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A Critical Analysis of Silver Nanoparticle-Based Front-Contact Metallization Paste for Enhanced Polycrystalline Silicon Solar Cell Performance

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Abstract

In order to improve the efficiency and performance of solar cells, this research details how nanotechnology was used to prepare silver metal paste for the front side metallization of polycrystalline solar cells. Converting sunlight into energy is the goal of photovoltaics (PV). When light from the sun hits a solar cell's surface, a photocurrent is formed inside the cell. This current may be extracted from the solar cell through metallization. This method may be used with either monocrystalline or polycrystalline solar cells. Crystalline solar cells built on silicon wafers often have a pn junction as their primary structural element. Electricity is collected via metal contacts on both the n and p type sides of the junction in commercial crystalline silicon solar cells. Typically, silver paste is screen-printed to create metal contacts, and then the paste is densified using a high-temperature fire treatment procedure. High shading losses due to a high percentage of front side metal covering are a result of the substantial shrinkage of silver paste during fire treatment and the difficulty of achieving silver electrodes with a high aspect ratio. Using cutting-edge nanotechnology, we can boost overall efficiency. Reduced shading losses, a higher aspect ratio, higher conductivity, and more efficiency for the solar cell are all possible thanks to the use of silver metal nanoparticles (in the nano range of 1 to 100 nm).

Polycrystalline solar cells, metallization, printing, drying, firing, silver nanoparticles, solar cell efficiency, etc. are some of the many terms that describe this technology.

1. Introduction

Research work concentrated on metallization to increase of efficiency and reduction of total cost of solar cells.

The current interaction in solar cells is based on the compatibility of the metal paste with base structure of thesemiconductor materials. The properties of the metalpastes like viscosity, density, electrical conductivity, adhesion properties, organic compounds and curing of thesolar cell with respect to the time is important.

Thick film and thin film technologies are available for metallizationCommercial screen printable silver pastes used for front side metallization to form a metal grid which extract photogenerated current from a solar cell. The resistivity of the metal paste is very important from power loss point of view. The advances made in paste formulation by using nanotechnology to increase conductivity, high aspect ratioand overall increase of efficiency of solar cell by reducing power loss. By using nano particles of silver metal and glass frit conductivity increase, power loss decreased. Thisis due to novel unique properties of high surface to volumeratio of nano particles, excellent thermal, electrical, opticaland catalyzing properties due to their nano size effects.

2. Metallization for solar cells

This study explains how silver metal paste was prepared using nanotechnology for the front side metallization of polycrystalline solar cells, which has been shown to increase solar cell efficiency and performance. The purpose of photovoltaics (PV) is to generate electricity from sunshine. When sunlight strikes a solar cell, it creates an electrical current known as a photocurrent. Metallization of the solar cell allows for the collection of this current. Both monocrystalline and polycrystalline solar cells may be utilized in this process. A pn junction is a common structural component of crystalline solar cells fabricated on silicon wafers. Commercial crystalline silicon solar cells gather electricity using metal contacts on both the n and p type sides of the junction. Metal contacts are often made by screen-printing silver paste, which is subsequently densified using a high-temperature fire treatment process. Significant shrinkage of silver paste during fire treatment and the difficulties of producing silver electrodes with a high aspect ratio lead to considerable shading losses owing to a large proportion of front side metal coverage. We can improve productivity all around by using state-of-the-art nanotechnology. The usage of silver metal nanoparticles (in the nano range of 1 to 100 nm) allows for a lower shading loss, a larger aspect ratio, a greater conductivity, and a higher efficiency for the solar cell.There are various words to describe this technology: polycrystalline solar cells; metallization; printing; drying; fire; silver nanoparticles; solar cell efficiency; etc.

3. Properties Required for Metal Paste

- Metal pastes are thixotropic in nature
- Viscosity in the range of 150-200Pa.s (The viscosity should not change during the application process and should be within ±25 to 50Pa.s).
- Shelf life (minimum 6 months or more).

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- Levelling time.
- Drying time.
- Firing temperature in the range of 250ºC to 900ºC.
- Bonding mechanism should be frit less or mixed.
- Density.
- Electrical conductivity.
- Adhesion properties.

4. Metal paste Manufacturing Technology

The main technology which is used for the production of metallization pastes is the conductive filler dispersion technique.

Method for Dispersing Conductive Fillers a) Wetting
Here, a filler's surface air and moisture are replaced by vehicle. What this means is that the contact between the filler and the air is converted into an interface between the filler and the resin solution when the air and moisture are removed. Filler spaces are invaded by a resin solution. The quantity of air pigments absorb, their polarity, and the shape of the filler particle all have a role in how well they wet. This highlights the significance of the wetting procedure.

(b) Grinder

Filler agglomerates are reduced in size by this procedure. In other words, the particle sizes of filler agglomerates are decreased by mechanical stress (mainly shock and shear). Ball mills, sand mills, bead mills, and three-roller mills are all common types of dispersion equipment. The paste's viscosity and the desired dispersion strength dictate the choice of dispersing apparatus. Grinding the filler particles down to a smaller size increases the surface free energy and renders the dispersion unstable by increasing the specific surface area. This causes the fillers to re-coagulate, necessitating a decrease in the surface energy of the pigment.

c) Dispersion stabilization

The goal of this procedure is to stop the precipitates and particles from re-clumping together.

5. Front Paste Composition

Metal pastes mainly includes Ag/Al main ingredients (70- 80%), glass frits (5%) and solvents (3-15%).

Metallic contacts are based on the use of silver as a conductive metal and should have good contact propertieswith n type silicon and excellent solder ability (needed forthe later interconnection of cells). To make the deposition of this metallic contact with a screen printing technique, with the goal of reaching a final correct mechanical adhesion to the surfaces and good electrical properties, special metallic pastes have been developed for the solar cell industry. Silver powder represents the 70-85% in weight of the commercial pastes with a mixture ofdifferent shaped particles, of different sizes (as spherical powder grains or flakes), that are responsible for the pasteconductivity and final cohesion of the contact.

Glass frits are metal oxides that play the most important role in the formation of the contact because its function is to melt the dielectric layers (by forming eutectic alloys of lower melting point), that are deposited or grown on the silicon emitter, allowing the metal particles to reach the silicon surface. Additionally its contact determines the adhesion of the paste to the silicon substrate.Organic compounds are used as a vehicle to transport the suspended silver and glass particles, allowing its disposal with the screen painting techniques. Among these organic compounds are : organic solvent to allow the mixture to beused as paint and organic binders to maintain the particlesjoined once the solvents have been evaporated (cellulosicresins) after transferring of pattern.

Other additives to modify the rheological properties of themixture and its interaction with the substrate surfaces (wetting agents).
Apart from this the exact formulation of the metallization paste are kept as a industrial secret, but it is possible to summarize the general components of a typical front contact paste can be shown as follows.

Components	**Wt.%**
Silver	70-85
Glass Frits	0-5
Cellulosic Resin	3-15
Solvent (Pine Oil or Glycol Ethers)	3-15

Additives (Rheological Modifiers and Surfactants)	0-2

Table-1: Components of industrial screen printing pastesfor the definition of the front contact.

Fig. outlines the characteristics of the pastes during the firing process. The steps in firing of metal paste when laidon silicon cell are as under [4],

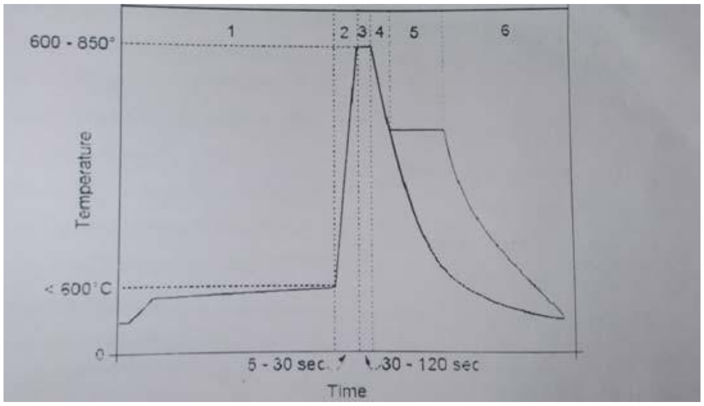

Fig-1: Co-firing temperature-time profile of solar pastefiring process

1) Burn-out
2) Ramp-up
3) Peak
4) Ramp-down
5) Tempering step
6) Cooling.

6. Advances in Metal Pastes

Due to high and sometimes volatile cost of silver metal, the need for solar cell metallization pastes with lowersilver content has become imperative.
Extensive research has been done on the development of front side pastes with decreased silver loading and

deposit. Experimental results have indicated that a threshold exists for silver reduction, below this silver loading, the performance of the paste begins tosignificantly degrade. It was found that an increase in busbar-to-busbar grid line resistance with decreasing silver content was the primary source of degradation. By tailoring the solid content and morphology, as well asusing proprietary additives, the performance of a low silver paste could be improved to the of the paste with a much higher silver loading. Thus research and development continuous to improve the performance-to- cost ratio of its PV metallization pastes to meet market demands and customer requirements.
Metal pastes are one of the key components that affect solar cell efficiency; especially front electrodes are known to have the greatest influence on the solar cell efficiency.

7. Paste Formulation Using Nano Particles

The silver paste for crystalline solar cells are prepared by the rotary evaporation method, specifically silver particles 80 wt % micron particles and nano particles in ratio (70:10), glass frit powders (4wt%) and organic vehicle(ethyl celluloses ad terpineol) (16 wt%) are mixed at a certain ratio (80:4:16) in ethyl alcohol. The contents are concentrated in a rotary evaporator at about 40ºC. After few hours, the ethyl alcohol can be eliminated and preliminary products are finalized by a three-roller-mill grinder.

The three-roller-mill grinder has widely been used in paste materials. The mill roller is usually made of high hardness alloy, which is also equipped with a cooling device for continuous operation. The final product (paste)thus obtained is ready for application on crystalline siliconwafers by using a screen printing machine followed by firing process in a conveyer infrared furnace.

Composition of silver paste contains mainly synthesised silver nano particles and micro particles in the range (50nm to 2µm), glass frit and organic binder. Lead free glass frit nano sized particles and silver nano particles areused to achieve high performance of crystalline solar cells.

Composition	Wt%

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Silver particles (micro particles + nano particles)	(70:10) 80%
Glass frit (lead free)	4%
Organic vehicle (Ethyl celluloses + terpineol)	16%

Table-2: Composition of silver paste

Silver electrode formed by new prepared paste containingnano particles and PV performance measured.
For comparison, a reference silver paste (denoted as pasteB) based on single micron silver particles was alsoprepared with the same composition ratio of the paste 'A' (80/4/16).

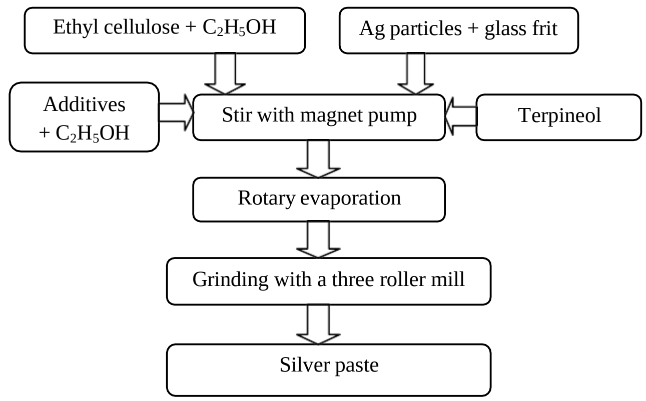


Fig-2: Flow sheet for preparing silver front contact paste

Silver fingers from paste B were also formed by screen printing on silicon wafers. Schematic diagrams of the two kinds of silver fingers before firing process were presented as shown in figure. Compositions of silver contact paste with silver nano particles (paste A) and without nano particles (paste B) was shown in table.

Paste ID	Silver particles	Glass Frit	Organic vehicle	Ratio
A	Nano particle aided	Bi-based	Ethyl celluloses + terpineol	70/10/4/16
B	Micron	Bi-based	Ethyl celluloses + terpineol	80/4/16

Table-3: Composition of silver paste A & B.

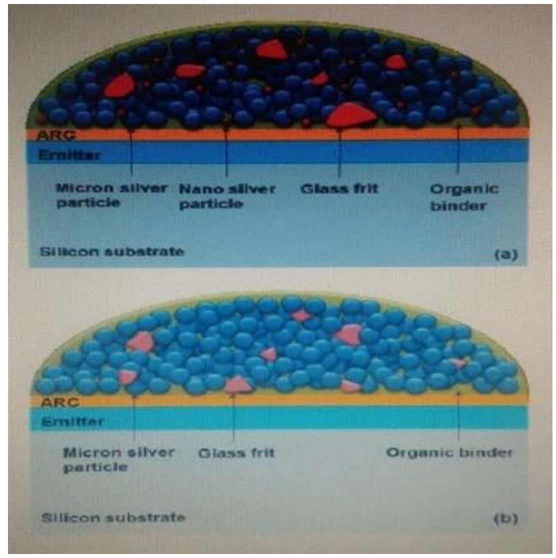


Fig-3: Schematic diagrams of the printed silver fingersbefore firing treatment: (a) Containing hybrid of micron silver particles and nano silver particles, (b) Containing single micron silver particles.

It can be seen that the silver thick film fabricated from silver paste containing silver nano particles exhibits denser structure (fig. 3 a) than that of thick film based on silver paste containing single micron silver particles (fig. 3b). The experimental results demonstrated that the silver nano particles which were added as a sintering aid into the silver paste, promoted sintering of silver particles.

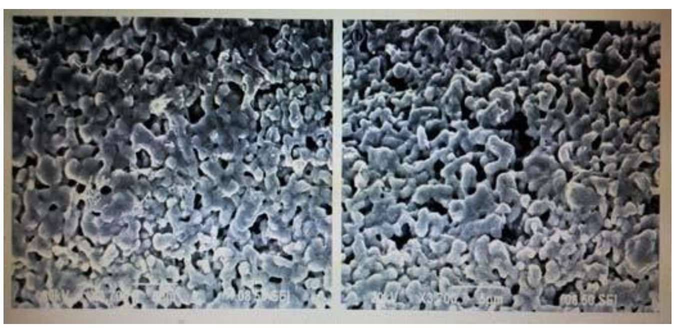
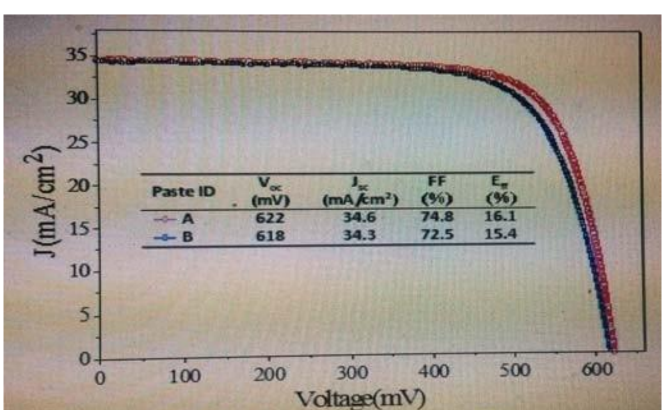


Fig-4: SEM morphologies of the surfaces of the silver thickfilm: (a) fabricated using hybrid silver particles and silvernano particles; (b) fabricated using single micron silver particles.

The photovoltaic performance of the fabricated crystallinesilicon cells resulting from the silver pastes A and paste B were shown in figure 4. it can be seen that the fabricated silicon solar cell based on paste A containing silver nano particles generated an open circuit voltage (V_{oc}) of 622 mV, a short circuit current density (J_{sc}) of 34.6 mA/cm^2, a fill factor (FF) of 74.8% and a conversion efficiency (E_{ff}) of16.1%. These are improved results compared with those resulting from the solar cell based on the silver paste B containing single micron silver particles (V_{oc} = 618mV, J_{sc} = 34.3mA/ cm^2, FF = 72.5%, E_{ff} = 15.4%).

The fabricated crystalline silicon solar cell containing the silver nano particles exhibited higher electrical energyconversion efficiency compared with that of the solar cell fabricated from the conventional silver paste containing single micron particles [5]



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.Fig-5: I-V performance of the fabricated crystalline siliconsolar cells based on different silver pastes under AM 1.5 (1000W/ m^2).

8. CONCLUSIONS

In comparison to thick films based on silver paste containing single micron silver particles, those created using silver paste containing silver nano particles have a denser structure (conducting network). Silver nanoparticles were added to the silver paste as a sintering aid, and the experimental findings showed that this addition accelerated the sintering of silver particles.

Solar cells made from a standard silver paste with single micron silver particles performed less efficiently in terms of electric conversion than those made from crystalline solar cells with silver nano particles.

Thus, the enhanced performance may be ascribed to the superior thick film produced by silver nano particles, which not only raise the line conductivity of silver electrodes but also enhance the compactness of thick film.

It can be inferred that employing silver nano particles in the silver paste may create excellent front metallization contact for the greatest efficiency of polycrystalline solar cell.

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