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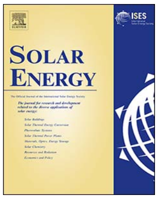

Investigated performance improvement of the micro-pressure sandblast-treated multi-crystalline Si wafer sliced using diamond wire sawing

Ting-Chun Wang[a,b], Hsin-Ying Lee[a,*], Ching-Ting Lee[c], Yu-Chin Cheng[b], Hung-Wei Chen[d]

[a] *Department of Photonics, Research Center Energy Technology and Strategy, Advanced Optoelectronic Technology Center, National Cheng Kung University, Tainan 701, Taiwan, Republic of China*
[b] *Wafering Technology Section, Wafer Technology Development Department, General Technology Development Division, Motech Industries Inc., Tainan 74145, Taiwan, Republic of China*
[c] *Department of Photonics Engineering, Yuan Ze University, Taoyuan 320, Taiwan, Republic of China*
[d] *Institute of Electronics Engineering, National Tsing Hua University, Hsinchu 30013, Taiwan, Republic of China*

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ABSTRACT

In this work, the textured surface of the multi-crystalline silicon (mc-Si) wafers sliced by the diamond wire sawing (DWS) technique was formed using the X-Y axis micro-pressure sandblast treatment and the acidic texturing process. From the scanning electron microscopy (SEM) images, the X-Y axis micro-pressure sandblast treated DWS-sliced mc-Si wafers could effectively remove the saw marks caused by the fixed diamond abrasives. Furthermore, the textured surface of the acidic-textured DWS-sliced mc-Si wafers was also observed in the SEM images. Besides, using the X-Y axis micro-pressure sandblast treatment, the average reflectivity of the DWS-sliced mc-Si wafers was reduced from 28.94% to 22.28%. Consequently, the short-circuit current of 8.70 A and the power conversion efficiency of 17.92% for the DWS-sliced mc-Si solar cells with micro-pressure sandblast treatment were respectively better than 8.59 A and 17.35% in comparison with the DWS-sliced mc-Si solar cells without micro-pressure sandblast treatment.

1. Introduction

Recently, the diamond wire sawing (DWS) technique is widely utilized in the slicing process of the single-crystalline silicon (sc-Si). It has rapidly gained the attention of the Si-based photovoltaic industry due to the higher productivity of the DWS technique compared with the multi wire slurry (MWS) slicing technique with slurry of silicon carbide (SiC) abrasives (Kondo et al., 2008; Watanabe et al., 2010; Tomono et al., 2013; Lin et al., 2010). Besides, in the DWS slicing process, the silicon powders in the cooling water are easily recovered and can prevent the environmental impact (Müller et al., 2008). However, there are many clearly visible saw marks formed on the DWS-sliced wafer surfaces (Chen and Chao, 2010), but the MWS slicing technique does not have this problem. This phenomenon is attributed to that in DWS slicing process, the stainless steel wires mounted the diamond abrasives by impregnating or electroplating techniques with high speed and high pressure were contacted with the sc-Si wafers, which the fixed diamond abrasives would form the saw marks on the DWS-sliced wafer surfaces. However, the SiC abrasives used in the MWS slicing technique are not fixed on the wire and roll between the wire and the slicing surface in the slicing process (Zhuang et al., 2016). These saw marks on the DWS-sliced wafer surface seriously influence the light incident into the solar cells, which degrades the cells performance (Cao et al., 2015). Although the saw marks on the DWS-sliced sc-Si wafers can be easily removed by chemical etching method (Yu et al., 2012), however, at present, the DWS technology has not been successfully applied in multi-crystalline silicon (mc-Si) wafer production due to the different orientation and atomic packing density in the mc-Si wafer (Rubya et al., 2002). Therefore, it is difficult to use chemical etching method to remove the saw marks on the surface of the as-cutting DWS-sliced mc-Si wafers. Consequently, the textured structure commonly used in the solar cells is difficultly performed on the DWS-sliced mc-Si wafers. Recently, the reactive ion etching (RIE) technique (Yoo, 2010; Ruby et al., 2005) and the wet method of metal catalyzed chemical etching (MCCE) technique (Kumaai, 2015) were developed to effectively overcome the high reflectivity and the texturing difficulty issues of the DWS-sliced mc-Si wafers. Unfortunately, the RIE system suffered from the high equipment setting cost and the MCCE technology suffered from the pollution problem of silver nitrate ($AgNO_3$). Furthermore, adding sulfuric acid (H_2SO_4) into the recipe of the traditional acidic texturing also reduces the light reflection of the DWS-sliced mc-Si wafers to a satisfactory requirement. However, the saw marks are still visible observation from

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[*] Corresponding author.
E-mail address: hylee@ee.ncku.edu.tw (H.-Y. Lee).

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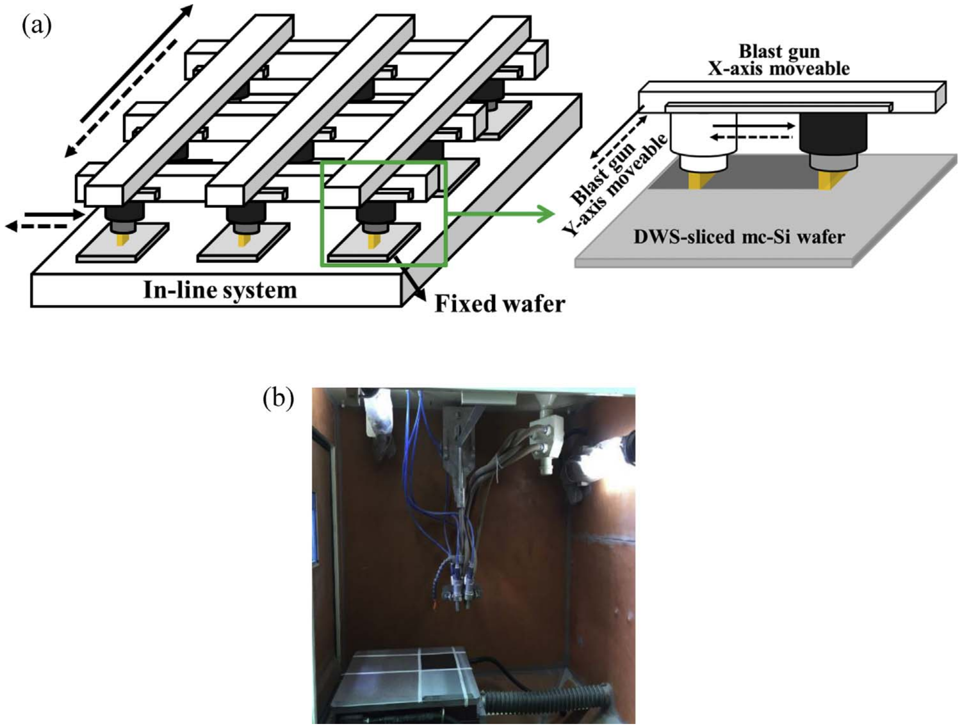

Fig. 1. (a) Schematic configuration and (b) photo of X-Y axis micro-pressure sandblast treatment system.

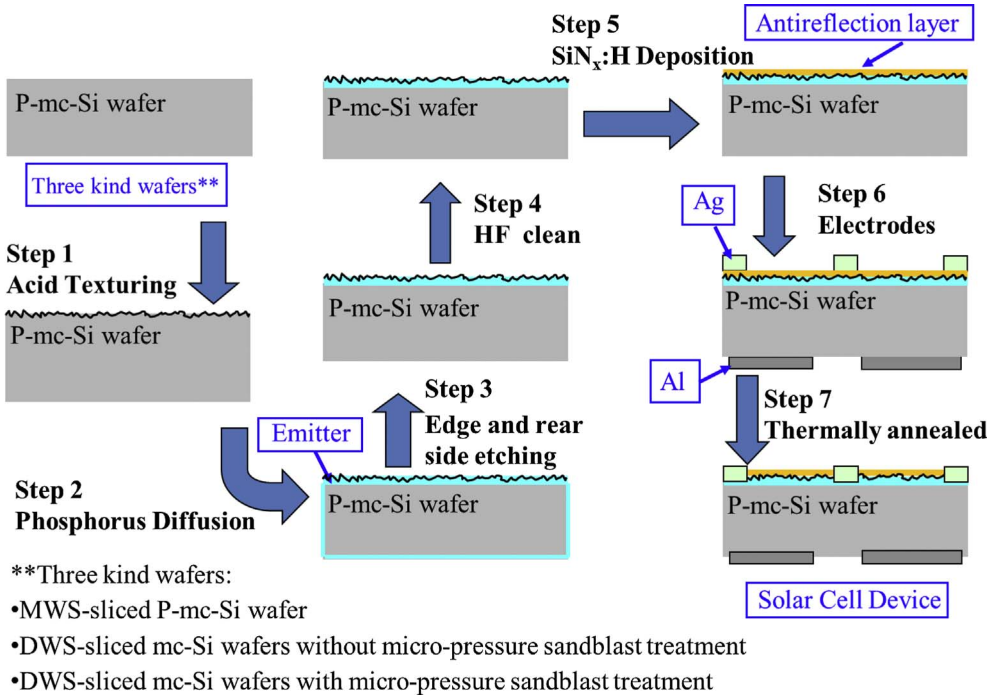

Fig. 2. The flow chart of the fabricated processes for the three solar cells.

the micrographs provided (Lippold et al., 2014). The traditional sandblast technique was also proposed to effectively remove the saw marks on the DWS-sliced mc-Si wafers (Takato et al., 2013a,b; Nishioka et al., 2012). In the traditional sandblast, the blast gun was fixed at the high position in the sandblast chamber. The spray-nozzle of the blast gun periodically swung with a small angle (~20°). In addition, the abrasives stream of a single spray-nozzle took shape as waterfall with abrasives in a cone structure. The overlap area of the abrasives streams would influence the treatment results. Therefore, how to arrange spray-nozzle position to optimize uniform abrasive stream in the sandblast process become the bottleneck issue of the traditional sandblast system. Otherwise, since the traditional spray-nozzle is the high pressure air input mode, higher wafer broken rate is induced due to the very high pressure bombardment on the mc-Si wafer surface by the jetted abrasives. Besides, the blast abrasive stream intensity is usually decreased with an increase of the treated time (Buckland and Berkey, 1952). Therefore, the surface uniformity of the mc-Si wafer is difficult to be obtained using the traditional sandblast treatment system.

In this work, to solve those disadvantages in the traditional sandblast system, the X-Y axis micro-pressure sandblast system was designed for the DWS-sliced mc-Si wafers. The spray-nozzle of the blast gun can be moved in X and Y direction, which is similar to the print mode of the