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Energy Procedia 67 (2015) 93 – 100

Energy Procedia

5th Workshop on Metallization for Crystalline Silicon Solar Cells

Characterization of Copper Diffusion in Silicon Solar Cells

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Abstract

In this work we investigate the degradation behavior of solar cells with a copper front side metallization based on a fine-line screen-printed silver seed-layer, a plated nickel diffusion barrier, a plated copper conductive layer and a silver capping. The results reveal that the cell degradation depends, besides the effectiveness of the nickel diffusion barrier, on the used seed-layer and the firing temperature of the seed-layer. The degradation behavior of cells, produced with different Ag seed-layer pastes resulting in different contact finger geometries after screen-printing and firing, was evaluated. With similar nickel diffusion barrier masses the seed-layer that generates the biggest metallized area at the cell surface shows the fastest degradation. Apart from that, the composition of the seed layer also has an impact on the degradation. The analysis of different firing temperatures shows that higher set-peak temperatures result in faster cell degradation due to copper migration.

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Peer-review under the responsibility of Gunnar Schubert, Guy Beaucarne and Jaap Hoornstra

Keywords: solar cell metallization; copper; nickel diffusion barrier; long term stability;

1. Introduction and Motivation

Solar cell metallization is the largest individual cost fraction in the costs of solar cell production, dominated by the front silver metallization costs [1]. The substitution of the silver with copper offers the potential to reduce the production costs of silicon solar cells significantly. The copper front side metallization investigated in this work is based on a fine-line screen printed seed layer, a plated nickel diffusion barrier, a plated copper conductive layer, and a thin plated silver capping [2] like it is shown in the microscope cross-section image in Fig. 1.

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Peer-review under the responsibility of Gunnar Schubert, Guy Beaucarne and Jaap Hoornstra
doi:10.1016/j.egypro.2015.03.292

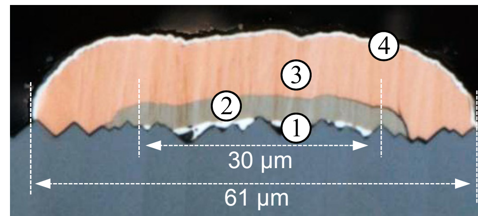

Fig. 1. Microscope cross section image of a contact finger of the copper metallization based on a screen printed fine line silver seed-layer (1) a nickel diffusion (2) barrier, a copper conductive layer (3) and a fine silver capping (4).

This metallization architecture offers the advantage of cost reduction by lowering the total front-side silver consumption to <16 mg per wafer [3]. The effectiveness of the used barrier materials (silicon nitride and nickel) were evaluated in our recent publication [4]. It was found that silicon nitride layers deposited by inline PECVD or inline sputtering avoid copper diffusion into the cell even if pre-treatment with HF dip (1%, 30s prior to copper evaporation) is applied or a high mechanical load is applied during screen-printing (100 N/cm squeegee pressure). We could show additionally that 20 mg plated nickel is sufficient to make long term stability issues due to copper migration improbable in a normal cell lifetime. In this work we present results with respect to influence of the type of applied seed-layer and of the respectively applied firing temperatures on the degradation behavior of the seed- and plate solar cell at elevated temperatures. To characterize the impact of these parameters the rapid cell degradation test at elevated temperatures, published by Bartsch et. al. [5] was used.

2. Experimental

2.1. Solar Cell samples

For the degradation experiments full size (156 x 156 mm^2), p-type, monocrystalline, solar cells were produced by screen printing front-side contacts on textured (random pyramids) Cz silicon wafers with PECVD silicon nitride anti reflection coating, a 90 Ω/sq phosphorous doped emitter and a standard aluminum backside metallization with silver pads. An H-pattern grid with 90 fingers and 3 straight (1.5 mm) or segmented busbars was screen printed on the samples using different silver front side pastes and an industrial, automated inline screen printing machine. The screen openings for the contact fingers were 25µm wide. Depending on the used paste, contacts with different shape were achieved. The samples were fired at set peak temperatures of 860°C, 890°C and 920°C in an inline furnace. Nickel as diffusion barrier, copper as conductive layer and silver as capping layer were plated on the fired contacts using a single side, light induced plating process on inline machines. For nickel plating a Watts-type nickel electrolyte working at a pH of ~4 was used. During this process the backside of the cells does not get in touch with the electrolyte. The nickel mass was varied from 5 mg per cell to 20 mg per cell.

2.2. Cell degradation at elevated temperatures

Cells were heat-treated on hotplates at 175, 200, 225°C, 250°C, and 275°C. The *pFF* was characterized using a Suns Voc measurement setup (Sinton Instruments) with containment to exclude an influence from ambient light. Before each measurement the cells were cooled down to room temperature for two minutes in ambient air. The measurement frequency was adapted to the degradation speed. Average intervals between 4h and 20 h were chosen. The temperature time pairs leading to a *pFF* degradation to 95% of the initial *pFF* value at different temperatures were evaluated using Arrhenius plots. If this value was not exactly measured a linear interpolation between the measured data point above and below 95% were performed to get the desired temperature/time pair.

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