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Application of modern technique to set the parameters of the monocrystalline solar cell and its structure

***Abstract**. The paper shows that co-firing in the furnace of silicon elements of solar cells from monocrystalline silicon including co-firing of the front electrode to its surface using the conveyor-type IR furnace influences the quality improvement by minimization of the resistance of a joint between the electrode and substrate. The influence of therefore obtained front electrode on electrical properties of solar cells was estimated. In order to manufacture the front electrode commercial silver paste was applied. The photovoltaic cell was performed from monocrystalline silicon p type boron doped in a form of wafers of ~230 μm thickness and the area of 100 cm^2.*

***Streszczenie.** Artykuł pokazuje że dodatkowe nagrzewanie krzemowych elementów baterii fotowoltaicznej w piecu podczerwieni poprawia jakość baterii przez minimalizację rezystancji połączenia między elektrodami i podłożem. (**Zastosowanie nowej technologii do poprawy parametrów monokrystalicznej baterii słonecznej**)*

Keywords: Electrical Properties, Silicon solar cell, Screen printing, Front electrode
Słowa kluczowe: bateria słoneczna, technologia, elektrody baterii słonecznej

Introduction

The research studies in the photovoltaic field are oriented to reduce the costs of electrical energy produced with the use of photovoltaic cells to the level competitive to the costs of energy produced from conventional energy sources. To obtain the above objective it is necessary to eliminate the technological process with expensive and difficult to automate operations and replace them with cheap ones whose production can be automated. One of such emerging production operations of photovoltaic cells is the deposition of electrical contacts. As it has been found by numerous research studies, electrode coating should satisfy different requirements to ensure low resistance between the interface zones of the electrode with the substrate. Of particular importance is the proper selection of material (of electrode and substrate), conditions of its fabrication, shape and size of electrode, adhesion of the electrode to the substrate and substrate morphology. In order to improve electrical properties of the front electrode, one fabrication technique is being analyzed – the screen printing, which is the most widely used contact formation method for commercial silicon solar cells [1-8].

Experimental procedure

The photovoltaic cell was performed from monocrystalline silicon p type boron doped in a form of wafers of 200 μm thickness and the area of 100 cm2 with the crystallographic orientation of (100), the resistivity of ~2 Ω•cm. Front metallization was performed from silver PV 145 paste produced by Du Pont company. Connecting back contacts were performed from PV 124 paste with the bismuth glaze and 2% addition of aluminum produced by Du Pont company. Back side metallization was printed from aluminum CN53-101 paste produced by Ferro company. Technology of manufacturing solar cell was performed in the Institute of Metallurgy and Materials Science in Krakow (Poland). The process steps for manufacturing solar cells were the following: chemical etching, p-n junction formation, parasistic junction removal, surface passivation of solar cell (SiO2), antireflection coating deposition (TiOx), screen printing deposition of front and back contacts, co-firing front and back contacts in the conveyor-type IR furnace. The conditions of co-firing solar cell in the conveyor belt IR furnace are presented in Table 1.

The following investigations were performed in the paper:

- The topography of both surface and cross section of front contacts using:
  - Zeiss Supra 35 scanning electron microscope (SEM),
  - Zeiss confocal laser scanning microscope 5 (CLSM),
- The topography of textured silicon wafer with using the atomic force microscope (Park Systems XE 100) in the non-contact mode.

Electrical properties of solar cell using the system for measuring the current-voltage characteristic produced by PV Test Solutions Tadeusz Zdanowicz company and the correscan instrument produced by Sunlab company.

Table 1. Conditions of co-firing in the furnace Si solar cell

Sample symbol	Temperature, °C		
	Zone I	Zone II	Zone III
A	530	580	920

Results and discussion

The observations in the scanning electron microscopy let us state that the morphology a front metallisation deposited from paste PV 145 and co-fired in the furnace shows a porous structure (Fig. 1). Based on the fractographic investigations, it was found that front metallization obtained from standard paste PV 145 by co-fired in the conveyor furnace method demonstrated connection with substrate without defects and delaminations. Electrode layer creates many homogenous connections with the silicon substrate, which are close to continuous connection (Fig. 2).

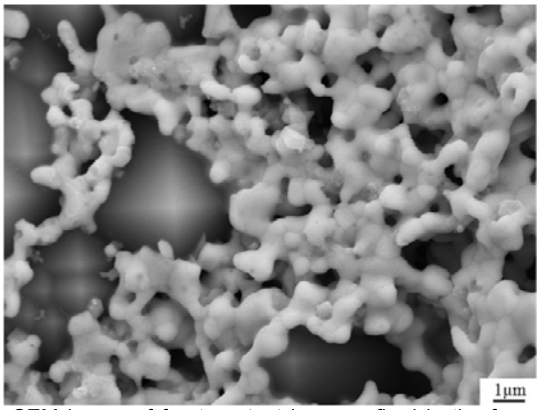

Fig.1. SEM image of front contact layer co-fired in the furnace at the 920 °C temperature from PV 145 paste on Si substrate with texture and antireflection layer

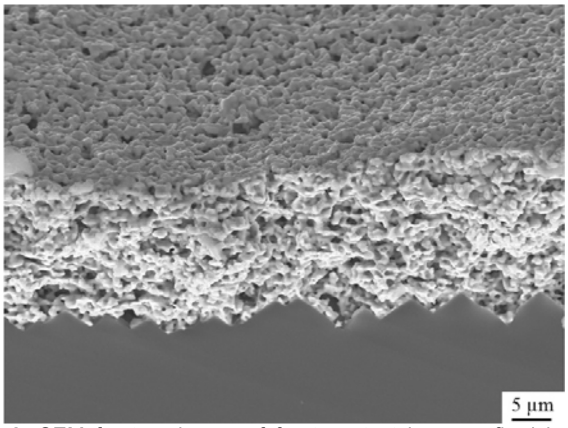

Fig. 2. SEM fracture image of front contact layer co-fired in the furnace at the 920 °C temperature from PV 145 paste on Si substrate without texture and with antireflection layer

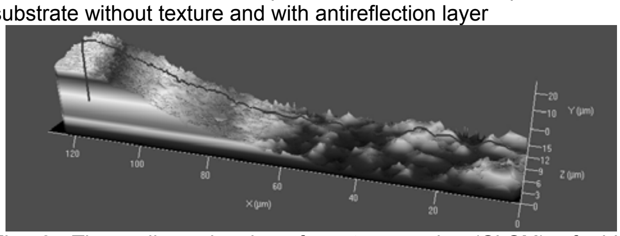

Fig. 3. Three dimensional surface topography (CLSM) of side metallization obtained from PV 145 paste on surface with texture and ARC layer co - fired in the furnace at 920 °C temperature (an example).

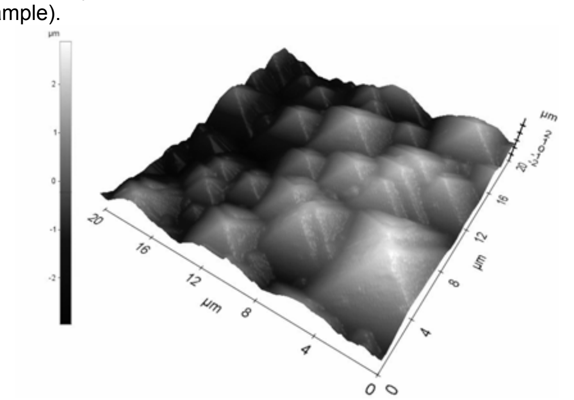

Fig. 4. Topography of the textured surface of solar wafer (AFM).

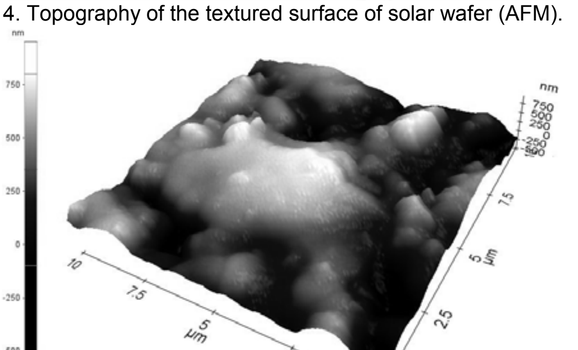

Fig. 5. An example of front side metallization topography of solar cell (AFM)

The thickness of front side metallization was determined based on the measurement of profile height three dimensional surface topography in the confocal scanning microscope (Fig. 3). In the atomic force microscope was observed the topography of textured silicon wafer. A medium height of pyramids was equal to 2 μm (Fig. 4).

In the atomic force microscope was also observed topography of front side metallization. A medium height of front contact was equal to 3 μm (Fig. 5).

Electrical properties of solar cell, with front side metallization obtained from PV 145 paste, co-fired in the furnace in the 920 °C temperature, determined from I-V curves let confirmed that their efficiency is equal to E_{ff} = 14.55 % and fill factor is equal to FF= 0.74 (Fig. 6, Tab. 2). In solar cell with the following reduced short circuit current value was obtained (I_{sc}) of 3.29 A and open-circuit voltage (U_{oc}) of 0.60 V (Tab. 2).

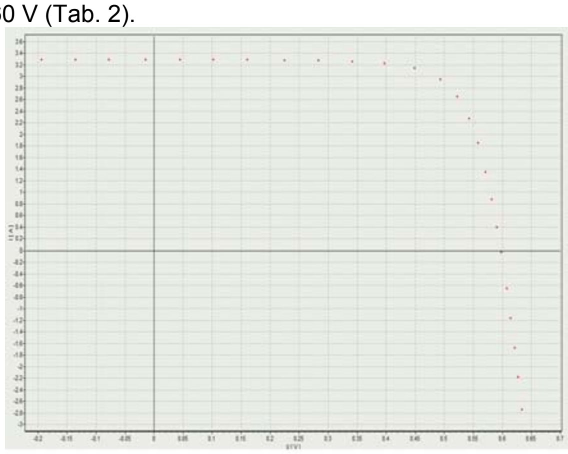

Fig. 6. Light I-V curve of solar cell co-fired at 920 °C temperature in the furnace from PV 145 paste.

The panel of Correscan instrument was introduced the following scan type: 1) Core Scan, 2) Shunt Scan, 3) LBIC-Scan.

In the first case in the panel of Correscan instrument was introduced the following date: current density 30 mA/cm, scan line spacing 1.5 min., scan speed 20 mm/s, finger spacing 2 mm, finger width 0.12 mm. During investigation the contact resistance and line contact resistance were calculated. Figure 7 is presented the results of investigation in a graphical and text form.

In the second case in the panel of Correscan instrument was introduced the following date: bias voltage 300 mV, scan line spacing 1.5 min., scan speed 20mm/s. During investigation the voltage was calculated. Figure 8 is presented the result of investigation in a graphical and text form.

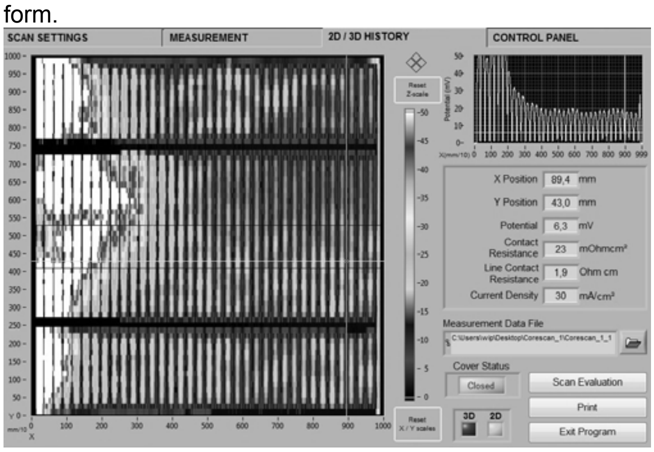

Fig. 7. A view of measurement results of contact and line contact resistance – Core Scan type.

In the third case in the panel of Correscan instrument was introduced the following date: lamp voltage 100%, scan line spacing 1.2 min., scan speed 20 mm/s. During investigation the current density was calculated. Figure 9 is presented the result of investigation in a graphical and text form.

Electrical properties of silicon solar cell with texture and ARC layer co-fired in furnace from PV 145 paste are defined as follows:

- Co-firing temperature 920 (°C)
- Open-circuit voltage of solar cell U_{oc} 0,597 V
- Short circuit current of solar cell I_{sc} 3,291 A
- A current in maximum power point of solar cell I_m 2,949 A
- A voltage in maximum power point of solar cell U_m 0.493 V
- Power of solar cell *P* 1.455 W
- Fill factor of solar cell *FF* 0,740
- Efficiency of solar cell E_{ff} 14.55

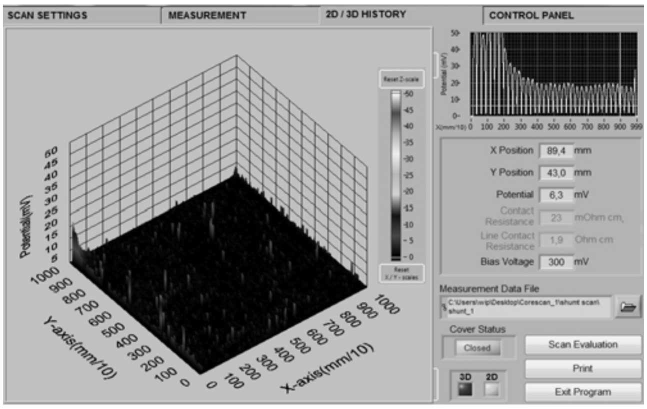

Fig. 8. A view of measurement results of potential – Shunt Scan type

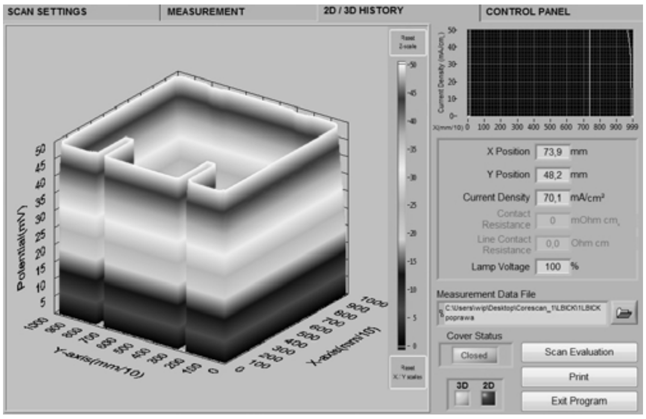

Fig. 9. A view of measurement results of current density – LBIC Scan type

Conclusion

Based on the metallographic observations, it was found that the morphology of front side metallization deposited from paste PV 145 and co-fired in the furnace shows a porous structure. Moreover, front side metallization layer creates many homogenous connections with the silicon substrate, which are close to continuous connection. It was found based on the observations in the atomic force microscope that a medium height of pyramids is equal to 3 μm. On the basis of electrical properties investigations using Correscan instrument it was found that in the 920 °C temperature the contact resistance is equal 23 mΩcm2 and the line contact resistance is equal 1.9 Ωcm with applied a current density 30 mA/cm2, the potential is equal with applied bias voltage 300 mV. It was found that Correscan instrument is an indispensable for optimisation of cell efficiency and especially for detailed surface mapping of contact resistance between the emitter and the front side metallization of solar cell.

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