CRYSATLLINE SILICON SOLAR CELLS IN MANUFACUTRING TECHNOLOGY ASPECTS – ARC LAYER AND METAL BACK AND FRONT CONTACTS

Kazimierz Drabczyk

[1)] Institute of Metallurgy and Materials Science, Polish Academy of Sciences
25 Reymonta St., 30-059 Cracow, Poland
e-mail: kazimierz.drabczyk@wp.pl

ABSTRACT

In this paper the third part of the typical technological process of manufacturing crystalline silicon solar cells realized in the Photovoltaic Laboratory of IMMS PAS at Kozy is presented. The process is based on plates after diffusion from $POCl_3$. In this step the TiO_x antireflection layer and screen printed contacts are described. The solar cells parameters have been characterized by current-voltage characteristics, spectral response (SR) methods. The measurement techniques to determine them are presented. We have achieved average efficiencies 16 % on 1 ohm*cm textured monocrystalline silicon and 13 % on multicrystalline silcon. The total number of processing steps has been reduced to seven so this cell efficiency of 16 % and 13 % has been obtained in a simple cell processing sequence. Some aspects playing a role in suitable manufacturing process are discussed.

TiO_2 antireflection layer deposition

After passivation process an antireflection layer was deposited. As an antireflection layer for solar cells the titanium dioxide layer was deposited by CVD method with tetraethylorthotitanat $(C_2H_5O)_4Ti$, using purified nitrogen as a carrier gas. The liquid source $(C_2H_5O)_4Ti$ had vapoured at 200 °C in a quartz bubbler and was transported via heated lines to a 5 mm diameter teflon nozzle located 10 mm above the heated from the bottom silicon wafer. In this experiment the wafers were heated at temperature of 300°C. During the deposition the teflon nozzle was mechanically moved with steady speed across the plates to create a uniform thickness. The TiO_2 layers on the top side of the wafers were depositing during 4 min. until the antireflective layers became dark blue in colour.

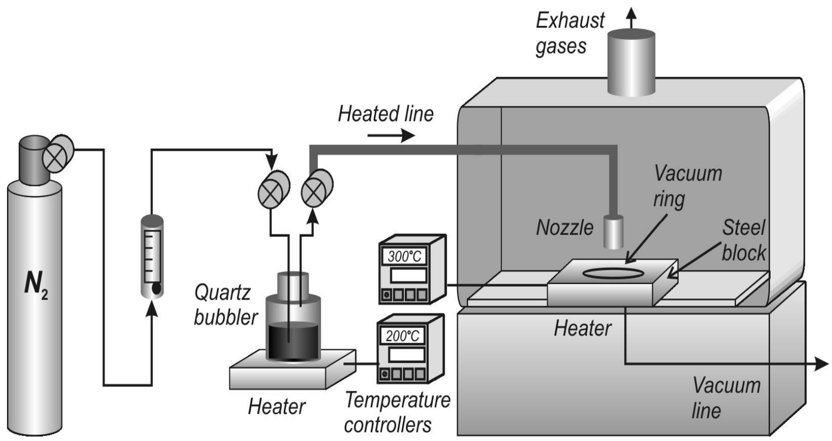

Fig. 1. Scheme of the TiO_2 antireflection layer deposition system by CVD method.

Transmission T(λ) and reflection R(λ) of the TiO_x layers were measured with a Perkin Elmer U/VIS/NIR Lambda 19 spectophotometer with an integrating sphere over the wavelength range λ=300-1300 nm (Fig. 2). [1]

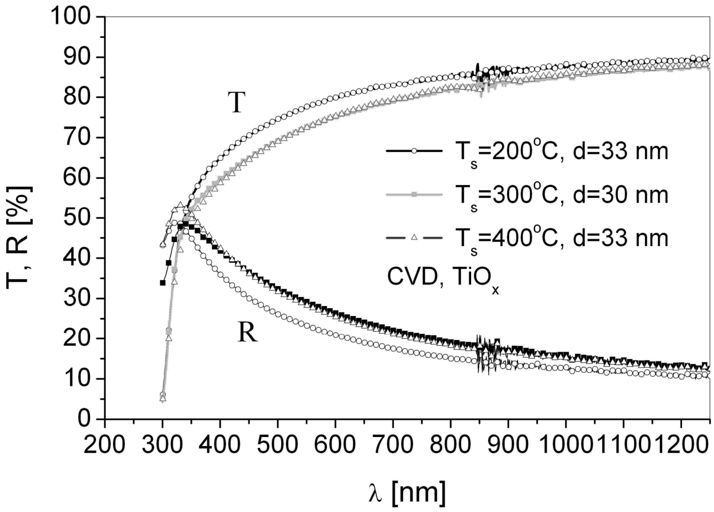

Fig. 2. The influence of the substrate temperature on the optical spectra of TiO2 layers. [1]

The thicknesses shown in Fig. 2 have been extracted from GIXR profiles of the TiOx layers. The wavelength-dependent refractive index n(λ) and extinction coefficient k(λ) were determined by fitting a single layer model to the data T(λ) and R(λ).

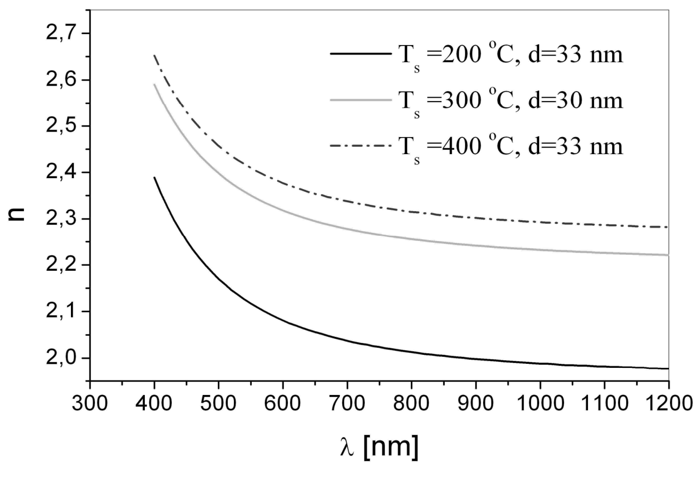

Fig. 3. Refractive index n as a function of wavelength λ.[1]

In the laboratory test for solar cell with TiO_2 ARC the best value of refractive index *n* has the layer deposited at 400 °C but for solar cells laminated in PV module capped with glass, the *n* closed to 2 for the wavelengths longer than 450 nm is more optimal.

Table 1. The I-V parameters of the solar cells in dependence on TiO_2 deposition temperature and surface texture. [1]

Cell No.	Deposition temperature [^oC]	I_{sc} [A]	V_{oc} [V]	R_{sh} [Ω]	R_s [mΩ]	P_m [W]	FF	E_{ff} [%]
Cz-Si (100) – regular piramidal texture								
2	200	870.49	600.30	18.36	15.1	384.46	0.736	15.32
3	250	873.75	601.68	36.68	17.4	393.69	0.749	15.68
4	300	872.27	601.34	32.26	18.1	391.53	0.746	15.60
5	350	846.45	599.62	48.60	19.8	389.12	0.767	15.50
6	400	837.35	597.98	55.04	21.6	382.82	0.765	15.25
mc-Si – random geometrical figures texture								
8	200	757.09	582.40	12.61	10.1	293.10	0.665	11.67
9	250	752.04	580.92	16.67	18.2	295.40	0.676	11.76
10	300	765.29	590.20	19.35	21.6	289.51	0.641	11.53
11	350	745.07	578.27	18.51	18.2	292.05	0.678	11.63
12	400	729.98	578.88	33,43	39.4	297.62	0.704	11.65

where: I_{sc} - short circuit current, V_{oc} - open circuit voltage, R_{sh} - shunt resistance, R_s - series resistance, P_m - power in optimum point, FF – fill factor, E_{ff} – conversion efficiency.

The I-V characteristics of solar cells were measured under standard radiation AM1.5G to determine its main electrical parameters in dependence on TiO_2 temperature deposition. According with the data enclosed in Table 1 the V_{oc} remains on the same level but I_{sc} and FF are growing along with the increase of the temperature of silicon substrate. The best value of E_{ff} was achieved at 400 °C. The similar results were observed for mc-Si solar cells. The process performed at 250 ^oC leads to the best photoconversion efficiency. This is a compromise between protection and antireflection role of TiO_2 layer in silicon solar cell structure. The effect is the same for the monocrystalline silicon solar cells with regular piramidal texture of the surface and for the multicrystalline silicon solar cells with random geometrical figures texture.

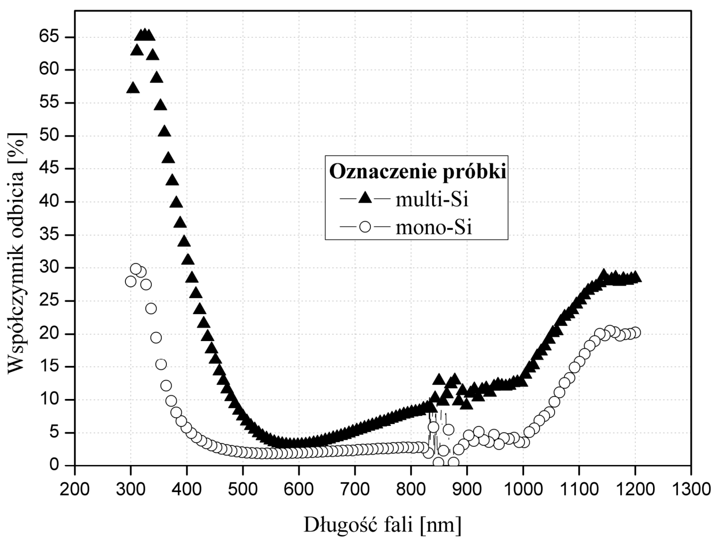

Fig. 4. Reflectance for multi and mono crystalline solar cells

Screen printing and cofiring of metal back end front contacts

The metallization of solar cells was made by the screen-printing process. After ARC deposition the silver paste for front and Al paste for back contact were screen-printed and dried. A silver paste PV145, manufactured by DuPont, was used for the front contact and aluminium T-14002A, produced by Engelhart was used on the back contact. Screen-printed contacts were applied to the front and rear of the cell, with the front contact pattern specially designed to allow maximum light exposure of the Si material with minimum electrical losses in the cell. [2]

After drying in air at 180 °C, the printed pastes were co-fired in the IR belt furnace. The simultaneously metallization process for front and back electrodes had place in 200 cm long infra-red (IR) conveyor furnace at a temperature peak of 880 ^{o}C and a belt speed of 160 cm/min. The parameters of the co-firing process are given in Table 2.

Table 2. The Parameters set for the co-firing process in the IR furnace

Process No.	Belt speed [cm/min]	Temperature [°C] Z1, Z2, Z3			Silicon type	Atmosphere
1	150	530	570	920	mono-Si	air
2	199	550	650	880	multi-Si	air

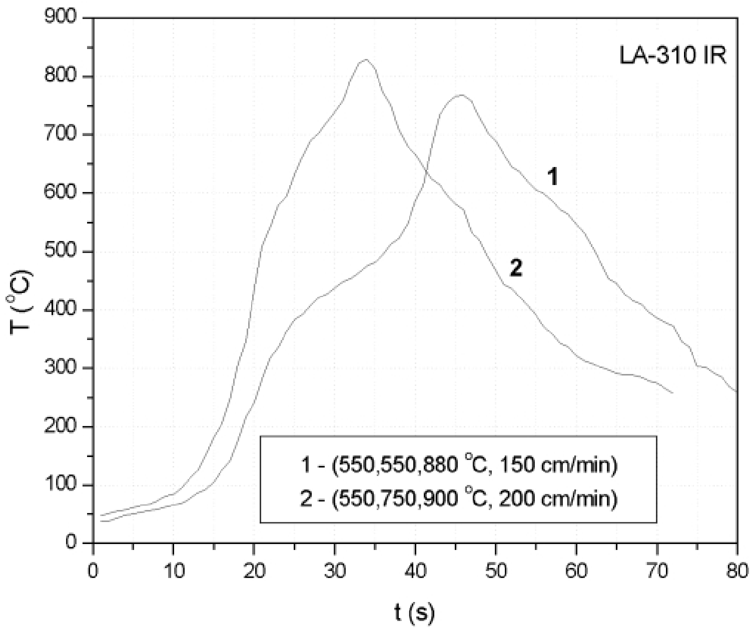

Fig. 5. Temperature profiles vs. elapsed time for solar cell metallisation in the IR furnace.

Measurements and results

The I-V characteristics of solar cells were measured under standard radiation AM1.5G to determine its main electrical parameters like: short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), fill factor (FF) and E_{ff} (Table 3).

Table. 3. The main illuminated I-V parameters of the solar cells made in PL IMMS PAS

Si type	J_{sc} [mA/cm2]	V_{oc} [V]	P_m [W]	FF	E_{ff} [%]
Cz-Si	35,9	0,599	0,399	0,749	15,8
mc-Si	29,8	0,579	0,322	0,746	12,9

Figure 6 shows the measured I-V characteristic for monocrystalline silicon solar cell (Cz-Si) and (mc-Si).

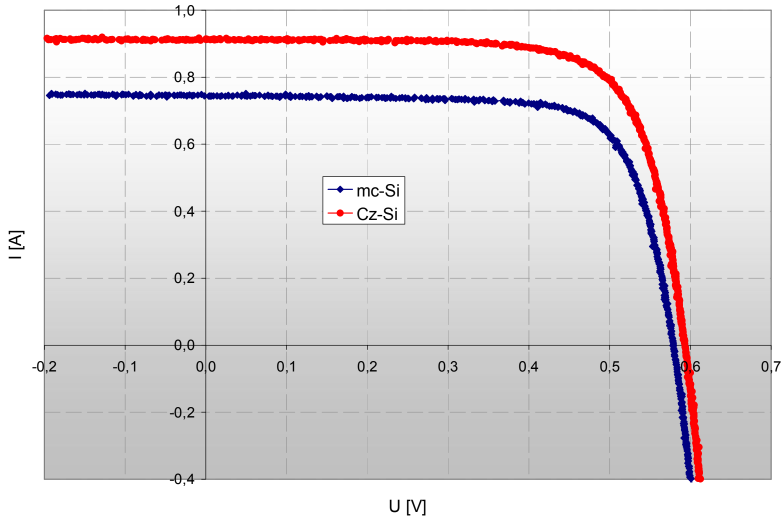

Fig. 6. The measured I-V characteristic for monocrystalline silicon solar cell (Cz-Si) and (mc-Si)

For characterization the materials and cells the spectral response characteristic are used. The spectral response was measured using a Jobi-Yvon H20 monochromator fitted with a 75 W Tungsten-Iodine lamp. The external quantum efficiency (EQE) of the silicon solar cells was measured with calibrated by Hamamatsu Si S2281 photodiode and was calculated using its external quantum efficiency. (Fig. 7).

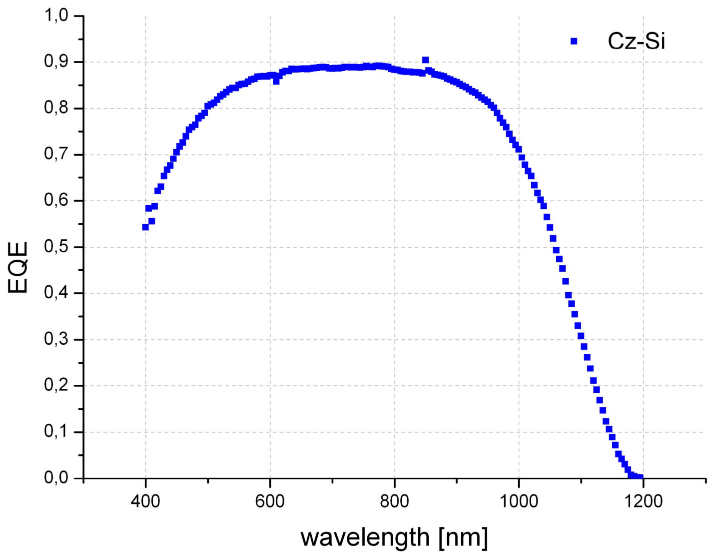

Fig. 7. External quantum efficiency (EQE) for solar cell with SiO_2 passivation layer and TiO_x ARC

The measurements of I-V and spectral characteristics of solar cells is the last step in their manufacturing. The prepared cells can be used for the production of PV modules.

SUMMARY

This paper summarises the research and development efforts undertaken in IMIM PAN Photovoltaic Laboratory during the last few years towards development of a low cost industrial solar cell process. The Institute of Metallurgy and Material Sciences of PAS sciences in Cracow has developed the manufacturing technology of solar cells based on crystalline silicon. This technology is being realized at the experimental line in The Photovoltaic Laboratory of The IMIM PAS at Kozy. This process can be directly implemented into industry without excessive investments.

We have achieved average efficiencies 16 % on 1 ohm*cm textured monocrystalline silicon and 13 % on multicrystalline silcon. This cell efficiency of 16 % and 13 % has been obtained in a simple cell processing sequence. Undoubtedly there is a possibility of the further improvement of solar cells parameters. But there is a necessity of research carrying on, which The Photovoltaic Laboratory at Kozy is appropriately prepared for, both in the field of equipment as well as in the field of its own research workers experience. The Photovoltaic Laboratory at Kozy is also ready to play a role of the research and development unit for the photovoltaic industry.

References

[1] P. Panek, K. Drabczyk, H. Czternastek, E. Kusior, P. Zięba, E. Bełtowska-Lehman, *"The Influence of Surface Texture and Temperature Deposition of TiO_2 Layer on Crystalline Silicon Solar Cells Parameters"*, Archives of Metallurgy and Materials, vol. 58, (2008), 103-106

[2] R. Singh, A. Rohatgi, K. Rajan, S. Venkataraman, K. F. Poole, *"Rapid Thermal Processing As A Manufacturing Technology for 21st Century"*, Electrochemical Society Proceedings, vol. 99-11, (2000), pp. 33-48.