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Physical understanding of printed thick-film front contacts of crystalline Si solar cells—Review of existing models and recent developments

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Abstract

Existing models of the silver thick-film contact to an emitter are summarised and recent developments focusing on contact formation and current transport mechanisms are presented. As a glass layer exists at the silicon-thick-film interface the current transport mechanisms are not obvious. The main hypotheses are: current transport via spike-like direct silver–silicon interconnections or via tunnelling through the chemically modified glass layer. Recent investigations showed that silver crystallites grow into the emitter from the glass frit containing dissolved silver [G. Schubert, B. Fischer, P. Fath, in: Proceedings of photovoltaics PV in Europe Conference, Rome, 2002, pp. 343–346 [1]]. These silver islands are covered by a thin glass layer [C. Ballif, D.M. Huljic, A. Hessler-Wyser, G. Willeke, in: Proceedings of the 29th IEEE PVSC, Glasgow, 2002, pp. 360–363 [2]]. Further investigations are necessary to study the crystallite-growth mechanism as well as the current-transport mechanism from the crystallites to the finger.

Keywords: Thick film; Metallisation; Silicon; Screen printing; Solar cell; Silver; Front side; Current transport; Contact formation

1. Introduction

The predominant technique in the photovoltaic (PV) industry to establish an ohmic contact to an n-type emitter of a crystalline silicon solar cell is screen printing of an Ag-based

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thick-film paste and firing through the ARC layer. More than 85% of all PV systems include solar cells with thick film contacts. Contact resistivities of $\rho_C < 10\,m\Omega\,cm^2$ typically require highly doped emitters ($R_{sheet} = 35$–$55\,\Omega/sq$, $N_{c,surface} > 2 \times 10^{20}\,cm^{-3}$). However, high doping concentrations lead to recombination losses which limit the cell performance. Lowly doped emitters (e.g. $R_{sheet} = 100\,\Omega/sq$, $N_{c,surface} = 1$–$2 \times 10^{19}\,cm^{-3}$) are more difficult to contact by Ag pastes aiming at a low ρ_C. Currently there are two approaches:

1. Using a selective emitter design with highly doped areas directly below the contacts. This can be achieved, for example, by applying self-doping thick film pastes [see for example Refs. [3–5]].
2. Optimisation of standard Ag thick-film pastes.

Further optimisation requires a detailed understanding of the electrical contact formation. Although screen printing technique is applied to solar cells since the 1970s [6], the knowledge of the silver thick-film contact to the emitter of a solar cell is still limited. In this work we present a review of early hypotheses and recent investigations that give more detailed insight into the contact formation and current-transport mechanisms.

2. Review of early hypotheses

A typical commercially available silver thick-film paste consists of silver powder, glass frit and organics comprising binder, solvent and certain additives to ensure proper printing properties. Usually a lead borosilicate glass with high lead oxide content is used [7]. For standard firing-through silicon nitride processes an IR-belt furnace providing a fast firing sequence is used. After drying and burning off the organics the contact is formed at peak temperatures below the silver–silicon eutectic temperature of 836 °C [8].

The glass frit plays the most important role during contact formation. Its main task is to etch through the antireflective coating (usually SiN_x) making way for the conductor particles to enable electrical contact to the emitter of the solar cell. Consequently a glass layer accumulates on the silicon surface, confirmed by many authors [9–13]. The glass frit is therefore supposed to affect the current transport from the emitter into the silver thick film to a great extent. Additionally, the glass dissolves several percent of Ag [9–11] and enhances the sintering process of the fine silver powder during firing [14].

The different hypotheses concerning the electrical contact formation to an n-type emitter and the resulting current-transport mechanisms are discussed in more detail below.

2.1. Contact formation

The interaction of the glass frit with silicon is the key point in electrical contact formation. Two main hypotheses exist in literature.

1. Some authors assume that silicon is dissolved in the glass. When cooling down the silicon is assumed to recrystallise epitaxially [2,15,16]. This hypothesis is mainly based on SIMS studies of the incorporation of elements contained in silver pastes in silicon below a thick film contact [17]. The recrystallised silicon layer beneath the contact is supposed to determine the contact properties at least partly [15,16].