Electrical and morphological study of screen printed silicon solar cells contacts

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Abstract

The screen printed contact quality influences directly the mono-crystalline silicon solar cells efficiency. This is the aim of this study. A batch of mono-crystalline silicon wafers have undergone all the technological processes such as chemical cleaning, phosphorus diffusion and finally screen printing metallization. According to the used silver paste technical data, the firing temperature should not be greater than 750°C. This is why for this last step, a temperature swept from 650°C to 750°C has been carried out. The principal purpose of this work is to evaluate the Ag/N^+ front contact quality by identifying the specific contact resistance, the resistivity and the morphology of each temperature profile. Transmission line method (TLM) is used as the technique for photovoltaic electrical characterization. It has been found that the best annealing temperature profile is750°C which corresponds to the lowest specific contact resistivity value of 1.65 mΩcm^2. Morphological study shows low contact porosity at 750°C which reflects its good quality.

Keywords: solar cell, TLM resistance, mono-crystalline silicon, screen printing, metallization, FERRO 3349

1. Introduction

Photovoltaic energy gained great attention these last years due to its high potential to be an alternative source of energy [1-5, 6].

Screen printing metallization is the most important step in large area mono-crystalline silicon based solar cells [7-9]. The best parameter which can reflect the contact quality is the specific contact resistance which can be deduced from Transmission Line Method TLM [10]. Each improvement for one step or process in solar cells fabrication is welcomes to make the photovoltaic solar energy competitive comparing to the other types of renewable energies [11].

Electrical characterization [12], is an important side after photovoltaic solar cells realization. It is the way by what can be detected the solar cell quality.

In our present work, we focus on Transmission line Method. It is based on the determination of the total resistance between two ohmic contacts as function of the distance which separate them [13]. This total resistance depends on the semiconductor resistance and on the specific resistance of the screen printed contacts [14]. A correlation with the morphological study has been made.

2. Experimental Details

A batch of mono-crystalline p-type silicon wafers with a resistivity of 1 Ωcm undergoes chemical cleaning process (degreasing+ RCA decontamination).

After that, a phosphorus diffusion by using solid sources PH-950 have been performed in order to create a N^+/P junction with 0.7 µm in depth.

Then, a silver paste (Ag) type Ferro 3349 is screen printed onto the N^+ Silicon front side according to the TLM pattern.

Finally, the contacts are annealed at temperatures between 650°C and 750°C.

The paste composition influences directly the annealing temperature profile. For example, L.A. Dobrzański et al. [18] ,worked at temperature interval 860°C-945°C while in our case and following the technical data of **FERRO 3349** silver paste [19], the annealing profile should be between 680°C and 750°C.

TLM measurements have been carried out by using equipment comprising a prober type Karl Suss AP4 and an analyzer type Agilent 4156 C.

Before starting TLM measures, TLM pattern contacts are isolated electrically by a mesa [15] in order to avoid vertical current circulation flow and consequently current leakage. The mesa consists of 4 grooves which form a rectangle, realized by diamond scriber with a depth greater than silicon junction depth.

3. Results & Discussion:

TLM pattern have been realized by lithography to measure the specific contact resistance.

As shown in figure 1, the TLM pattern consists of rectangular contacts with variable dimensions screen printed onto mono-crystalline silicon solar cells.

It has the following characteristics:

- The length L which equals the finger contact width L= 270µm with 10 µm thickness Ag silver paste.
- A conventional distance between two fingers s=3 mm.
- TLM distances between contacts (i.e between TLM lines 1 to 5) are given by

D1= d_{12} =0.3s =0.9 mm   D2=d_{23} =0.5s =1.5 mm

D3=d_{34} =0.9s =2.7 mm   D4=d_{45} =1.3s =3.9 mm

Samples 1, 2, 3 and 4 were prepared by annealing the TLM grid at temperatures 650°C, 680°C, 700°C and 750°C respectively.

Current –Voltage characteristics I(V) for each TLM distance at annealing Temperatures varying from 650°C to 750°C are represented in Figure 2.

From these curves are deduced resistances which are the inverse of I(V) slope for each distance D.

And finally, from Figure 3 which shows resistance variation with TLM distance D, is deduced TLM resistance for each temperature profile.

Following reference [16], TLM resistance is half the intersection of the curve R(D) with y-axis (figure 3).

Total resistance (R_T) between two neighbouring contacts is expressed by **[20]** :

$$\mathbf{V/I = R_T = 2R_c + R_\square \; D/Z} \tag{1}$$

Where R_T is the total resistance between two contacts, Rc is the contact resistance, R is the sheet resistance, D is the contact spacing.

The width of contacts (Z=6mm) is defined by the width of the mesa; their length (W) is equal to the width of the finger.

According to reference [20]:

If $L_T \geq 2L$: $\rho_c = R_c \, L_T \, Z$ (Ωcm^2)

If $L_T < 2L$: $\rho_c = R_c \, L \, Z$ (Ωcm^2)

TLM Results are gathered and summarized in the table 1.

It represents TLM resistance with annealing profile. One can remark that contact resistivity starts with a value of 8.16 mΩcm^2 at 650°C, reaches a maximum of 8.26 mΩcm^2 at 680°C and then decreases to 3.34 mΩcm^2 at 700°C and arrives to 1.65 mΩcm^2 at 750°C.

So, the lowest contact resistance occurs at 750°C annealing profile. This means that a metallization at 750°C is required for mono-crystalline silicon solar cells in order to get higher conversion efficiency. This value is comforted by what is given in literature around 2 mΩcm^2 [21-23].

Figure 4 illustrates SEM micrographs for the Ag/N$^+$ contact at temperatures sweeping 650°C to 750°C.

One can observe the high porosity of the contact at 650°C, which increases at 680°C and start decreasing at 700°C until being compact at 750°C. This result is comforted by the previous contact resistance study and converges to the conclusion that the metallization annealing profile at 750°C is the best to obtain high conversion efficiency [17].

4. Conclusion

Screen printed contacts for photovoltaic silicon solar cells have been studied.

From I(V) measurements made on metallic contacts of Ag on the front Silicon junction N$^+$/P with metallization temperature annealing varying from 650°C to 750°C.

The values for specific contact resistance were deduced by the transmission line method (TLM). The obtained results show that the Ag contact reaches its smallest value at 750°C.

The above results can be explained as due to the high contact quality at 750°C as illustrated in SEM figures.

The contact shows high compactness and consequently low porosity at this temperature profile. This means that the eutectic between the silver paste and silicon is well formed during metallization annealing at 750°C.

As a conclusion, screen printing metallization in silicon solar cells is in perpetual optimization. It depends essentially in the sheet resistance of the front junction, the annealing type: classical or RTP (rapid thermal annealing), the employed paste and the annealing profile.

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Table 1. Specific contact resistance results deduced by TLM method

Annealing Temperature (°C)	650	680	700	750
Contact resistance (Ω)	3.67	4.53	2.83	1.79
Transfer Length L_T (mm)	3.71	3.04	1.97	1.54
Specific contact resistance If $L_T \geq 2L$: $\rho_c = R_c\, L_T\, Z$ If $L_T < 2L$: $\rho_c = R_c\, L\, Z$	8.16 $m\Omega cm^2$	8.26 $m\Omega cm^2$	3.34 $m\Omega cm^2$	1.65 $m\Omega cm^2$
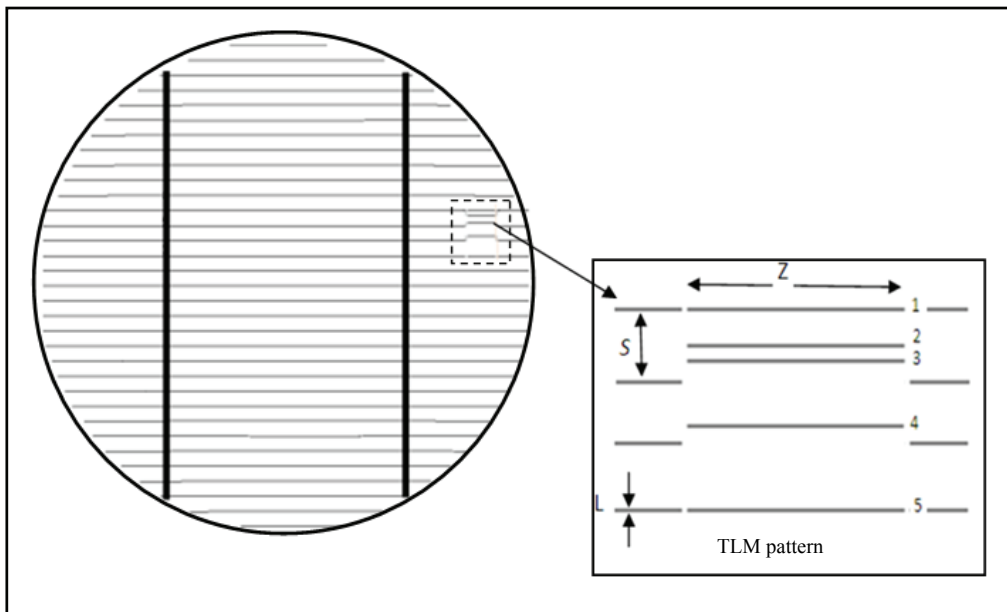
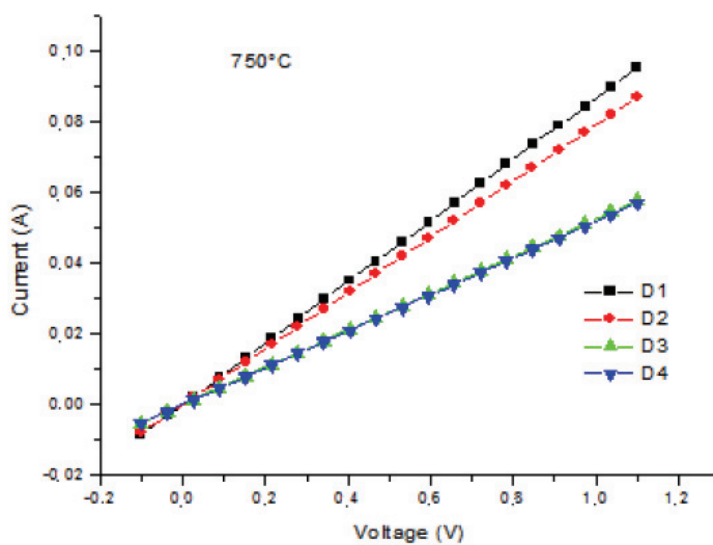Figure 1: Metal grid for characterization TLM
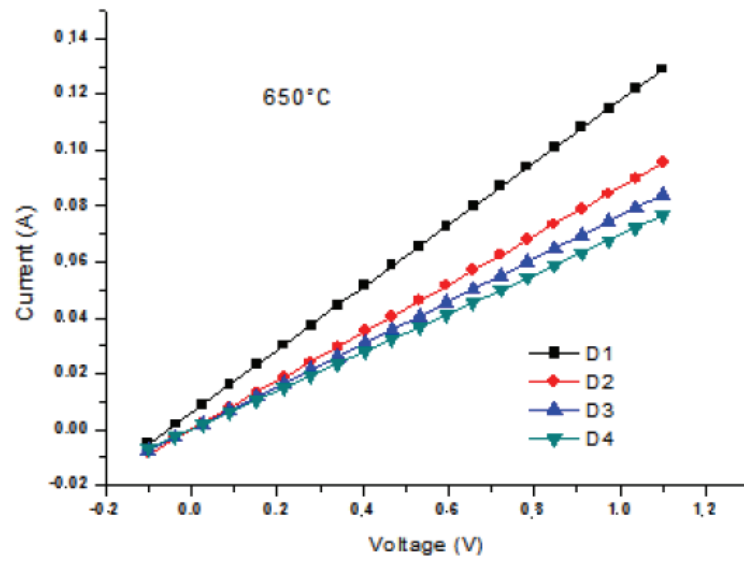
(a)
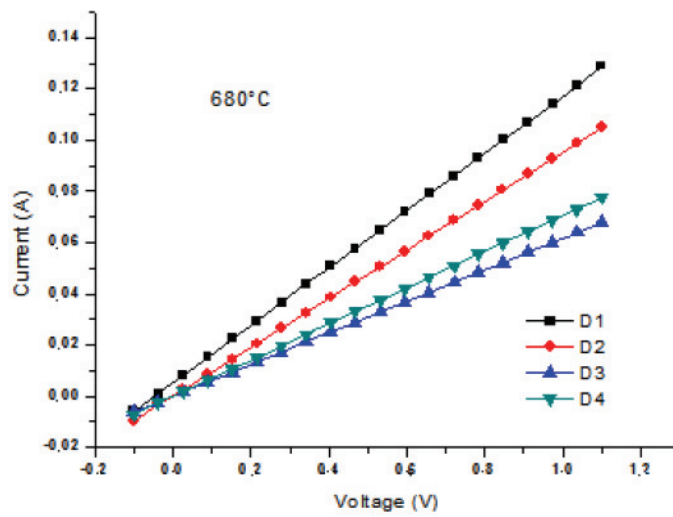
(b)
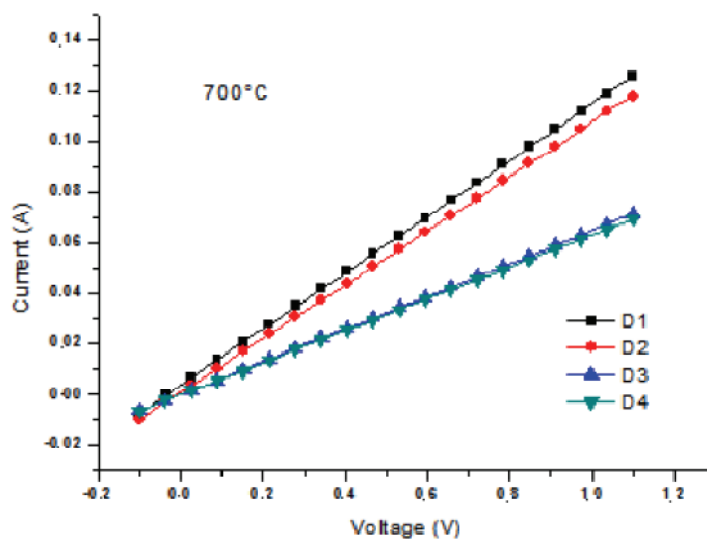
(c)

(d)

Figure 2. Current-voltage I (V) characteristics for each TLM distances for screen printed samples annealed at : (a) 650°C, (b) 680°C, (c) 700°C and (d) 750°C.
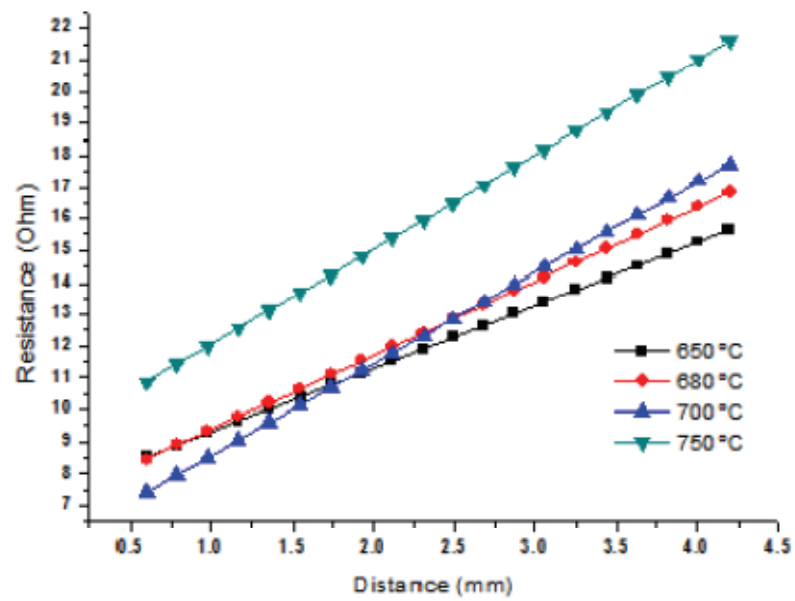
Figure 3. Plot of resistance versus TLM distances at temperatures 650°C, 680°C, 700°C, 750°C.
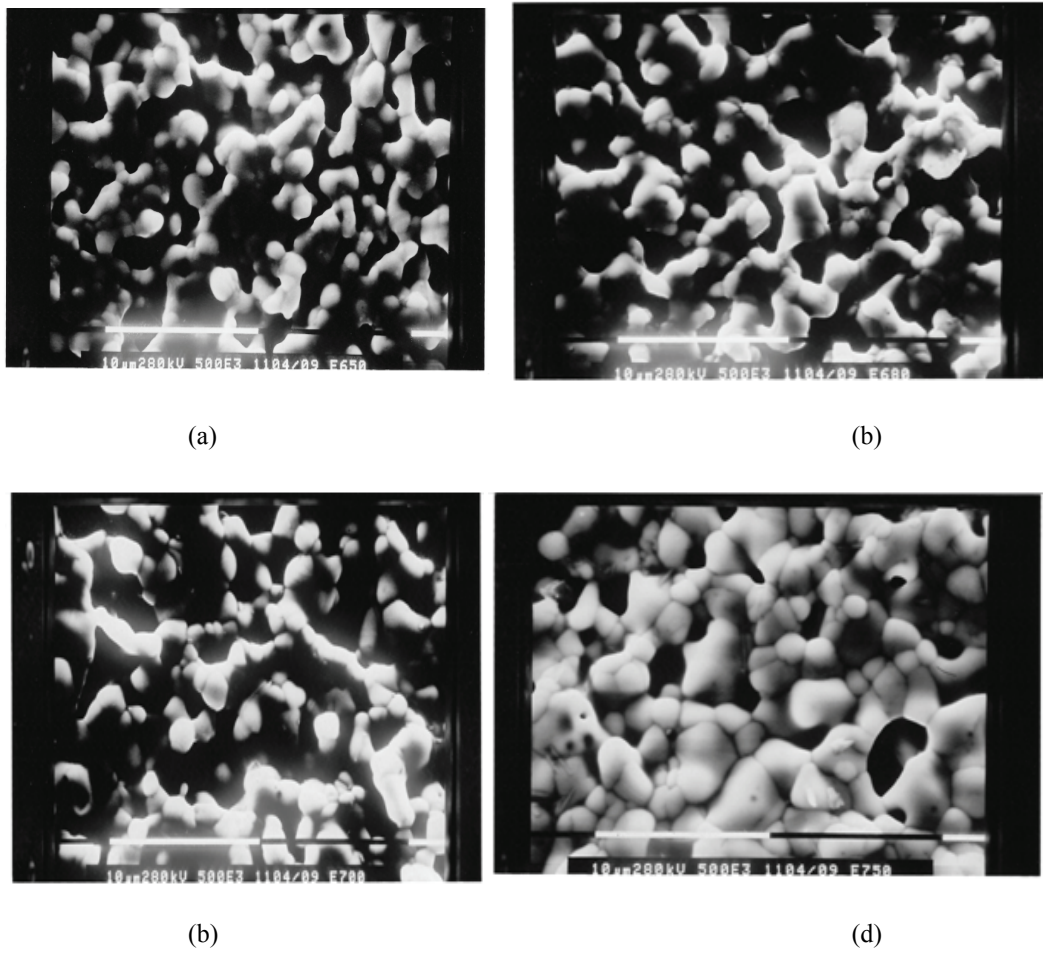
(a)

(b)

(b)

(d)

Figure 4. SEM micrographs of Ag/Si(N$^+$) contacts for different temperatures :

(a) 650°C, (b) 680°C, (c) 700°C and (d) 750°C