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Effect of diamond wire saw marks on solar cell performance

Hubert Seigneur[a,b,c]*, Eric J. Schneller[a,b], Narendra S. Shiradkar[a,d], and Winston V. Schoenfeld[a,b,c]

[a]Florida Solar Energy Center, University of Central Florida, Cocoa, FL 32922, USA
[b]c-Si Division, U.S. Photovoltaic Manufacturing Consortium, Orlando, FL 32826, USA
[c]CREOL, the College of Optics and Photonics, University of Central Florida, Orlando, FL 32826, USA
[d]Jabil Inc., St. Petersburg, FL 33702, USA

Abstract

Diamond wires from several manufacturers were investigated in term of their impact on wafer quality and cell performance. It was identified that under identical ingot sawing conditions the diamond wire make had an impact on the resulting cell performance. Several cells exhibited defects that remained with the cell even after the saw damage etching process. These defects were investigated in terms of there impact on various solar cell performance parameters. This analysis was performed using photoluminescence imaging and spatially resolved quantum efficiency and reflectance measurements. The diamond wire marks were observed to have the largest impact on the local short-circuit current density across the cell.

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Keywords: Silicon solar cell; Diamond wire saw; Ingot; Photoluminescence; Quantum efficiency; Spatially resolved loss analysis

1. Introduction

The photovoltaic industry utilizes multi wire slurry saw to slice silicon ingots into wafers of appropriate thickness for cell manufacturing [1]. This process, although effective, exhibits several drawbacks including large waste and relatively slows processing speeds. To overcome these shortcomings, diamond wire sawing processes have been developed in recent years [2-4]. Alternatively, the downsides of diamond wire sawing are the high cost of the wire

* Corresponding author. Tel.: +1-407-823-6151
E-mail address: Hubert.Seigneur@uspvmc.org

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itself and the extensive damage created at the surface of the wafers. The damage has been shown to vary greatly from wire to wire [3, 5] and from one sawing process to another [3, 6]. The generated damage consists of amorphization of the silicon, pits, and periodic structures, the so-called pilgrim waves. It was recently suggested that these pilgrim waves would have an impact on cell production [6]. The impact is especially observed during texturing, where the standard industrial texturing process for slurry-based sawing does not work as well for diamond wire sawing [7].

Furthermore, the random nature of the pilgrim waves in addition to the direct correlation between the diamond particle size and surface damage depth [3] lead us to believe that for a given sawing and cell fabrication process, the choice of the diamond wire can affect the solar cell performance. Such result is consequential inasmuch as solar cell manufacturers, while using established unvarying processes, typically have multiple wafer suppliers. Because each supplier evidently employs a different diamond wire and sawing process, cell manufacturers may need to look into adequate specifications for incoming wafer surface properties with respect to the dominant pilgrim wave type in addition to the usual lifetime, average thickness, and total thickness variation. Accordingly, in this work, we seek to show evidence of the impact of the diamond wire make and saw marks on solar cell performance. We do so by varying only the wire make while using matching sawing and cell manufacturing processes.

2. Experiment

Wafers were cut from two Czochralski (CZ) ingots using diamond wire from three different manufacturers under identical conditions. We used the Takatori WSD-K2 diamond wire saw to perform the cuts at 600 m/min wire speed, 0.6 mm/min table speed, and a 1m/min fresh wire feed rate, and Aquaslice coolant (5%). Each wire had identical core diameter (120 μm) and diamond size distribution (10-20μm). We used 0.35 mm pitch work rollers, resulting in approximately 200 μm thick wafers. We were able to saw as many as 28 wafers at a time using the WSD-K2 R&D saw. Cutting a limited number of wafers helped keeping the resistivity, oxygen concentration, and lifetime constant across the sample set. We also processed all the wafers as part of the same batch. Therefore, we can reasonably attribute changes in cells performance to changes in the diamond wire make. In reality though, diamond wire sawing is a dynamic and convoluted process with complex interactions between sawing parameters, wire properties, and coolant properties. In this work, we assume those interactions are the same for all diamond wires.

A cleaning step was performed using a KOH based cleaner from Process Research Products called Ultraclean PFS (2%) in an ultrasonic bath (50Hz) for 4 minutes at 60^{o}C, followed with a DI water rinse. It has been shown that there exist significant interactions between wafer cleaner types from wafer producers and cell manufacturers texturing processes [8]. All wafers were subjected to the same cleaner/texturing process. After that, the wafers were sent to a fabrication facility, and solar cells were fabricated using a standard aluminum back surface field process fabrication process. We started with SDE/texturing, then the emitter diffusion/oxidation, followed by PECVD SiN, edge isolation, and metallization. Shunting issues at the cell edges due to a slight mismatch between these lab-produced wafers and the standard size printing screen at hand required that the cells were cut with a laser to an area of 13.5 x 13.5 cm^2 (some of the wafers were cut out of an ingot a bit larger than 200mm). All the cut solar cells I-V characteristics were measured. Spatially resolved photoluminescence and quantum efficiency analyses were performed to identify which performance parameters are most affected by the diamond wire induced defects.

3. Effect of wire type on cell performance

Wires from three manufacturers were used each having the same diameter (120 μm) and diamond size distribution (10-20μm). The wire sawing process along with the cell fabrication (including the saw damage removal step) was identical for each wafers produced from the three wire types. The effect of using different diamond wires on the performance of solar cells was investigated. The statistical analysis shows that wire three clearly outperforms the others resulting in up to 0.15% higher mean efficiency. The improvement in the efficiency is driven by current, voltage and shunt resistance gains.