Front Side Metallization Issues of a Solar Cell with Ink-jet Printing

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Abstract

The metallization of a multi-crystalline silicon solar cell has been challenged because the thickness reduction of a solar cell wafer decreases the breaking force of a solar cell wafer. Therefore, ink-jet printing has drawn attention of researchers in the art in place of conventional screen printing which requires the direct contact with a solar cell wafer to transfer silver paste. In this study, a preliminary study for the front side metallization of a solar cell wafer with ink-jet printing was conducted. Firstly, multi-crystalline silicon solar cell wafers, the size of which is 156 mm by 156 mm, were coated with a 0.2 wt% fluorocarbon solution. After laser-patterning to selectively remove the SiN_x layer and prepare for the surface energy patterned finger electrode regions, silver nanoparticulate ink was delivered with a piezo Drop-On-Demand ink-jet print head and baked at the peak temperature of 830 ˚C after drying at 100 ˚C. The measured cell efficiency of an ink-jet metallized solar cell was about 12.1% and the cause of the low cell efficiency is addressed here.

Introduction

The thickness of a multi-crystalline silicon solar cell wafer has decreased from 250 μm in 2005 to 180 μm in 2010, and further efforts to decrease its thickness down to 100 μm are being made to reduce the cost of a solar cell wafer [1,2]. As the thickness of a solar cell wafer decreases, however, the current metallization using screen printing will be significantly challenged because a thin solar cell wafer has less endurance to the downward pressure of screen printing while silver paste is transferred. Therefore, non-contact printing techniques such as nozzle dispensing [3]. aerosol jet [4-6], and ink-jet [7] have been tested to replace screening printing. However, directly metallized solar cells have exhibited low efficiency around 8% and below [8-11]. The only successful way to achieve high efficiency approximately 20% has been two step metallization processes, where the first conductive seed layer is formed with a printing technique and then light induced electroplating (LIP) is conducted to thicken the formed seed layer [4-7].

The direct metallization has a great advantage over two step metallization processes because it not only reduces the overall process steps but also eliminates chemical wastes produced while electroplating is conducted. Therefore, identifying the cause of low efficiency of a directly metallized solar cell has significant importance. In this study, two types of silver nano-inks were used to investigate their impact on efficiency by characterizing electrical and morphological characteristics.

Experimental Details

Multi-crystalline silicon solar cell wafers (Millinet Solar Co., Ltd., Republic of Korea) were provided with the formation of back surface field and bus bars, and the first co-firing. They were coated with a 0.2 wt.% fluorocarbon solution (FZ-630A, Kanto Kasei, Co., Ltd., Japan) to prevent too much spreading of silver nano-ink. Surface energy patterning with laser (KORTherm Science Co., Ltd., Republic of Korea) was performed to confine silver nano-ink.

Two types of silver nano-inks were used to form the front side grid of a solar cell. The first type of silver nano-ink has silver nano-particles approximately 10 nm on average. On the other hand, the second type of silver nano-ink has silver nano-particles approximately 180 nm.

They were deposited with an ink-jet printer, SSP-01 (Samick THK, Co., Ltd., Republic of Korea), which is specialized for the front side metallization of a solar cell wafer. As shown in Fig. 1, it has two cassettes which unload and load solar cell wafers automatically. Three ink-jet print heads (S-128, Fujifilm Dimatix, Inc., USA) are installed in a head array module to deposit silver nano-ink on a solar cell wafer. Its production capacity reaches up to 500 wafers per hour.

The deposited silver nano-ink was dried at 100 ˚C for 2 min and then sent back to Millinet Solar Co., Ltd., to be co-fired again. The used co-firing conditions are not disclosed here due to the nature of commercial confidentiality.

The overall solar cell fabrication steps with ink-jet printing are shown in Fig. 2 and Figure 3 shows screen and ink-jet printed solar cells, respectively. They show no visually distinct difference

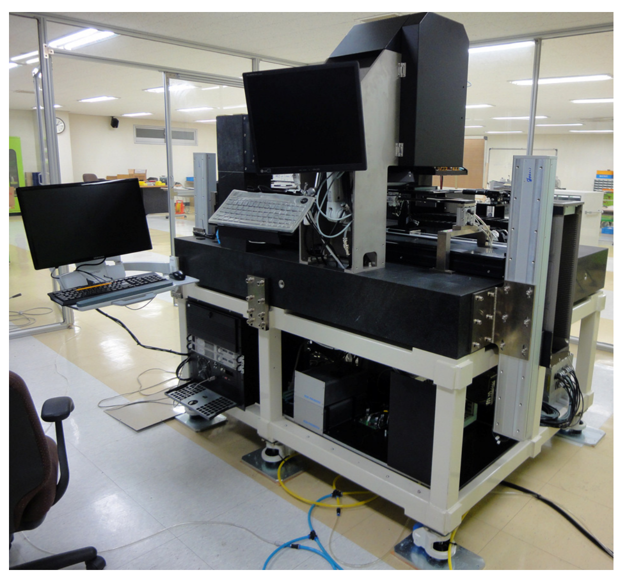

Figure 1. *Developed ink-jet printer,SSP-01, for the front side metallization of a solar cell wafer.*

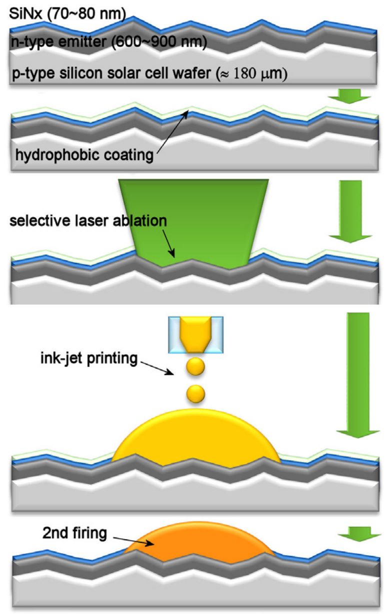

Figure 2. *Schematic illustration of solar cell fabrication steps with ink-jet printing.*

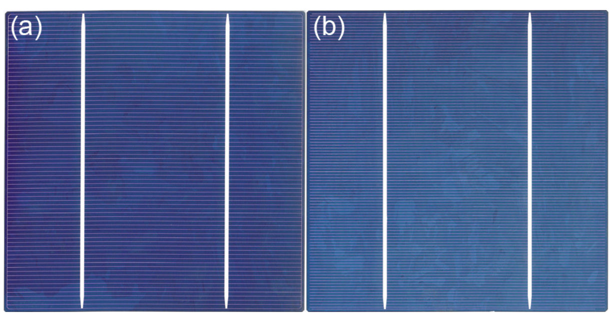

Figure 3. *Comparison of solar cells with different printing techniques, (a) screen printing, and (b) ink-jet printing.*

except the number of finger electrodes. The screen printed one has 72 finger electrodes but the ink-jet printed on has 102 finger electrodes. The use of the different number of finger electrodes was suggested by Millinet Solar, Co., Ltd., to compensate their line resistance difference.

Results and Discussion

The efficiency of solar cells with two types of silver nano-inks for the formation of the ink-jet printed front side grids was measured by Millinet Solar Co., Ltd., and compared each other. When the first type of silver nano-ink was used, its maximum efficiency was 8.6%. On the other hand, the maximum efficiency with the second type of silver nano-ink reached around 12.1%, which is the first multi-crystalline silicon solar cell exceeding 10% with the direct ink-jet metallization, to the authors' best knowledge.

It is noteworthy that the solar cells with direct ink-jet metallized front side grids were co-fired twice due to a reason from Millinet Solar Co., Ltd. According to experiments, this duplicated co-firing is found to result in efficiency reduction by 1.4%. Therefore, the expected efficiency, if properly co-fired only once, is 13.5%. To answer the question why two types of silver nano-inks exhibit different efficiency results, the cross sections of ink-jet metallized electrodes were examined. When the first type of silver nano-ink is used, severe delamination of finger electrodes were observed even with excessive amount of glass frits. On the other hand, delamination of finger electrodes was mitigated with the second type of silver nano-ink.

The different degree of lamination is found to result from the volume ratio of dispersant to silver. The TEM image of silver nano-particles in Fig. 4 reveals that the thickness of dispersant, polyvinylpyrrolidone, is approximately 2.5 nm. When the average diameter of silver nano-particles changes with the constant dispersant thickness, the volume ratio of dispersant to silver dramatically increases, as can be seen in Fig. 5. Therefore, the co-fired finger electrodes with the first type of silver nano-ink tend to exhibit higher volumetric shrinkage than those with the second type of silver nano-ink. Higher volumetric shrinkage produces higher residual stress after the co-firing process and hence finger electrodes tend to delaminate from the surface of a solar cell wafer. This poor contact formation eventually leads to low efficiency.

Conclusions

In this study, the solar cell efficiency exceeding 10% with direct ink-jet metallization is presented. Although ink-jet printing

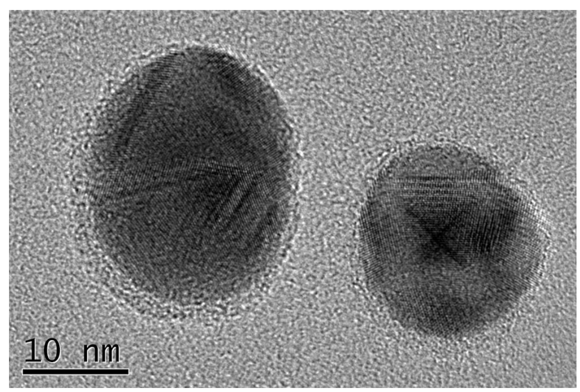

Figure 4. *TEM image of silver nano-particles surrounded with a capping agent.*

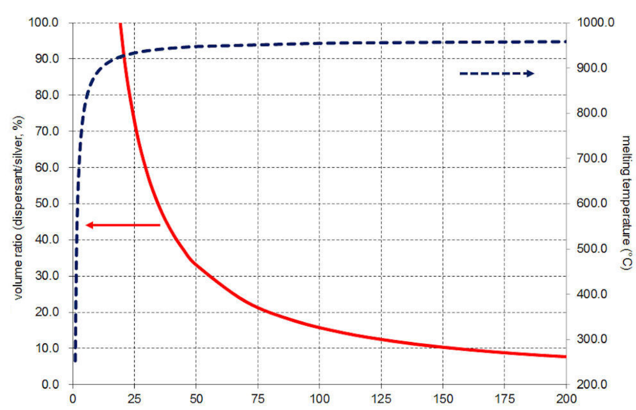

Figure 5. *TEM image of silver nano-particles surrounded with a capping agent.*

is the very promising non-contact based printing technique suitable for solar cell wafers as thin as 150 μm and below, it needs to be further improved to match with screen printed solar cells. According to experimental results with two different types of silver nano-inks, it is found that the volume ratio of dispersant to silver is a key factor to determine the solar cell efficiency. When the average diameter of silver nano-particles becomes as small as 10 nm, then the volume of dispersant is 2.4 times more than that of silver. High volumetric shrinkage after thermal decomposition of dispersant induces high residual stress between finger electrodes and the surface of a solar cell wafer, resulting in unwanted delamination. By using silver nano-particles as big as a few hundreds nm and optimizing the composition of silver nano-ink with nano-glass frits, solar cell efficiency as high as that of screen printed solar cells is expected to be obtainable.

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Author Biography

Dong-Youn Shin received his BS in mechanical engineering from Seoul National University (1997) and his MS and PhD in mechanical engineering (1999) and materials science (2003) from UMIST, UK. After a postdoctoral period at UMIST, he served at LG Chem Research Park to develop ink-jet printed color filters for TFT LCD and at Korea Institute of Machinery and Materials to develop ink-jet related equipments and applications. He is currently an assistant professor at Pukyong National University. His research has focused on the theoretical and experimental analysis of the microfluidic behaviors in a piezo DOD ink-jet print head and fine pattern generation for displays, electronics and photovoltaic applications.