:	≥2 (us)
Microcrystal:	10/cm^2
Saw Depth:	<20 (μm)
Bevel Edge Angle:	90°±0.3
Bevel Edge Length:	1±0.5 (mm)
Rectangular Angle	0.3°
Edge Defect:	No crack, no V-Shape Chip
Surface Quality:	As cut, cleaned, no stain; No water mark, no contamination, no pits on the surface.
Edge Chips:	Length 0.5mm, Depth 0.3mm, 2 per wafer.

2. Experimental Setup

This chapter presents the experimental setup and describes the sensors and the analyzer used. The specimens used are single-crystalline Czochralski (Cz) silicon wafers. Since the purpose is to detect cracks in wafers there are different types of specimens tested. In this research, the cracked specimens have been deliberately damaged with a diamond pin. In all, thirty different cracked specimens were made and tested.

2.1 Sensor

An impact hammer and a sound level meter are the two sensors used in this experiment. The impact hammer, model PCB 084A17, is made by PCB Piezotronics Inc. The sensitivity of the impact hammer is 22.5 mV/N. The hammer's weight is 2.9 grams and the aluminum handle is 101.6 mm long, the hammer has a stainless steel head with a diameter of 6.3 mm and a red vinyl tip with a 2.5 mm diameter. The hammer is connected by a 0.18G10 coaxial cable, which is 3 m long, with a 5-44 connector terminating in a 10-32 connector that is connected with a BNC to the SigLab dynamic analyzer. The used sound level meter model 2900 manufactured from Quest Technologies. The meter is set to measure sound pressure in the range of 60- 120 dB. The sensitivity of the sound level meter is 5V/120 dB. The sound level meter and the SigLab dynamic analyzer are connected from the ac output of the meter with a 6 ft shielded cable 1/8" plug to an RCA plug. The RCA plug is connected with a gold plated RCA to BNC adapter and connected with the female BNC connection of the analyzer.

2.2 Analyzer

The analyzer is SigLab model 20-42 and is manufactured by DSP Technology Division. The SigLab has 4 input channels and 2 output channels. The impact hammer is connected to input channel 1 and the sound level meter is connected to input channel 3. The analyzer calculates the frequency response with the impact force as the input and the sound pressure as the output. A laptop is connected to the SigLab with a Slim SCSI PC card, the PC runs the SigLab software which is written in MatLab R12. In the SigLab software, the bandwidth is set to 1.0 kHz and the record length is 8192, which gives a delta frequency of 0.313 Hz and a record time of 0.3 seconds. Also, the sensitivity of the hammer and the sensitivity of the sound level meter are included in the analyzer setup. The hammer sensitivity is set to 44.4 N/V for channel 1 and the sound pressure level sensitivity is set to 24 dB/V for channel 3.

2.3 Frequency response

The frequency response is computed with the impact force, F, (in units of Newtons) applied from the hammer as the input and the sound pressure level, S, (in units of dB) from sound meter as the output. Time trace measurements of theinput and output are obtained. The measurements are windowed (i.e., box window for the input and exponential window for the response) and the Fast Fourier Transforms of the windowed time traces are computed. The measurements are repeated eight times,n, and then averaged. Power spectra (PFF (f), PSS (f)) and cross spectra (PSF (f)).

2.4 Setup

The test setup is shown in Figure 2.1. The specimen is set on a piece of convoluted foam of dimensions 7 x 33 x 26.5 cm. The sound level meter is attached to a rigid fixture and the microphone is set at 1.2 cm above the specimen. The microphone is set perpendicular to the wafer. The impact hammer is connected to channel 1 of the SigLab analyzer and the sound level meter is connected to channel 3 of the SigLab analyzer.

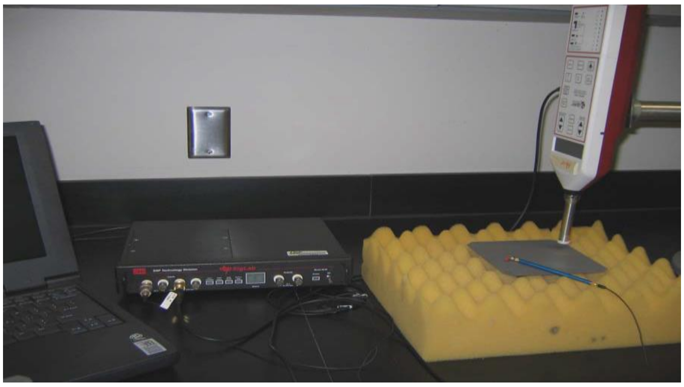

Fig. 1 Experimental setup

2.5 Position of hammer and microphone

The horizontal position of the hammer and the sound level meter with respect to the specimen is shown in fig. 2.

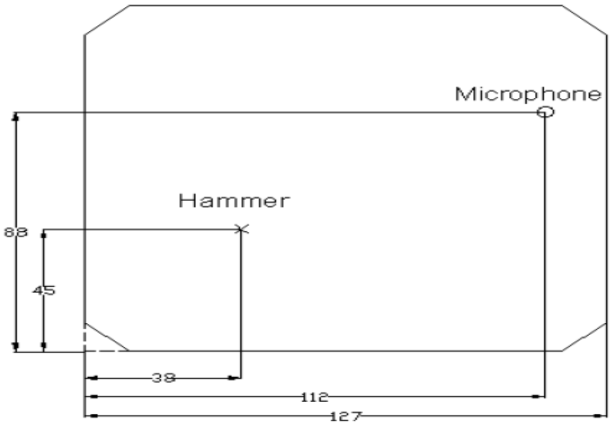

Fig. 2.Position of hammer and microphone relative to wafer all the units are in mm

The decision on where to locate the hammer and microphone with respect to the wafer was made by keeping the hammer in the same place and moving the microphone and then moving the hammer while keeping the microphone in the same location.

2.6 Procedure

- To detect cracks from vibration measurements introducing by striking the silicon wafer with an impact hammer. Such a method would reduce costs in the production of solar cells.
- To compare the differences in frequency between the cracked silicon wafers and the non-cracked silicon wafers.
- These differences could be used to detect damaged product in a solar cell production line.
- To make the impact hammer automated instead of manually hitting the hammer for quick repeatable test.
- A non-automated impact test takes about 15-30 seconds. If automated this could be reduced to a few seconds.
- Different crack lengths should be investigated to establish a quantitative sensitivity limit for the millimeter size cracks.
- Explore further tests to different crack locations can be study.
- To develop an endurance test to investigate how many impacts can be applied on the cracked wafer with a critical length of 1 cm before it breaks. This would represent an endurance test is applicable or not.

3. Results and Discussion

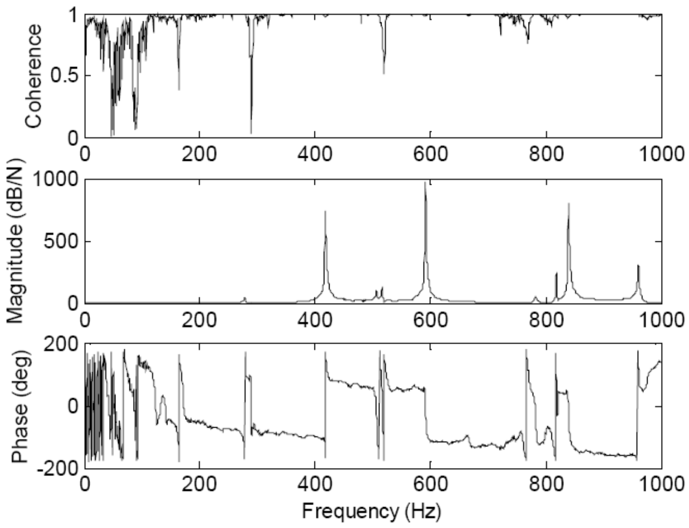

Chart-1: Frequency response of crack-free wafer number 29

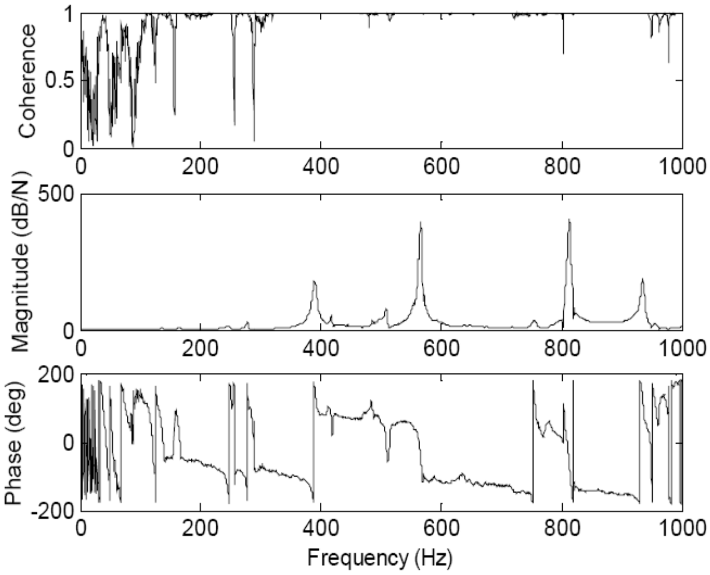

Chart-2: Frequency response of large crack wafer number 35

For the large crack wafer set, four wafers (numbered 31, 35, 48, and 27) shows significant deviation in the natural frequencies for the four modes. For the magnitude peaks, eight wafers (numbered 39, 31, 35, 48, 32, 40, 36, and 27) show a significant difference. For the damping ratio, four wafers (numbered 31, 35, 48, 27) show a significantly difference. Only four from the twelve large crack wafers set showed significant deviation in frequency, magnitude and damping ratio. These four large crack specimens have continuous cracks as opposed to segmented cracks as in the other 8 large crack specimens. From the miscellaneous wafer set, wafer numbers 23 and 8 show a difference in the normalized frequency. Looking at the magnitude, six of the cracked wafers show a difference compared to the crack-free wafers. The damping ratio was higher for number 23, 25, 47 and 8. In other words, 50% of the cracked wafers were different from the crack-free data set considering the damping ratio and the magnitude. The small crack wafer set did not show any notable change in frequency, magnitude or damping ratio. The crack lengths of the wafers were too small to detect the cracks using the impact method described in this thesis.

4. CONCLUSIONS

The results showed some deviations in the four dominate audible modes that were measured for cracked versus crack-free wafers. Differences in the natural frequencies and in the magnitudes were found by the test. Also, the cracked wafers had higher damping ratios than the crack-free wafers. This is expected due to frictional damping introduced within the crack. For the large crack wafers considering the second audible mode, 33% of the cracked wafers showed a significant difference in frequency, and

67% had a significant difference in peak magnitude, and 33% had a significant difference in damping. Note that only 33% of the large cracked wafers had continuous cracks. Therefore, 100% of the wafers with continuous large cracks showed significant differences in all 3 parameters. For the miscellaneous wafers, 25% of the cracked wafers had a notable difference in frequency, 75% had a notable difference in peak magnitudes and 50% had a notable difference in damping. The small crack wafers did not show any notable difference between the crack free wafers and the wafers with cracks for the frequency, magnitude, or damping. Overall, the data showed that the peak magnitude was the most sensitive to cracked wafers, followed next in sensitivity by the damping ratio and the natural frequency.

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