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Silver powder effectiveness and mechanism of silver paste on silicon solar cells

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ABSTRACT

Since the silver paste plays a major role in the mass production of silicon solar cells, this work has succeeded in optimizing the silver paste in 80–85 wt.% and optimizing its particle size in 1–1.5 μm spherical powder. As the firing temperature is increased, the growth trend of silver grain is improved. The result of this work has showed that the lowest sheet resistance is 4 mΩ/sq during the 860 °C sintering process. The scanning electron microscope (SEM) observation has showed that the formation of silver oxide is formed during the melting process of glass and triggered redox reaction of Ag crystallites to grow on the interface. It has proven by transmission electron microscope (TEM) that a thin layer of silicon oxide (75–150 nm) was formed, respectively.

1. Introduction

In the past view year, the application of front side metallization of silicon solar cells is screen printed on a desired pattern on the substrate which is consist of composition paste. Silver paste are usually apply for electrical contacts in silicon solar cells. The paste usually consists of three constituents: silver powder, organic vehicle, and glass frit. Silver powder, which happens to be the primary component in such type of conductor, may differ in shape and size of the particles depending upon the process parameters during its preparation. Glass frits were widely used as a adhesion binder, which could promote sintering of metal powders during firing and provide the strength against warp. Organic vehicle were disperse the metal and glass powder to allow high aspect rations for silver paste [1,2].

Cho et al. [3,4] indicated that, when silver is sintered in the air, it is unlikely to be oxidized due to higher free energy so the silver paste is better than aluminum or copper paste (easily oxidized), and is the optimal material next to gold. Hong et al. [3,4] proposed a chemical reaction process, and assumed that when oxygen partial pressure is increased, silver is gradually precipitated on the silicon interface as the amount of silver powder increased, and the particle sizes are distributed in ascending order. Both of this research have the same conclusion of redox reaction which cause the interface to grow a thin silicon oxide. Therefore, the determination of thin silicon oxide is necessary, in order to keep the oxidation at a minimum.

There have been many researchers optimizing the performance of screen-printed front contacts for crystalline silicon solar cells such as glass powder additive, the co-fired temperature and sheet resistance [5–8]. However, the effectiveness of silver powder in silver paste after co-firing has not been reported widely. In this paper, we report on the development of Ag pastes, and fabricated on silicon substrate. These pastes (SP-1(A–C) and SP-2) have the same glass frit content but different silver shape and size. The pastes were co-fire at various temperature. In addition, the effectiveness of the Ag paste is demonstrated by comparing its performance with SEM, TEM, and electrical performance. Preparation of silver powder in particle characteristics is important for thick film formulation to achieve the best smooth and dense microstructure on the surface of the films. The results of this research is to understand the effects of silver morphology in the pastes after sintering.

2. Experimental procedures

Conductive film of front contacts was prepared having the composition of silver, glass, and a mixture of organic vehicle. The main components of glass material were Bi_2O_3 (Junsei, 99%) and B_2O_3 (Kanto, 99%). Table 1 shows the composition of the silver paste used in this study, whose silver morphology are shown in Fig. 1. Two kinds of commercial silver powders, which have different kind of particle size and shape were used in the experiments: (1) silver particle size of 1.26 μm with angular shape (Technic, 99.8%), and (2) silver particle size of 1.56 μm with spherical shape (Metalor, 99.8%), respectively. The silver powder and organic vehicle were carefully mixed in a mixer. The paste was then grinded by three roll milling and were screen printed on the silicon substrates. According to the stainless stencil mesh no. 325, the line width is 25 μm, and the aperture is 45 μm, where L_D is the line width of mesh, W_w is the aperture of wet paste that squeeze though the stencil, and W_D is the width of dried paste after sintering, as shown in Fig. 2.

The paste, designated as SP-1(A–C) and SP-2, was dried and fired in a conventional furnace at three different peak temperature 830, 860, and 890 °C for 10 min. The experimental pastes prepared from two different kind of silver powders after firing was examined using a scanning electron microscope (SEM) (JEOL

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Table 1
Compositions and specimens investigated in this study.

Specimen number	Composition (wt.%)			Morphology		Mean particle size (μm)	
	Silver	Glass	Polymer	Silver	Glass	Silver	Glass
SP-1(A)	75	3	22	Angular	Angular	1.26	8.81
SP-1(B)	83	3	14	Angular	Angular	1.26	8.81
SP-1(C)	95	3	2	Angular	Angular	1.26	1.26
SP-2	83	3	14	Spherical	Angular	1.56	8.81

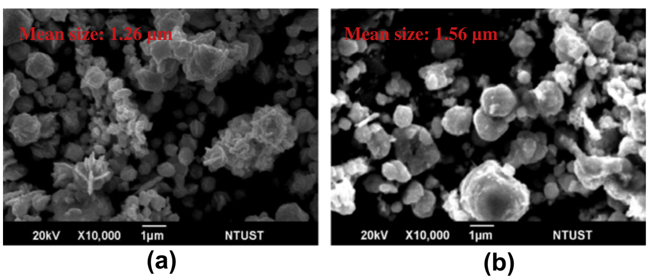

Fig. 1. Morphology of the silver powders (a) angular and (b) spherical used in this study.

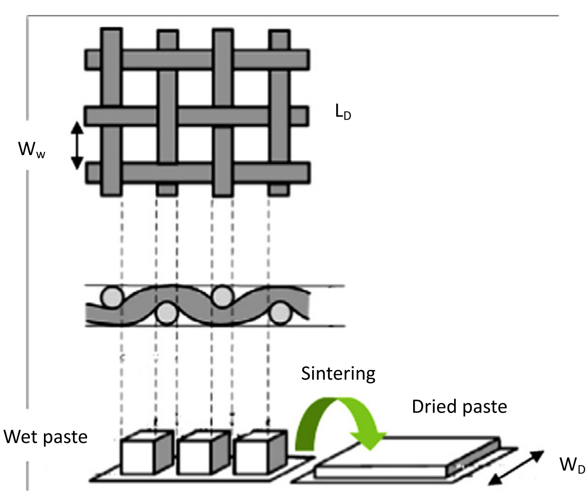

Fig. 2. Schematic drawing of a screen printing process on silicon substrate.

JSM-T330). Energy dispersion analysis of X-rays (EDAX) which is attached with the SEM has been used for the elemental analysis. Cross-sectional sample was observe by transmission electron microscope (TEM) (Philips FEI–TEM) operating at an accelerating voltage of 200 kV. The sheet resistance of the fired films was measured using the four-point technique (KEITHLEY 2400).

3. Results and discussion

The most important constituent of silver paste is the silver powder, which accounts for more than 80% of most conducting pastes, thus, the silver powder is the key constituent of the entire conducting paste. The current discussions on silver powder in conducting paste can be divided into four points, which are silver powder addition ratio, size, shape, and sintering atmosphere. Larger amount of silver powder can produce better conductivity; however, the key point is that the height of electrode is related to width. The most ideal design is a larger height and a smaller width. At present, the no. 325 mesh for a commercial screen is most

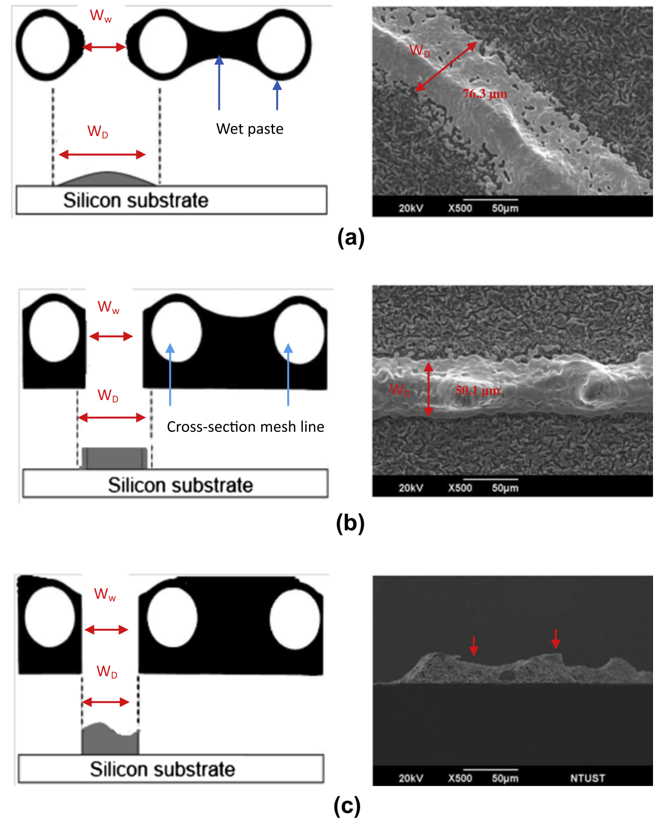

Fig. 3. Schematic screen printing results and SEM micrographs of top view (a) SP-1(A), (b) SP-(B), and cross-section (c) SP-1(C) for silver paste.

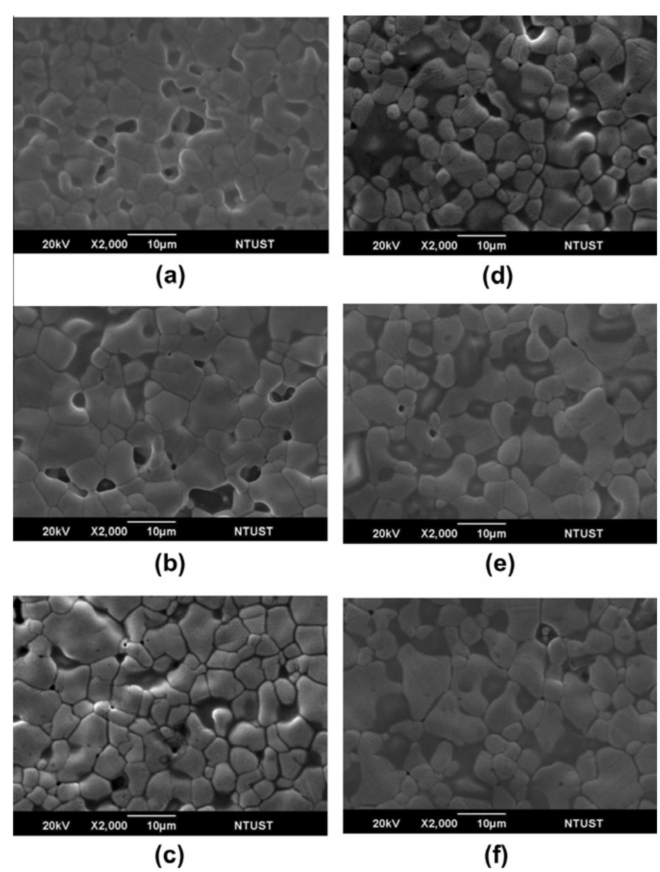

Fig. 4. SEM micrographs of top view SP-1(B) fired at (a) 830 °C, (b) 860 °C, (c) 890 °C and SP-2 fired at (d) 830 °C, (e) 860 °C, and (f) 890 °C.