

## Optimized front silver metallization for high-Ohmic emitters

P. van Eijk<sup>1</sup>, H. Kerp<sup>1</sup>, K. Albertsen<sup>1</sup>, T. Pham<sup>2</sup>, M.N. van den Donker<sup>3</sup> and A. Shaikh<sup>2</sup>

<sup>1</sup>Ferro Electronic Material Systems, Frontstraat 2, 5405 PB Uden, The Netherlands.

*E-mail* [eijkp@ferro.com](mailto:eijkp@ferro.com), phone +31 413 283313, fax +31 413 283 369.

<sup>2</sup>Ferro Corporation, Electronic Material Systems, 1395 Aspen Way, Vista CA 92083, U.S.A.

*E-mail* [shaikha@ferro.com](mailto:shaikha@ferro.com), phone +1 760 305 1000, fax + 1760 305 1009.

<sup>3</sup>Solland Solar Cells BV, Bohr 10, 6422 RL Heerlen, The Netherlands.

*E-mail* [mvandendonker@sollandsolar.com](mailto:mvandendonker@sollandsolar.com), phone +31 45 8800 686, fax +31 45 8800 605.

**ABSTRACT:** When the sheet resistivity of the n-type emitter in industrial p-type wafer-based solar cells exceeds 70 Ohm/sq it becomes of critical importance to produce homogeneous emitters combined with a high quality front contact. The screen printable silver paste should enable low contact resistance, minimized shunting risk, high specific conductivity and a wide process window. This paper evaluates new silver pastes for contacting low doped emitters. The experiments confirm that the contact resistance strongly depends on both emitter sheet resistivity and firing conditions. It is demonstrated that by using robust paste chemistries the process window is increased compared to standard pastes. One of the investigated pastes, 'paste B', makes good electrical contact with emitters up to 100 Ohm/sq over a broad firing range. More work is needed to fully understand the mechanisms taking place during the firing process on a microscopic level.

**Key Words:** high-Ohmic emitter, front silver metallization, contact resistance.

### 1 INTRODUCTION

In order to achieve further cost reduction of wafer-based crystalline silicon solar cells the cell efficiency needs to be increased to be able to compensate for e.g. increased costs of energy and raw materials. Increasing the sheet resistivity of the n-type emitter in standard p-type cells is a way to harvest higher currents, because especially the blue part of the solar spectrum can be used more efficiently. The main challenge for cell producers is to produce homogeneous high-Ohmic emitters (> 70 Ohm/sq) and to establish a good front contact metallization process. As this type of emitters is usually relatively shallow (< 0.3  $\mu\text{m}$ ), it is of key importance to avoid shunts by emitter perforation. Besides that, the contact resistance must be sufficiently low not to contribute to the series resistance of the solar cell. In current cell production lines the dominant process for front contact formation is still screen printing and subsequent firing of silver pastes. It is a challenge for the paste producer to formulate its products such that they provide excellent conductivity, low contact resistance and minimized shunting risk. Additionally the pastes have to provide a wide processing window in order to allow stable processing in the printer lines.

This paper describes the steps towards optimization of a screen printed front electrode for  $n^+$  phosphorous emitters with a sheet resistivity higher than 70 Ohm/sq. The process of  $n^+$  contact formation has been studied widely during the last years. It has been shown that this process is mainly governed by Ag island formation and properties of the interfacial glass layer (see e.g. [1,2]), a model which explains quite well the contact properties of emitters with a relatively high phosphorous concentration at the surface, i.e. in the range of  $> 2 \times 10^{20} \text{cm}^{-3}$  [3].

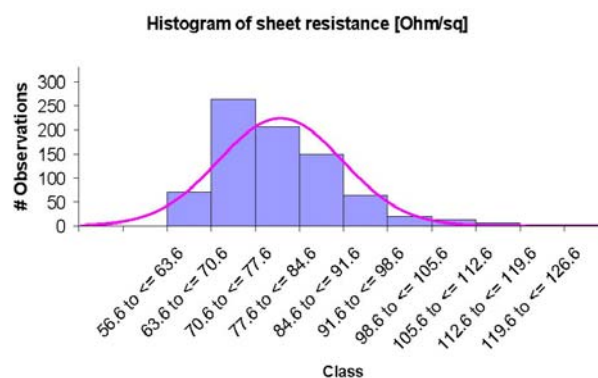
This study presents the electrical performance of two new silver pastes that have been especially designed to contact shallow emitters with a relatively low surface concentration (as the increase of the sheet resistivity usually leads to a lower surface concentration of phosphorous). The employed emitters were prepared on a semi-production scale and range from 60 until 100 Ohm/sq. The results provide insight in the dependency of contact resistance on sheet resistivity. Besides

we will compare the performance of these pastes with a commercial paste as a function of firing temperature. The sensitivity of paste formulation against firing temperature and emitter sheet resistivity will also be discussed.

### 2 EXPERIMENTAL

#### 2.1 Sample preparation

The diffused and silicon-nitride coated samples were prepared by Solland Solar on a semi-production scale, using 6 inch multi-crystalline wafers. The following process steps were applied: surface texturization, phosphorous emitter formation,  $\text{SiN}_x$  AR coating deposition. A high-Ohmic phosphorous emitter was deposited with ultrasonic evaporation and diffused according to large volume procedures. The sheet resistance was varied in a wide range between 60 and 100 Ohm/sq. by changing the phosphosilicate glass thickness.



**Figure 1:** Targeted sheet resistance.

The emitter obtained in this way can be characterized as a 'high-Ohmic emitter finite source'. It is a deep emitter with a lower surface phosphorous concentration. Recent cell improvements on the front side based on this type of emitter have been reported [4].

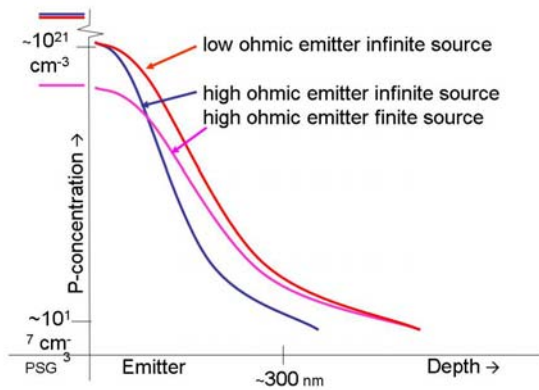


Figure 2: Schematic representation of emitter types.

2.2 Silver pastes

Two new Ferro front side silver pastes (A and B) were developed to contact high-Ohmic emitters. A standard Ferro paste (CN33-462) was used as a reference material. In order to obtain a better electrical contact between the front contact and the emitter the silver particle size of paste A and B was decreased with respect to the standard Ferro paste. At the same time the glass softening point Tg was increased for paste A and B to avoid junction penetration.

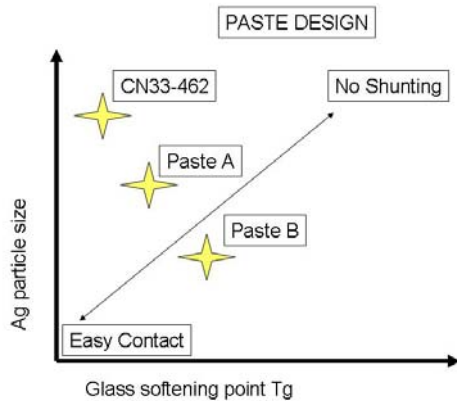


Figure 3: Criteria for paste design.

The silver paste was applied with screenprinting on the wafers using a TLM pattern. The wafers were fired in a 3 zone RTC IR kiln with 0.19, 0.38 and 0.19m zone length at 3050 mm/min belt speed. Zone 3 was varied over a 120 °C wide firing window.

The contact resistance was measured on a TLM pattern which was specially designed for this purpose. Contact pads of 0.2 cm² were printed at distances 0.25; 0.5; 1.0; 2.0; 4.0; 8.0 mm.

3 RESULTS

3.1 Contact resistance

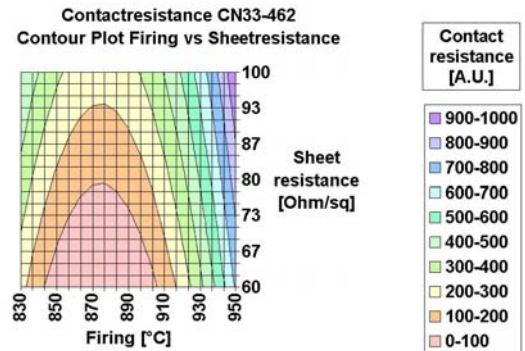


Figure 4: Contact resistance distribution for commercial paste CN33-462 as a function of sheet resistance and firing temperature.

The standard Ferro paste CN33-462 already demonstrates excellent contact resistance for high-Ohmic emitters up to 70 Ohm/sq over a broad firing window, but at higher firing temperatures the contact resistance rapidly increases. It is proposed that the more fluid glass of this paste forms a thicker glass layer between silver islands at the contacting interface and bulk silver at higher firing temperatures, restricting the contact between silver islands and bulk silver [1].

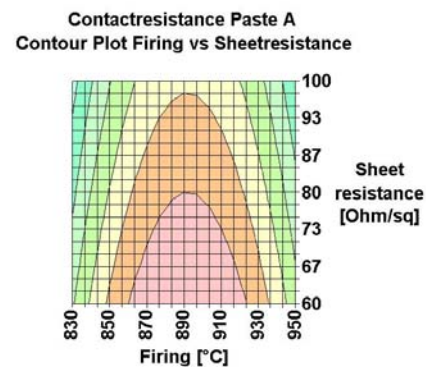
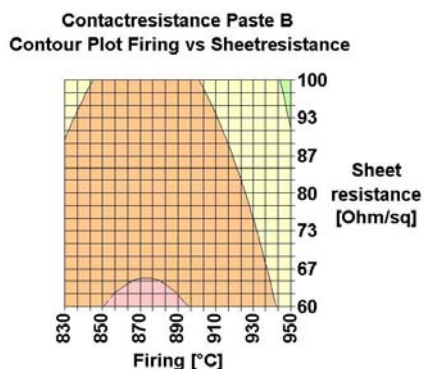


Figure 5: Contact resistance distribution for Paste A as a function of sheet resistance and firing temperature.

Paste A demonstrates the same low contact resistance up to 70 Ohm/sq over a broad firing window as paste CN33-462, but the contact resistance increases at a lower rate when going to either higher sheet resistance or away from the optimum firing setting. It is proposed that the less fluid glass of paste A forms a thinner glass layer at higher firing temperatures.



**Figure 6:** Contactresistance distribution for Paste B as a function of sheet resistance and firingtemperature.

Paste B demonstrates the lowest increase in contact resistance when going to higher sheet resistances or away from the optimum firing setting. The area with lowest contact resistance is smaller than the reference paste. A possible explanation could be that the fine silver particles of the paste are more reactive and form larger silver islands already at low firing temperatures. These larger silver islands have more contacting surface with the n-type silicium, resulting in less dependency on sheet resistance and firing settings.

#### 4 SUMMARY AND CONCLUSIONS

We have investigated the effect of sheet resistance and firing temperature on the contact resistance of two especially designed silver pastes on high-Ohmic emitters, and compared them to a commercial paste. Both the magnitude of the contact resistance, as well as the dependency of the contact resistance on sheet resistance and firing settings is changed by applying paste with different silver particle size and glass softening point.

The two new Ferro front side silver pastes have been successfully applied in new cell concepts like the PUM cell [5,6] the ASPIRe cell [5,6] and the Sunweb cell [7].

In order to clarify the role of the silver particle size and the glass softening point, more detailed micro structural investigations are necessary.

#### 5 ACKNOWLEDGEMENTS

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