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# Structure and electrical properties of screen printed contacts on silicon solar cells

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Properties

## ABSTRACT

**Purpose:** The aim of the paper was to apply a conventional method - "screen printing" using micrometric pastes to improve the quality of forming front side metallization of monocrystalline solar cells.
**Design/methodology/approach:** The topography of co-fired in the infrared belt furnace front contacts were investigated using confocal laser scanning microscope and scanning electron microscope with an energy dispersive X-ray (EDS) spectrometer for microchemical analysis. There were researched both surface topography and cross section of front contacts using SEM microscope. Phase composition analyses of chosen front contacts were done using the XRD method. Front contacts were formed on the surface with different morphology of the solar cells: textured with coated antireflection layer, textured without coated antireflection layer, non-textured with coated antireflection layer, non-textured without coated antireflection layer. The medium size of the pyramids was measured using the atomic force microscope (AFM). Resistance of front electrodes was investigated using Transmission Line Model (TLM).
**Findings:** The high of deposited front metallization has an influence on value obtained from the contact resistance. This high of silver contact depends on: a paste composition, obtained structure after fired into a infrared belt furnace, the quantity and type of creating connections material molecules between themselves and with a silicon substrate.
**Research limitations/implications:** The contact resistance of the screen-printed front metallization depends not only on the paste composition and firing conditions, but is also strongly influenced by the surface morphology of the silicon substrate.
**Originality/value:** This paper investigates the front contact formation using silver pastes about different composition on silicon solar cells in order to decrease contact resistance and increase efficiency in this way.
**Keywords:** Electrical properties; Silicon, Contact; Screen printing; Transmission line model

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## 1. Introduction

In order to obtain greater solar cell efficiency, it is important to keep the shadowing effect caused by the contact finger to an absolute minimum. Metallization is one of manufacturing operations of high efficiency solar cells [1-5,11-15]:

Metallization by screen printing (Fig. 1) is realized with keeping a specific sequence of stages [6-10]

1. printed back connection contacts (Al/Ag) and dried into the dryer,
2. printed front contacts (Ag) and drying into a dryer,
3. fired front and back contact in the furnace.

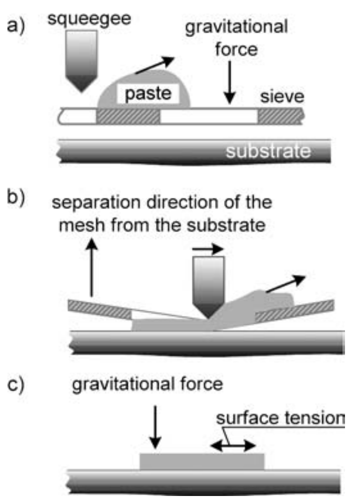



Fig. 1. Process for paste deposition: a) before printing, b) during printing a paste fill up meshes of sieve, c) after printing [6]

## 2. Experimental procedure

The investigations were done on wafers from monocrystalline silicon produced by Deutsche Solar (Germany). The basic parameters of these wafers are presented in Table 1.

Table 1.
The basic parameters of silicon

| Type | p | p |
|---|---|---|
| Doped | boron | boron |
| Thickness | 200 ± 30 μm | 330 ± 10 μm |
| Area | 5 cm x 5 cm | 5 cm x 5 cm |
| Resistivity | 1-3 Ω·cm | ~1 Ω·cm |
| Carbon concentration | $8x10^{16}$ at./cm$^3$ | $\leq 1x10^{18}$ at./cm$^3$ |
| Oxygen concentration | $1x10^{18}$ at./cm$^3$ | $\leq 2x10^{17}$ at./cm$^3$ |

The technology used to produce solar cell was performed in the Institute of Metallurgy and Materials Science (IMMS). The process for the fabrication sequence of silicon solar cells is presented in Figure 2. In experiment were used four series of the wafers characterized by different state of surface:

- textured with deposited antireflection coating,
- textured without deposited antireflection coating,
- non textured with deposited antireflection coating,
- non textured without deposited antireflection coating.

The chemical procedure for cleaning the wafers before the donor doping process is given in Table 2.

The emitter was generated in an open quartz tube using $POCl_3$ as a doping source.

The parasitic junction was removed by means of special teflon clamp in which the silicon wafers were stacked by surface EVA foil separation. Next to the clap was immersed in $HF:HNO_3:CH_3COOH$ solution, followed by rising in $DIH_2O$. The phosphorous-silicate glass ($xSiO_2 \cdot yP_2O_5$) was removed by immersion in a bath of HF.

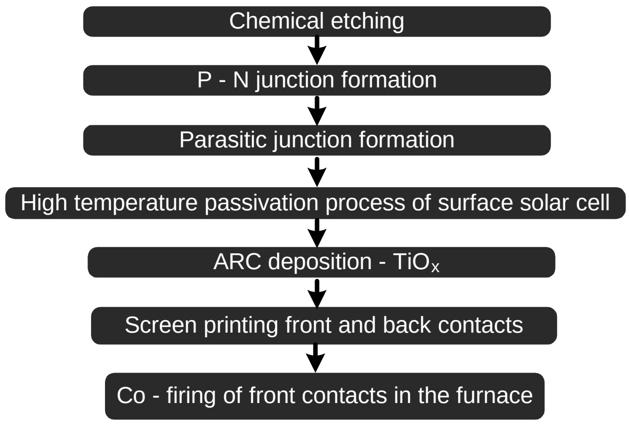



Fig. 2. Production stages of solar cells on base monorystalline silicon

The surface passivation was obtained by the growth of a thin, invisible passivating dioxide $SiO_2$ in a controlled atmosphere both $O_2$ and $N_2$.

Next, $TiO_x$ was deposited before contacts were screen-printed in the front side of solar cells.

Table 2.
Chemical processing of silicon wafers

| | Chemical process | Chemical recipe |
|---|---|---|
| | Washing in acetone | $CH_3COCH_3$ |
| | Rinsing | $DIH_2O$ |
| | Removing of distorted layer | 30% KOH |
| | Rinsing | $DIH_2O$ |
| Texturi-zation | Draughting in solution | 2%KOH:6% IPA:92%$H_2O$ |
| | | $H_2SO_4$ |
| | Rinsing | $DIH_2O$ |

Finally into investigations were prepared two silver pastes applied to co-firing in the belt furnace:

- 60.6%Ag+39,4% organic carrier (K1),
- 83.33%Ag+16.67% organic carrier (K2).

The silver pastes were consisted of micrometric powder and organic carrier. The silver powder used during investigations is presented in Figure 3.

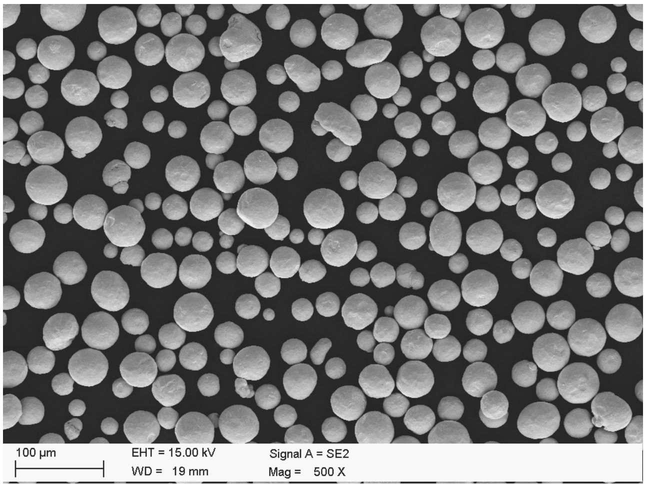



Fig. 3. The SEM micrograph of silver powder

The front paths were printed by screens of 325 mesh. There was prepared a special test structure, which was composed of series parallel paths about different distances between them. Test structure was prepared by screen printing method: sizes of front paths were: 2 x 10 mm (wide x length), distances between them were: 20 mm, 10 mm, 5 mm, 2.5 mm. Test structure (Fig. 4) was prepared to evaluate the contact resistance of the metal-semiconductor junction.

Before co-firing of front metallization, the wafers with silver metallization was drying in the dryer (Tab. 3).

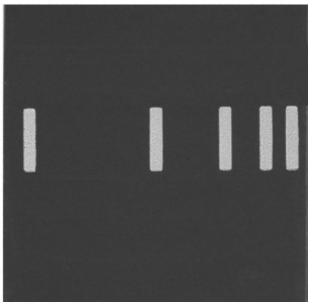


Fig. 4. Example testing structure of front contacts performed from silver K2 paste on textured surface without deposited antireflection coating

The following investigations were performed in this paper:

- The contact resistance $R_c$, specific contact resistance $\rho_c$, transfer length ($L_T$) of front contact solar cell using Transmission Line Model (TLM) method. TLM consists in direct current (I) measurement and voltage (U) measurement between any two separate contacts.
- The topography of monocrystalline silicon wafer with texture and ARC layer using the atomic force microscope (Park Systems XE 100) with uncontacted trybe. The medium size of the pyramids was also measured using this microscope.
- Phase composition analyses of chosen front contacts using the XRD method.
- Microchemical analysis of front chosen contacts using the scanning electron microscope equipped with an energy dispersive X-ray (EDS) spectrometer.
- The topography of both surface and cross section of front contacts using:
  - SEM microscope (Zeiss Supra 35) using secondary electron detection with accelerating voltage in the range 5-20 kV,
  - CLSM 5 microscope (Zeiss Exciter 5) in which the source of light was a diode laser about power 25 mW emits radiation about wave length 405 nm. The profile of height contact was determined on the basis of six medium measurements.

Table 3.
Parameters for the co-firing in the IR furnace, temperature in the zones: I - 530˚C, II - 570˚C, the belt feed rate was 200 cm/min

| No | Type of monocrystalline solar cells | Paste composition | Temp. in the third zone,°C |
|---|---|---|---|
| 1 | Textured with $TiO_x$ | K2 | 830 |
| | | | 860 |
| 2 | Textured without $TiO_x$ | | 890 |
| 3 | Non textured with $TiO_x$ | K1 | |
| | | | 920 |
| 4 | Non textured without $TiO_x$ | | 945 |

## 3. Results and discussion

In the paper were obtained specific contacts resistance of front electrode results for given value of current: 10, 30 and 50 mA depending on determined conditions of co-firing samples in the furnace (Fig. 5). Figure 6 presents an example of the series of test samples co-fired from K1 paste in the temperature range of 830-945°C onto silicon solar cell without ARC layer and texture - for a given value of current: 10 mA. Figure 7 presents an example of the series of test samples for silver pastes (K1 and K2) and different surface morphology - for a given value of current: 10, 30, 50 mA

Based on electrical properties investigations using TLM method it was found that the specific contact resistance values of test electrodes structure in the temperature range of 860-945°C is equal 0.44-57.21 $\Omega\cdot cm^2$. However, the smallest specific contact resistance was obtained in the range from 0.44 to 0.57 $\Omega\cdot cm^2$ (with the smallest value equals 0.44 $\Omega\cdot cm^2$ in temperature of third zone 945°C) for front metallization co-fired from the K1 paste on the surfaces non texture without ARC layer of solar cells.

In the atomic force microscope were observed topographies of silicon wafers with texture and ARC layer. A medium height of pyramids was determined by atomic force microscope. It is equal 2 μm (Fig. 8).

The qualitative analysis of phase composition (Fig. 9) carried out with the X-ray diffraction method confirms that on the electrodes from sintered pastes, the layers contain the phase Ag, which was generated in congruence with the assumptions. On the X-ray diffractograms obtained with the use of Bragg-Brentano technique also the presence of the reflexes from phase Si present in the substrate materials was demonstrated.

The front contact makes a connection between a metal and a semiconductor. In case of front contacts made from silver pastes: K1 and K2 co-fired it was found that individual grains of electrode contact each other and the surface of contact have a point character, what cause a considerable porosity. The connections formed (between silicon and silver electrode) from mentioned pastes have a point character indecently of co-firing temperature and morphology of silicon (Fig. 10c). Based on metallographic investigations confirmed some uncover silicon substrate areas inside an electrode, especially in case of electrodes about 40 μm height (Fig. 10).

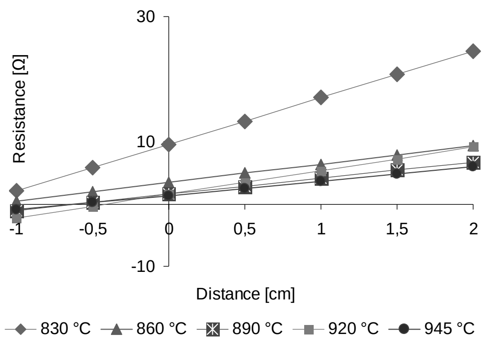



Fig. 5. Plot of resistance versus contact distance for the determination of contact parameters ($\rho_c$, $L_T$ and $R_c$), the given value of current: 10 mA

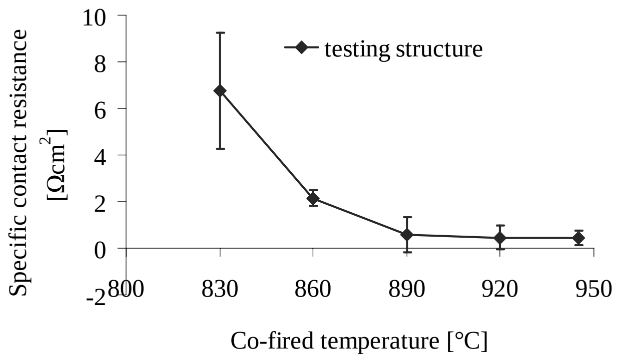



Fig. 6. Dependences the specific contact resistance of front contact on co-firing temperature for silver K1 paste (chosen example)

Table 4.
The height of front contacts formed from silver pastes (K1, K2) and co-fired in the furnace, next measured by the CLSM 5 microscope

| The surface of silicon solar cells | Co - fired temp., °C | The medium height of front contact | |
|---|---|---|---|
| | | Before | after |
| | | co-fired in the furnace | |
| Non textured with ARC | 830 | 40 | 39 |
| | 920 | | 36 |
| Non textured without ARC | 830 | 40 | 38 |
| | 920 | | 35 |
| Textured without ARC | 830 | 60 | 57 |
| | 920 | | 54 |
| Textured with ARC | 830 | 80 | 77 |
| | 920 | | 74 |

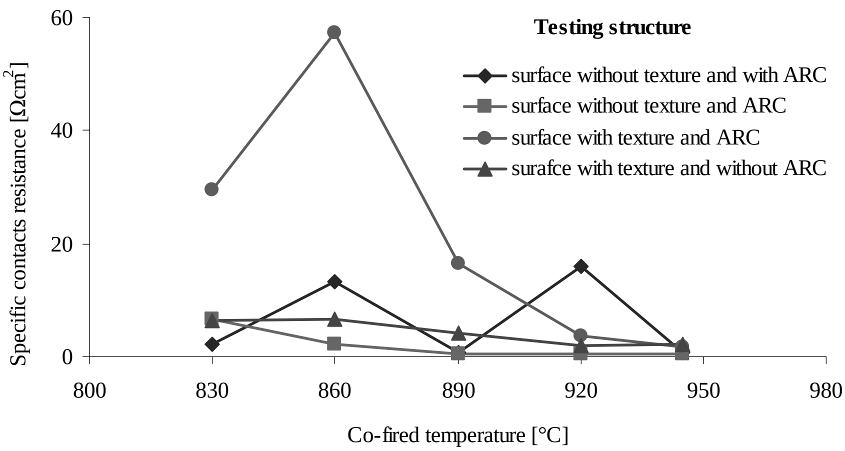



Fig. 7. The dependence of specific contact resistance of the front contact on co-firing temperature in the furnace for silver pastes and different surface morphology

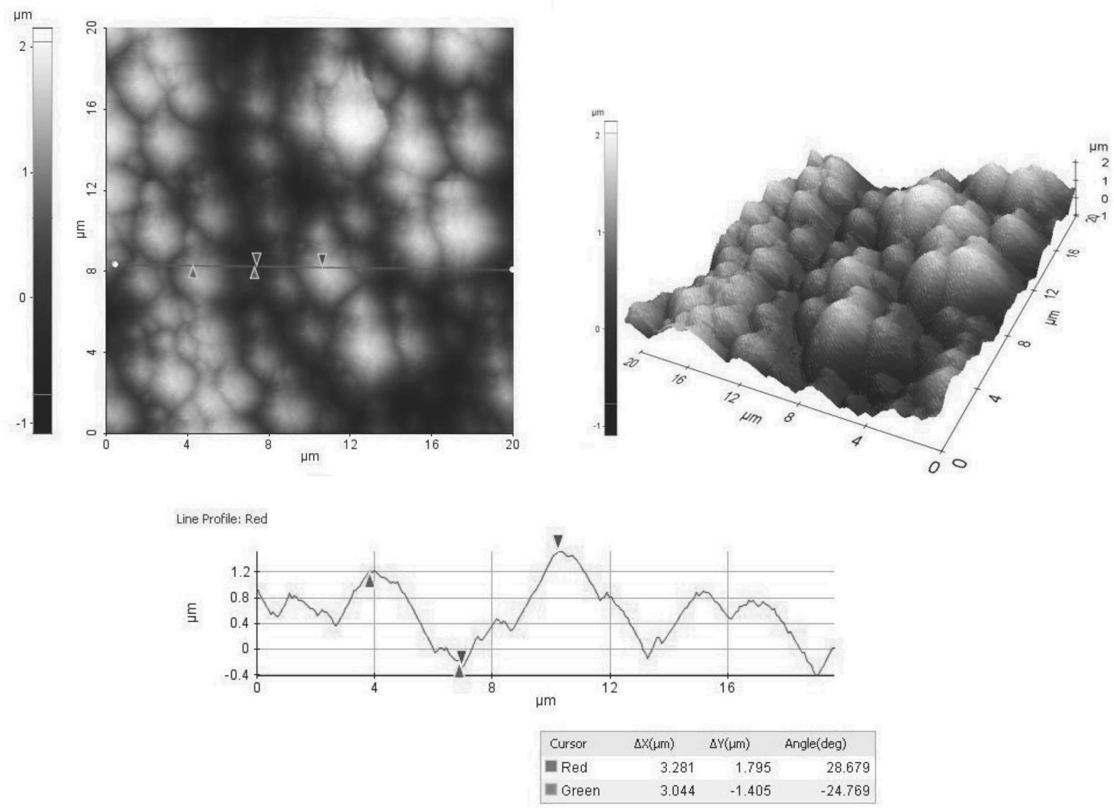



Fig. 8. The topography of monocrystalline silicon wafer with texture and ARC layer (an example)

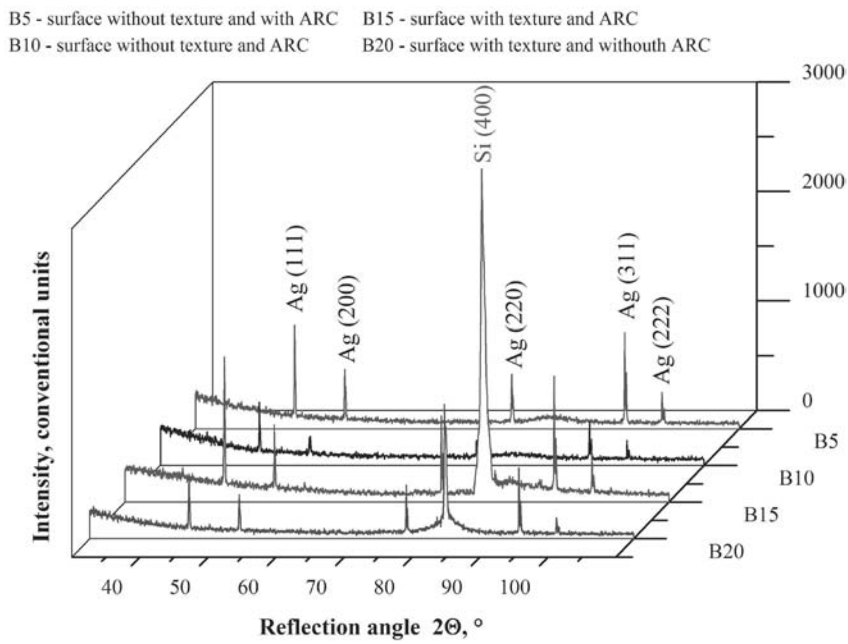
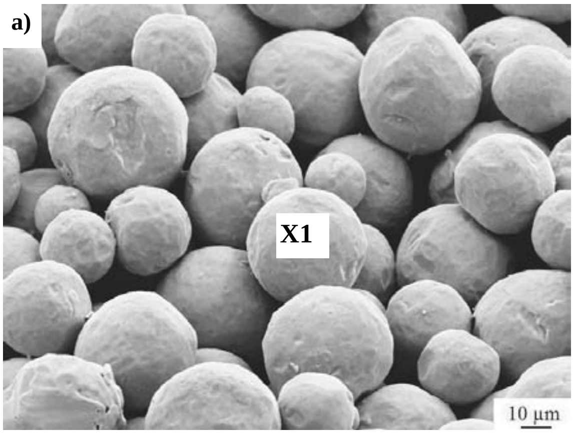
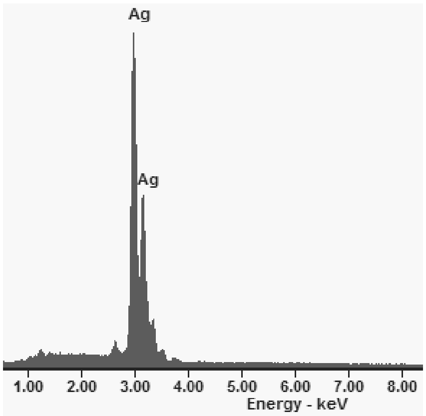



Fig. 9. X-ray diffraction spectra of the paste: K1 (B5, B10), K2 (B15, B20) deposited onto surface with different morphology and co-fired front metallization in temperature 920°C

a)




b)




c)

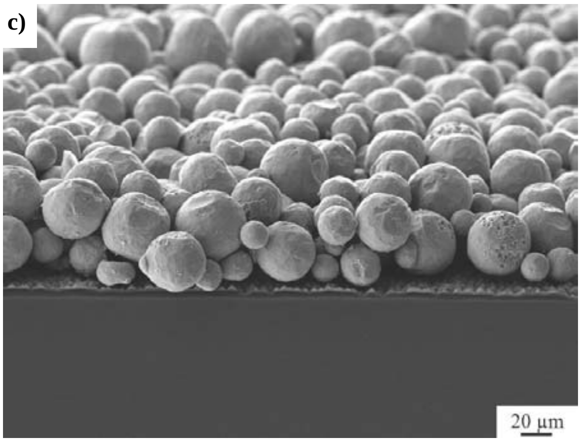
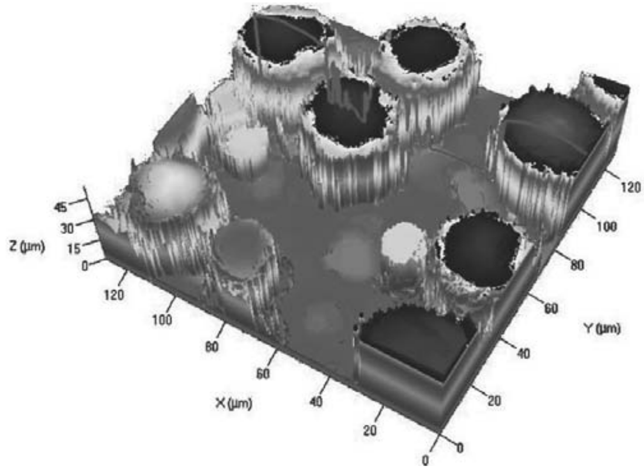



Fig. 10. SEM images of front contact layer from K2 paste onto Si substrate with texture and ARC layer by co-fired in the furnace of 830°C temperature: a) topography image, b) EDS spectra from X1 area, c) fracture image

The height of three- dimensional profile of front contacts was determined on the basis of surface topography performed in the Confocal Laser Scanning Microscope (Fig. 11). Based on metallographic observations The results of metallographic observations are presented in Table 4.



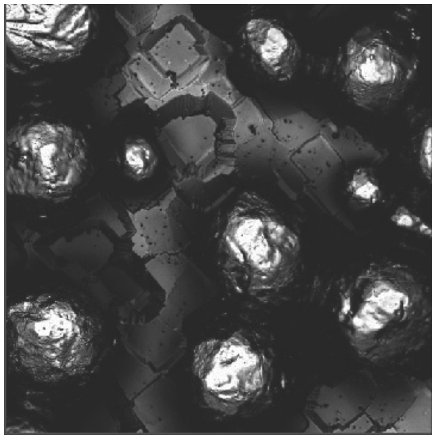



Fig. 11. Three- and two- dimensional surface topography (CLSM) of front electrode performed from silver paste (K1) on the surface without texture and with ARC layer co-fired in the furnace in 830°C temperature (chosen example)

## 4. Conclusions

Based on electrical properties investigations using TLM method, it was found that in the temperature range of 860-945°C, the specific contact resistance of testing structure co-fired from the K1 paste is equal 0.44-57.21 $\Omega\cdot cm^2$ onto substrate having different surface morphology of silicon solar cells.

Based on electric measurements and metallographic observations confirmed that both lack of ceramic glaze and too grate content of organic carrier into paste composition is responsible for stability value of obtained results.

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