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Ultrasonication pretreatment of diamond wire sawn multi-crystalline silicon wafers for texturing

Jinbing Zhang[a,b], Yeqing Peng[b], Xingfang Ye[a], Xiaoying Zhou[c], Gang Hao[b], Lang Zhou[a,*]

[a] Institute of Photovoltaics, Nanchang University, Nanchang 330031, PR China
[b] National Engineering Technology Research Center for Photovoltaics, LDK Solar Co. Ltd., Xinyu 338032, PR China
[c] School of New Energy Science and Engineer, Engineering Xinyu University, Xinyu 338004, PR China

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ABSTRACT

Ultrasonication vibration as the pretreatment process, combined with wet acid etching, was utilized for the texture of diamond wire sawn (DWS) multi-crystalline silicon wafers. The SiC particles in the ultrasonic device were imposed for cavitation-generating blasting action on the DWS wafers surfaces. The blasting action exceeding 5 min can remove saw marks and smooth zones on the DWS wafer surfaces by producing new pits. After wet acid etching，the texture morphology of ultrasonically pretreated DWS mc-silicon wafers was quite uniform as compared to wet-textured as-cut DWS mc-silicon wafers, similar to wet-textured slurry wire saw(SWS) mc-silicon wafers. Light reflectivity tests confirmed the beneficial effect of the ultrasonic pretreatment of DWS mc-silicon wafers. This technique could be a potential solution to the texturization problem of DWS mc-silicon wafers.

1. Introduction

As a type of renewable energy, solar energy has attracted significant attention. The materials of solar cells are dominated by silicon due to the corresponding durability, abundance and nontoxicity. The diamond wire saw (DWS) wafering technology, which has been developed rapidly in recent years, can lower the wafering cost significantly, as compared to the conventional slurry wire saw (SWS) wafering technology. Since 2016, the DWS has been almost completely applied for the wafering of mono-crystalline silicon wafers in production [1]. In contrast, up to now the DWS wafering technology has not been significantly successful in multi-crystalline silicon(mc-silicon) wafer production due to no compatible surface texturization to this type of wafers [2].

The surface texturization of wafers is an important process for the production of mc-silicon solar cells. It can reduce the reflected light of the front surface and increase the light absorption, consequently improving the solar cell efficiency. The microstructure of as-cut wafers' surfaces has a significant impact on the texture genrated by conventional acid-texturization process (commercially HF-HNO_3-H_2O etching solution for multi-crystalline silicon wafer) [3]. The conventional slurry wire sawn (SWS) wafers can be well textured by the conventional acid-texturization process, while diamond wire sawn (DWS) wafers can not. A thin amorphous silicon layer along the saw marks on the DWS wafers restrains the etching by the acidic etching solution [4]. Usually, subsequent to the conventional acid-texturization, the light reflectivity of DWS mc-silicon wafers is 3–5% higher in average than that of SWS mc-silicon wafers, in the visible light range [5,6].

Current attempts for texture improvement of DWS mc-silicon wafers in PV industry, such as Reactive Ion Etching(RIE) technique and Metal Catalyzed Chemical Etching (MCCE) technique, are either too expensive or too complicated [7–10]. Alternative effective texturization technologies should be developed for mass production of DWS multi-crystalline silicon wafers.

In this work, a new method for the texturing of DWS multi-crystalline silicon wafers was proposed. The present study focused on a pretreatment process on DWS multi-crystalline silicon wafers prior to conventional acidic texturization. The pretreatment was conducted through ultrasonication in a bath containing SiC powders. The effects of the pretreatment processes on weight loss and surface morphology of the DWS wafers, and their further effects on the subsequent conventional acid-texturization, were investigated. For reference, weight loss behaviour of SWS wafers and polished wafers under the ultrasonic treatment were parallely investigated, too.

2. Experimental procedure

The DWS p-type mc-silicon wafers of ~190 µm in thickness and 156

* Corresponding author.
E-mail address: lzhou@ncu.edu.cn (L. Zhou).

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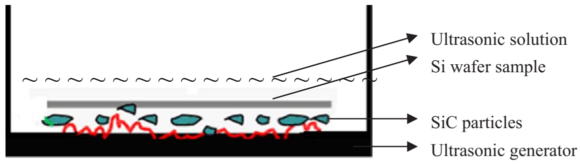

Fig. 1. Illustration of Si wafer ultrasonic vibration.

× 156 mm^2 in size were processed in this study. For comparison, samples of SWS mc-silicon wafers were also analyzed in parallel. All wafers were provided by LDK Solar Co. Ltd

The ultrasonic vibration(Ultrasonic generator, 40 kHz, Power max 900w, Durasonic Corporation), as a pretreatment for the uniform microstructure damages production on the surfaces, was tested on as-cut DWS mc-wafers. The suspension in ultrasonic pretreatment was prepared by the SiC particles(average grain size of 13 μm) and tap water mixing, whereas only tap water for ultrasonic solutions was also used as a reference. The height of suspension in the ultrasonic vibration tank was approximately 5 mm. This ultrasonic vibration process is presented in Fig. 1.

During the etching experiments, the wafer samples were textured with the Inline Texture Etching Machine(InTex, RENA Corporation) for 90 s at 8 °C. Also, the solution in the etching tank was the HF(49 wt%)-HNO_3(69 wt%)- H_2O of 1:4.4:2.7 in volume ratio. This etching process is also conventional for the SWS mc-silicon wafers in production.

The scanning electron microscope (SEM, S-3700N, Hitachi Corporation) was utilized to characterize the surface appearances of the wafers. A laser scanning confocal microscope (Olympus LEXT OLS4100 model) was utilized to examine the topography of the textured mc-silicon wafers. The light reflectivity of the acid-texturized samples was examined through an Ocean Optics USB4000 spectrometer. The average reflectivity in the wavelength range of 400–900 nm was utilized to represent the light reflectivity of the samples.

3. Results and discussion

3.1. Effects of process conditions on ultrasonic vibration

Ultrasonic vibration was utilized for the manufacturing of micro-defects on the surface of as-cut DWS mc-silicon wafers, whereas certain factors such as the SiC concentration in ultrasonic solutions as well as ultrasonic power, were of important consideration during the surface treatment. The manufacturing micro-defects on the surface will inevitably result in the weight loss of the DWS mc-silicon wafer. Consequently, the variation rule of ultrasonic vibration manufacturing of micro-defects was investigated through weight loss testing under different parameter conditions. The SiC concentration along with the ultrasonic power, were altered. Certain attempts with several parameters in the ultrasonic treatment for mc-silicon wafers were made, whereas each data element was derived from the average of three parallel samples. The results are presented in Figs. 2 and 3.

Fig. 2 presents the weight loss of the DWS mc-silicon wafer versus SiC concentration, whereas as it could be observed, the 10 wt% of the SiC concentration was regarded as a proper parameter in ultrasonic vibration according to the weight loss of the samples. A possible explanation for this was that fewer impacting particles existed at the relatively low concentration of SiC, which resulted in lower amount of micro-defect formations on the surfaces of the as-cut DWS mc-silicon wafers. In contrast, when the concentration of SiC exceeded 10%, the impact force of SiC particles to wafers was weakened due to higher amount of SiC particles being deposited at the bottom of the tank. The effects of ultrasonic power on the weight loss of DWS mc-silicon wafer presented in Fig. 3, and the weight loss increased as the power increased. The impact force of the SiC particles derived from the ultrasonic power. Also, the high ultrasonic power would supply the SiC particle energy for strong vibration, which would benefit the manufacturing of micro-defects on the surface of the DWS mc-silicon wafers.

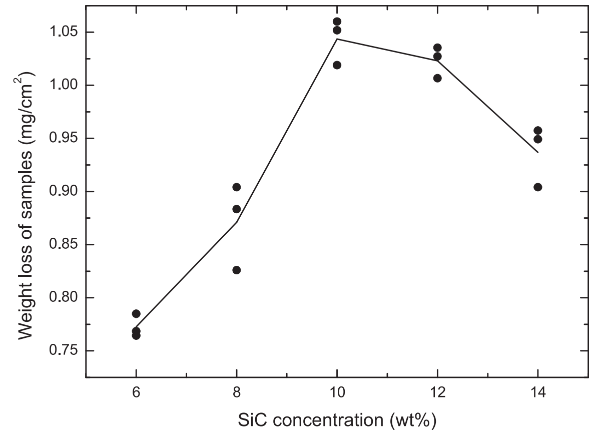

Fig. 2. Weight loss of as-cut DWS mc-silicon wafers under different SiC concentrations within 5 min and 900 W of maximum ultrasonic power.

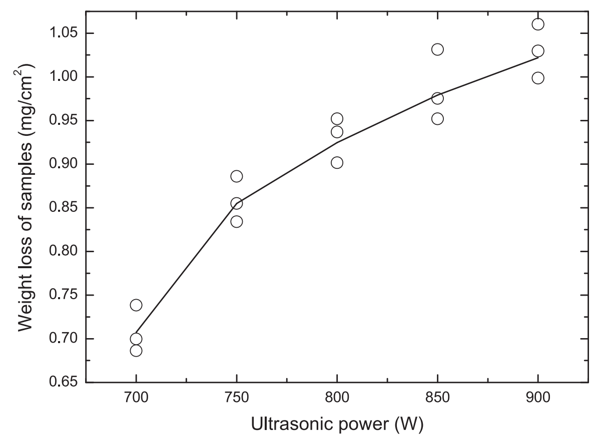

Fig. 3. Weight loss of as-cut DWS mc-silicon wafers under different ultrasonic power within 5 min and 10 wt% of SiC concentration.

In addition, the wafer surface condition effects on ultrasonic vibration was also studied for a better insight SiC blasting on the wafer surfaces. Three different surface states of silicon wafers such as the DWS wafers, the polished DWS wafers by an alkaline solution and the SWS wafers were researched in this work. The results are presented in Fig. 4.

As it could be observed from Fig. 4, the weight loss of the SWS wafers was the highest, whereas the polished wafers weight loss was the

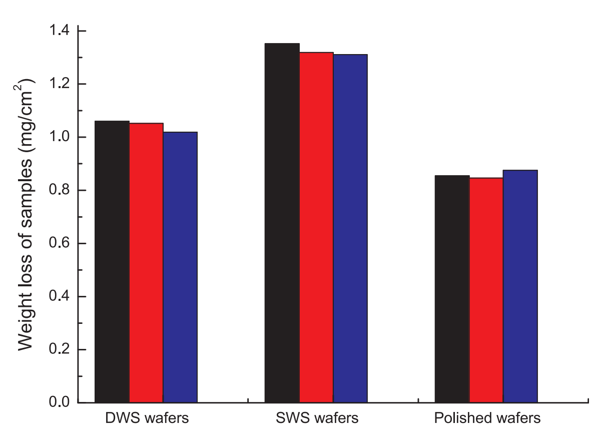

Fig. 4. Weight loss of different kinds of wafers under conditions of 5 min, ultrasonic power of 900 W and 10 wt% of SiC concentration. Each bar represents result of a sample.