ANALISYS OF THE TOPOGRAPHY AND ROUGHNESS OF MICRO PROCESSED SOLAR CELLS COMPARED TO THE TOPOGRAPHY AND ROUGHNESS OF UNPROCESSED SOLAR CELLS

Dorin LEŢ [1], Alin BUCURICĂ [1], Ioana DULAMĂ [1], Zorica BACINSCHI [2], Simona MIHAI [1], Viviana FILIP [1,2]

[1] Multidisciplinary Scientific and Technologic Research Institute, Valahia University of Targoviste, Romania
[2] Valahia University, Materials and Mechanics Dept., Targoviste, Romania

E-mail: ldorin@icstm.ro

Abstract:. *Photovoltaic conversion systems are one of the most interesting technical solutions to the energy supply problem. The purpose of the research performed for this paper is to develop an experimental model of solar cell with an improved efficiency of solar energy conversion using surface micro processing and antireflection coating deposition techniques in order to enhance the optical absorption properties of the material. Comparative analyses have been performed on micro processed and unprocessed solar cells, using optical microscopy techniques; the electrical conversion performances of the cells have been tested and the results have been interpreted.*

Keywords: *solar cell, silicon, deposition, renewable energy, roughness, topography, micro processing, conversion, absorption*

1. INTRODUCTION

One of the main sources of renewable energy is solar energy. Researchers from all over the world have been working for hundreds of years to increase the efficiency of solar cells (made of materials with electrical conversion properties), which transforms solar energy into electricity. The word “photovoltaic” describes the direct conversion of light energy into electrical energy. “Solar cell” is a model which, under the action of solar radiation, acts as a generator of electricity.

The basic material used for making solar cells is the monocrystalline silicon (or mono-Si), due to the high conversion efficiency of the material (maximum η = 22%), the advanced processing technologies, and the proven conversion reliability (more than 20 years of maintenance-free operating period) [1]. As yet, there haven’t been explored all the ways leading to maximum efficiency in mass production, simpler technological processes and a good quality and inexpensive material.

The operation of semiconducting models is based on the charge carriers’ (electrons and holes) moving in the material. The energy levels that electrons can occupy in the solid material are ranged inside allowed energy bands, separated by forbidden bands, where electrons cannot have energy. At temperatures above absolute zero, there are always a number of free electrons and holes, as a result to the breaking of certain covalent bonds (the phenomenon known as generation of electron-hole pairs). These carriers are quasifree, as they do not belong to a particular atom and can move through the crystalline structure, participating in the conductivity of the material [2]. Sometimes they may form a covalent bond and disappear as free carriers (the phenomenon known as electron-hole recombination). With a view to minimizing losses and thus increasing the photoelectric conversion efficiency, the literature mentions several techniques to improve the physical properties of materials, such as: surface micro processing (Figure 1) and antireflection coating deposition (Figure 2) [3].

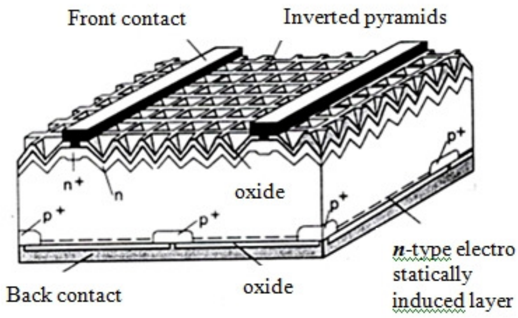


Fig. 1. Structure of a surface micro processing solar cell [3]

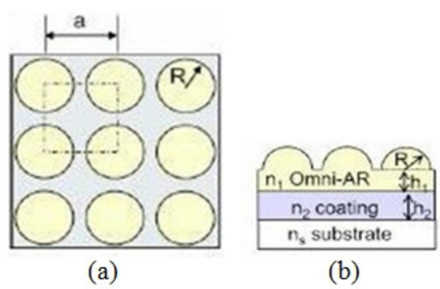


Fig. 2. The structure of an antireflection coating AR
a) top view of the AR coating surface, b) longitudinal section of the AR coating [3]

Also, during the operation process there have occurred some other issues having to do with: the spatial sun-related orientation; the necessity to eliminate the cell surface reflectivity, the assembling in solar modules, the heat resulting from radiations that do not take part in the photovoltaic conversion process etc. [4].

The purpose of the research performed is to develop an experimental model of solar cell with an improved solar energy conversion efficiency, using techniques of enhancing the physical properties of the material. The design of this experimental model aims at improving the absorption optical properties, decreasing the impact of the collecting grid on the active surface of the solar cell, and optimizing the antireflection coating.

2. MAKING THE SET OF MASKS

To achieve solar cell structures with an area of 2 cm x 2 cm each, a set of masks has been designed. To make the masks, we used the DWL 66fs Laser Lithography System manufactured by Heidelberg Instruments Gmbh. The equipment (Figure 3) is provided with a 442 nm wavelength He-Cd laser and two 20 mm write heads with a maximum resolution of 4 µm and a completion time of several hours, and a 2 mm head with a maximum resolution of 0,6µm - 0,8µm and a writing time that can last days.

Also, the device is provided with four filters for laser radiation with transmissions of 1%, 10%, 32% and 50%, which can be changed depending on the write head used. The equipment consists of a file conversion station containing the drawing of the mask and an exposure control station.

Fig. 3. DWL 66fs system used for making the masks

2.1 Micro Processing the Silicon Wafers

The cell manufacturing process based on single-crystal silicon (mono-Si – the material selected for the experimental research) uses, as a substrate, p-type (boron), crystallographic orientation, silicon wafers obtained by the Czochralski technique [5].

The 3 inch-diameter, (100) orientation, p-type, 1...2 Ω cm resistivity and 450 µm thickness wafers used for making the solar cells have been grouped in accordance with the type of micro processing and the size of the cells. The size of the solar cell structures obtained is 1 cm x 1 cm and 2 cm x 2 cm. The resistivity and thickness of each wafer was measured, then each wafer was marked for tracking the processing history. After marking the wafers, in order to remove the silicon powder resulting from scratching them with a diamond-tipped pencil, they were cleaned with ultrasonic deionized water and then dried by centrifugation.

The silicon wafers were cleaned in acid solutions, then rinsed repeatedly in deionized (DI) water, in order to remove all organic contaminants and impurities (metal deposition). After washing, the wafers were dried by centrifugation.

In order to remove the organic residues, there were used hydrogen peroxide-based solutions, namely, the Piranha mixture known also under the name of Caro acid (H_2SO_4: H_2O_2 = 3: 1).

To remove the thin layer of oxide containing impurities (metallic deposition), we used a diluted hydrofluoric acid solution named "dip" (HF: DI H_2O = 1:10).

Figure 4 shows the micro processing flow for the silicon wafers.

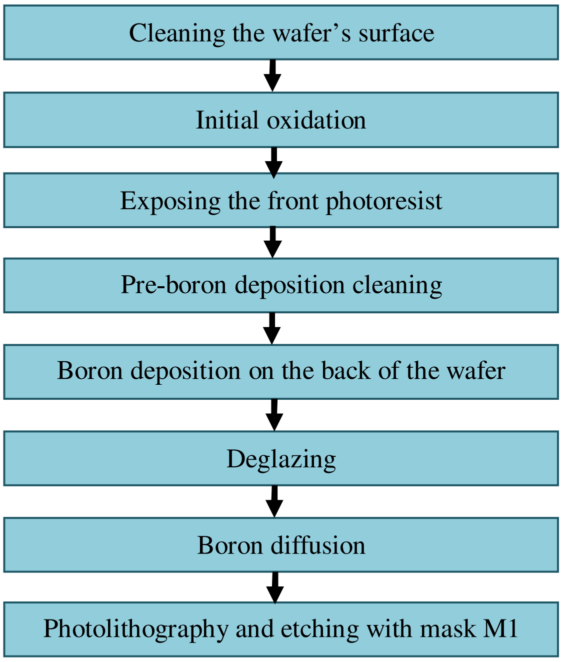


Fig. 4. Flow chart for the front surface micro processing

The 3 inch-diameter, (100) orientation, p-type, 1...2 Ω cm resistivity and 450 µm thickness wafers used for making the solar cells have been grouped in accordance with the type of micro processing and the size of the cells. The size of the solar cell structures obtained is 1 cm x 1 cm and 2 cm x 2 cm. The resistivity and thickness of each wafer was measured, then each wafer was marked for tracking the processing history. After marking the wafers, in order to remove the silicon powder resulting from scratching them with a diamond-tipped pencil, the wafers were cleaned with ultrasonic deionized water and then dried by centrifugation.

Before they were immersed in the corroding solutions, the wafers were first kept for 5 minutes in deionized water in an ultrasonic bath, then in an ultrasonic solution of HF: H2O2Di (1:50) and then for another 5 minutes in deionized water in the ultrasonic bath.

2.2 Making the experimental model of solar cell

The experimental model of solar cell was made using the planar technology. In order to remove the photoresist residues, the silicon wafers are cleaned in hydrogen peroxide-based acidic solutions (Piranha mixture) and rinsed repeatedly with deionized water. After washing, the wafers are dried by centrifugation for 5-10 minutes, at the temperature of 120° C.

The purpose of the photolithography process using the M2 mask is to open the active area (the emitter) on the front side of the wafer and hereby protect the back of the wafer. Considering these requirements, we exposed the wafers with positive photoresist by centrifugation at 3000 rev/min, for a 1.2 µm-thick resist. Between the two successive exposures with photoresist, front and back, the wafers went through a pre-annealing heat treatment at T = 90° C, in the oven. The order of the operations in the photolithography process is given in Table 1.

Table 1

Steps	Equipment	Process parameters
Wafers' dehydration	Oven	T = 200°C, t = 1h
Immersion in Hexamethyldisilazane - (HMDS) solution	Solution	T = 21°C, t = 30min
Positive resist exposure	Spiner (Centrifugation)	3ml FR, 3000 rpm,
Pre-annealing treatment	Oven	T = 80°C, t =15-30min
Alignment/exposure	Aligning machine	
Development	Alkaline solution (KOH/NaOH)	T = 21°C, t = 1min
Development optical control	Optical microscope	Zoom 40X and 100X
Pre-annealing treatment	Oven	T = 100-120°C, t = 30min
Etching	Thermostatic bath	Oxide corroding with (6:1) NH4F:HF (T = 32°C, Vcor. oxid = 100 nm/min)
Etching optical control	Optical microscope	Zoom 40X and 100X
Removing the resist layer	Cleaning	T = 21°C, T = 5-10min
Final optical control	Optical microscope	Zoom 40X and 100X

The process flow-chart for the solar cell obtained through mono-Si surface micro processing is shown in Figure 5.

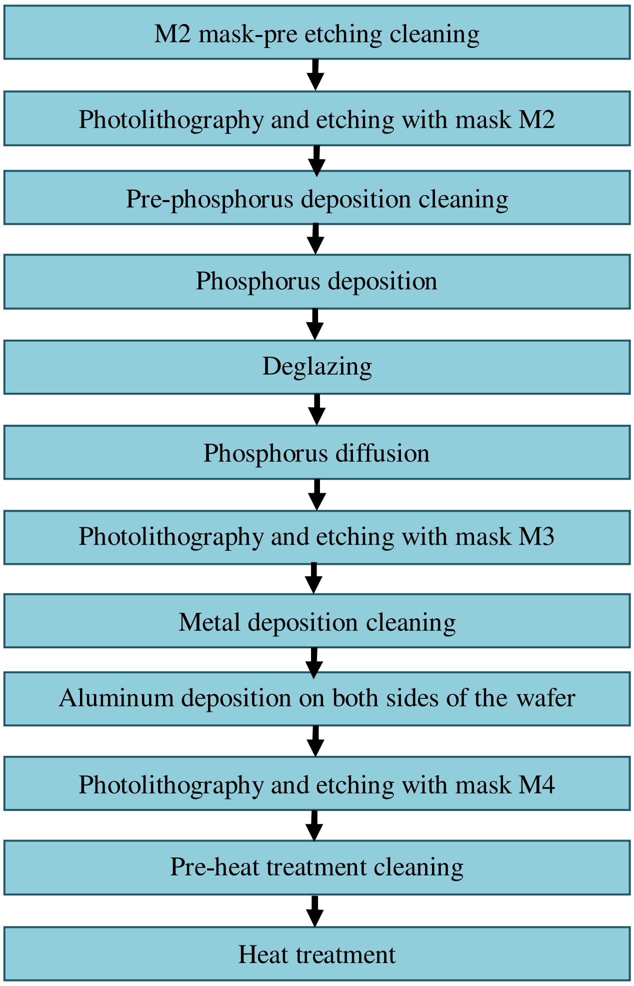


Fig. 5. The process flow used in the manufacturing of mono-Si solar cells by surface micro structuring

Figure 6 shows the micro processed solar cells.

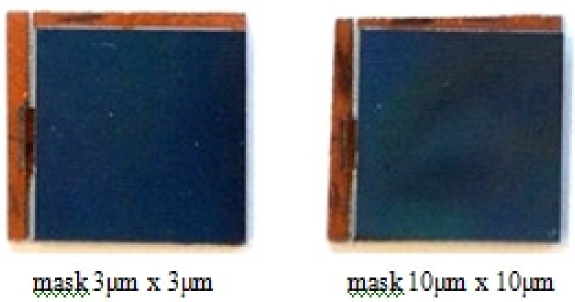


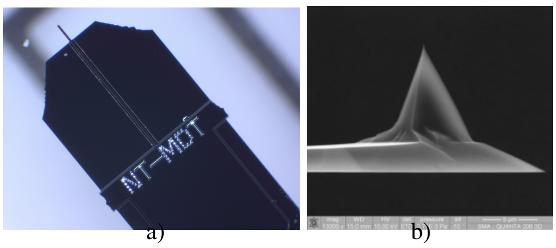
Fig. 6. Micro processed solar cells (2cm x 2cm)

3. ANALYSIS OF THE SURFACE TOPOGRAPHY AND ROUGHNESS

The investigations on the roughness and topography were performed using the atomic force microscope NTEGRA Prima (Figure 7) in the laboratory of materials for energy conversion (Valahia University of Targoviste - ICSTM Research Institute). The microscope allows working in very small fields (under1µm x 1µm); the optical system has a resolution of 1µm and provides real-time imaging of the scanning process.

Fig. 7. NTEGRA Prima atomic force microscope

The equipment was prepared for measurements in contact with a CSG10 / 10 cantilever (Figure 8), with the following specifications: N-type, 0.01 to 0.025 Ω cm resistivity, Sb-doped and Au-coated single-crystal silicon. This has a typical radius of curvature of 6nm to 10nm and resonates at a frequency of 22 kHz.



a) b)

Fig. 8. CSG10 / 10 Cantilever used for the AFM investigations

a) Image shown on the stereomicroscope b) Image from the spec sheet

The sample was attached to the base with a double-sided carbon strip, then, using the x6.5 optical zoom and an adjustable focal length, we selected the area of interest (Figure 9).

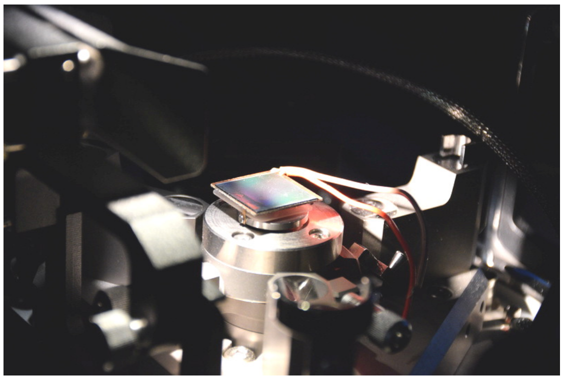
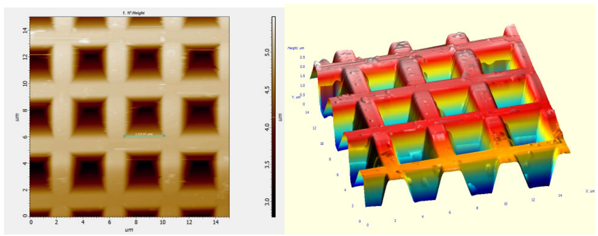


Fig. 9. Preliminary alignment of the sample for the AFM investigations

The AFM topography after processing with the M1 (3µm x 3µm) mask is shown in Figure 10.



a) b)

Fig. 10. AFM topography after processing with the M1 (3µm x 3µm) mask

a) 2D image b) 3D image

As can be seen, the expected micro processing dimensions resulted as follows: the base of the pyramid is 3µm x 3µm, the distance between structures is 1µm and the depth of the structure is 2,66µm.

From investigating the depth profile (of the 3µm x 3µm M1 mask shown in Figure 11) for the 15µm x 15µm scan area (2.42µm deep), and the maximum depth (2.50µm) observed in the 3D image shown in Figure 10, it appears that the microstructures have the same depth profile.

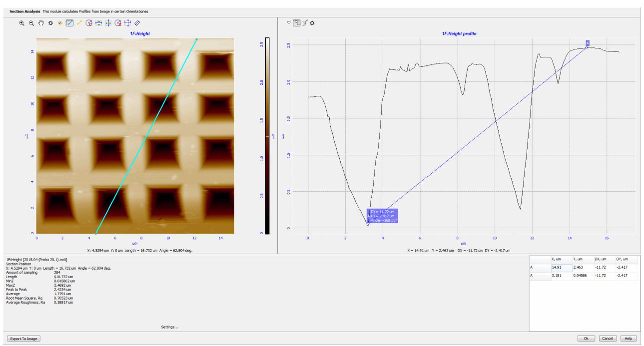
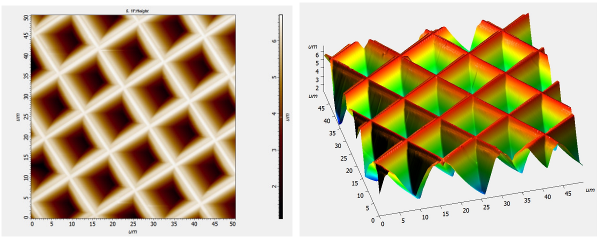


Fig. 11. Determining the micro processing depth for the sample obtained with the M1 (3µm x 3µm) mask

The AFM topography after processing with the M2 (10µm x 10µm) mask is shown in Figure 8.



a) b)

Fig. 12. The AFM topography after processing with the M2 (10µm x 10µm) mask
a) 2D image b) 3D image

As can be seen, the expected micro processing dimensions resulted as follows: the base of the pyramid is 10µm x 10µm, the distance between structures is 2µm and the depth of the structure is 6,5 µm.

From investigating the depth profile (of the 10 µm x 10 µm M2 mask shown in Figure 13) for the 50µm x 50µm scan area (4.23 deep), and the maximum depth (6.50µm) observed in the 3D image shown in Figure 12, it appears that not all the microstructures have the same depth profile.

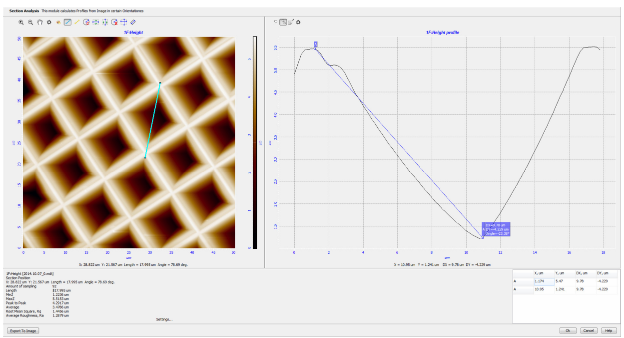


Fig. 13. Determining the micro processing depth for the sample obtained with the M2 (10µm x 10µm) mask

4. DETERMINING THE ELECTRICAL PERFORMANCE

The electrical performance was determined using the Class AAA Oriel Sol3A solar simulator (certified in accordance with IEC 60904-9, Issue 2 (2007), JIS C 8912 and ASTM E 927-05 for spectrum of emitted radiation - Class A, waveform non-uniformity - Class A, stability of radiation - Class A), shown in Figure 14, from the Laboratory of photovoltaic cells and modules. Testing and Characterization (Valahia University of Targoviste, ICSTM Research Institute)

Fig. 14. Oriel Sol3A solar simulator

The simulator uses a 450W ozone-free, 5-20 bar Xenon short-arc lamp. This lamp reproduces the UV-VIS solar spectrum with dominant Xenon lines between 750 and 1000 nm. The simulator was configured with an AM1.5 global radiation filter which allows the passing of the entire solar spectrum (direct and diffuse) when the sun is at its zenith angle of 48.2 °. The filter is ASTM E892 certified.

The samples were measured after the solar simulator had reached its rated operating parameters and the temperature had reached the value suited for measurements (25° C, according to IEC 60904-2 standard). The sample was fixed using a vacuum system (minimum 150 mm Hg). Before measuring the sample there were checked the operating parameters of the simulator (1 sun) using the NIST-certified reference cell based on ISO-17025 (Figure 15).

Fig. 15. ISO-17025 certified reference cell

For the interpretation of the results we used the Oriel PVIV-2.0 application, by which we acquired the measured values through the GPIB (General Purpose Interface Bus) interface from the Keithley source.

The conversion efficiency of the unprocessed sample was 9.4604 η [%]; the sample processed with the 3µm x 3µm mask showed a conversion efficiency of 10.1265 η, and the sample processed with the 10µm x 10µm mask showed a conversion efficiency of 9.5352 η.

The I-V current-voltage characteristic is shown in Figure 16.

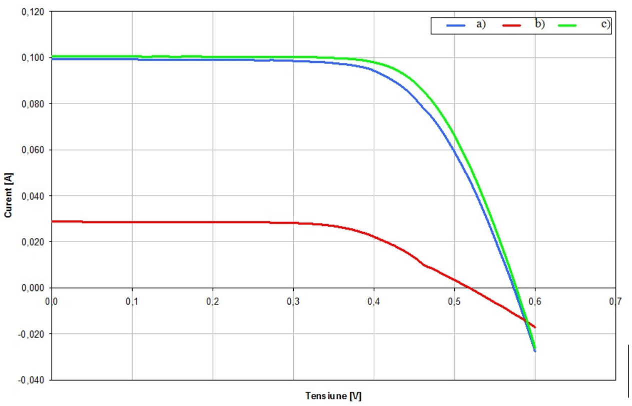


Fig. 16. The I-V curve according to IEC 60904 (η> 9%) for the samples:
a) 10µm x 10µm Mask (blue), b) unprocessed sample (red), c) 3µm x 3µm Mask (green)

In Figure 16, the graph represents the I-V curve for the antireflection layer-coated samples; on the abscissa there was measured the I_{sc} (short circuit current) and not the J_{sc} (short circuit current density), which is why the difference between the unprocessed sample and the micro processed samples appears so obvious. As can be seen, for the sample that was micro processed with the 3µm x 3µm M1 mask, the I_{sc} value is higher than that of the 10µm x 10µm M2 mask-processed sample; this is due to its higher optical performances and to its ability o collect higher energy photons.

The conversion efficiency of each sample is shown in Table 2.

Table 2. The conversion efficiency of the samples

Sample	**Processing status**	**Conversion efficiency– η [%]**
M1	10µm x 10µm	10.1265
M2	3µm x 3µm	9.5352
Unprocessed	Unprocessed	9.4604

Following to the measurements there were determined the I_{max} and V_{max} values, and from the calculations performed there resulted the P_{max} values. The results obtained are shown in Table 3.

Table 3. P_{max} values for the investigated samples

Sample	**I_{max} [A]**	**V_{max} [V]**	**P_{max} [mW]**
10µm x 10µm Mask	0,0906	0,4210	**38.1409**
Unprocessed	0,0260	0,3634	**9.4603**
3µm x 3µm Mask	0,0931	0,4352	**40.5061**

5. CONCLUSIONS

Investigations on the topography and roughness of the experimental model of monocrystalline silicon wafers micro-processed with 3µm 10µm x 10µm x 3µm inverted pyramid structures have helped obtaining a material with improved optical properties compared to the unprocessed wafers.
The improved structures of the solar cell have a higher solar energy conversion efficiency due to the forming of the antireflection coating.
The micro processing obtained can be applied to silicon structures made by planar technology, improving their performances.

6. REFERENCES

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