Increasing solar cells conversion efficiency by front surface micromachining texturisation

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Abstract: This paper presents a new method for increasing conversion efficiency of the silicon solar cell structures by the front surface texturisation using micromachining technologies. A ’honeycomb’ textured front surface has been obtained using a photolitographyc process to generate patterns (disc holes) on the top surface followed by isotropic etching in HNO_3 : HF : CH_3COOH up to join together of the wells.

For the front surface losses characterization,the spectral dependence reflection has been investigated by spectrophotometric measurements. The surface reflectivity was lowered at 5 % (40% in the case of untextured monocrystalline surface).

The p-n junction made by phosphorus diffusion at ~ 0.8 μm follows the honeycomb profile. In order to ensure low series resistances a p^+ bor diffusion on the back of the structure was made. The fabrication process was completed with an ohmic contacts (Al: on top and on the back surface).

Key-Words: solar cells, micromachining, texturisation, isotropic etching, honeycomb, low reflectivity, increased conversion efficiency.

1 Introduction

The photovoltaic technology is well established as a reliable and economical one for small sources of electricity in many applications.

The main research activities in the photovoltaic field are:

- materials development, which can be obtained at relatively low cost
- the conversion efficiency improvement.

Starting with the ’90 years, silicon solar cells with 23.4% efficiency have been obtained [1, 2, 3].

One of the known ways to increase the conversion efficiency is to reduce the radiation losses at the front surface of the cell.

There have been reported various methods of increasing silicon solar cell conversion efficiency such as: rear surface preparation to ensure the unabsorbed light reduction at the first path through structure and front surface texturing for the most reducing of the surface reflection [4, 5, 6].

Front surface texturing of single crystalline silicon cells depends on the etch solution and on the mask geometry.

This paper aims to optimize the solar cells fabrication processes with texturing surfaces to obtain an as low as possible reflectance and to increase the conversion efficiency.

2 Manufacturing Technology

Solar cells technology, based on surface microtexturisation of monocrystalline silicon, is the planar technology for the integrated circuits. We used silicon CZ wafers, <111> and <100> p type, with 1-2 Ωcm rezistivity and 400 μm thickness. Microfabrication of the monocrystalline silicon wafers surface was performed using MEMS technology.

The technological flow has the following steps:

1. thermal oxidation at $T = 1100\ ^oC$; the SiO_2 thickness is 1.2μm and this layer is used as etch mask;
2. the diffused contact on the wafer back side was

made from the solid source B^+ at T= 1050 ^{0}C /N_2; the prediffused layer has x_j = 0.6μm thickness and V/I =4-5 Ω; the next step is an oxidation at T =1000^{0}C / vapours. An SiO_2 layer, 6200 Å thickness, is used as mask-layer for the next steps;

3. microfabrication of the wafer surface (texturisation): M1 the photoresist configured oxide was etched in (NH_4F:HF=6:1) solution with 1000 Å/min rate. For the hemispherical walls we used isotropic silicon wet etching in HNO_3:HF:CH_3COOH–25:1:10;
4. oxide etching from the active area M2;
5. diffusion in the active area: the diffused junction of the solar cell was made by predifusion from the liquid source $POCl_3$ at temperature T=1050^{0}C: the predifused layer has x_j=0.6μm thickness and V/I=1.5-2.5 Ω; the next step is a diffusion at temperature T=975^{0}C / vapors, t=10 min;
6. in the Phosphorus diffusion process an 1200Å, antireflective oxide was grown, in this layer, by photolithographic techniques, there were opened the contact windows, M3**;**
7. aluminum deposition: the front and back side of the wafer for metallic contacts; the metal layer was deposited by evaporation from high-vacuum installation, thickness, 1μm;
8. metal photolithography on the front side of the wafer;
9. sinterization at temperature T = 450^{0}C , time t = 30 min. in atmosphere of 3% H_2 in N_2.

The masks were made on 4” Cr plates, for the positive resists and the wafers had 3” diameter, the solar cell structure size is 1x1 cm^2.

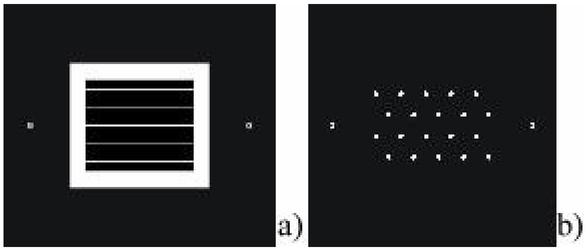

Fig. 1. Mask M1: a) structure detail b) lay-out of the honeycomb structures

The masks used for the textured surface solar cells are:

M1 – opening windows in the thick oxide for the microfabrication of the silicon surface, these windows are located in the broad band between the contact areas. Details for the broad band geometry are shown in Fig. 1 (b) – holes of 4μm in diameter in the angles of the equilateral triangle with 20μm web.

M2 – opening windows for the active area; the rest of the oxide is removed, after the silicon microfabrication, for the diffused junction and the antireflective thin oxide grown at the same time with the junction diffusion.

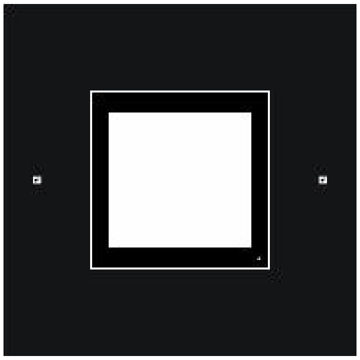

Fig. 2 Mask M2 - active area

M3 **–** opening contact windows; the contact width is 60 μm and the charge carriers are collected by 5 metallic lines.

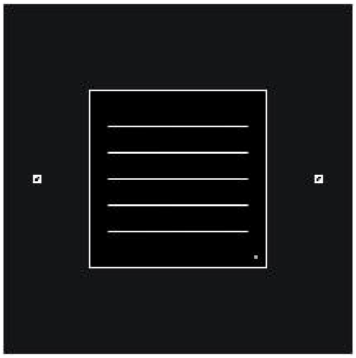

Fig. 3 Mask M 3 – contacts

M4 **–** opening the metallization windows; the width of the metallic line is 80 μm and the aluminum thickness is 1μm.

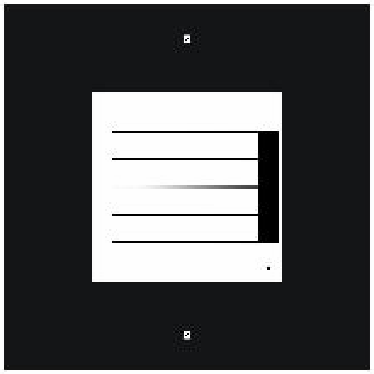

Fig. 4 Mask M 4 - metallization

Few details of solar cell are presented in Fig. 5.

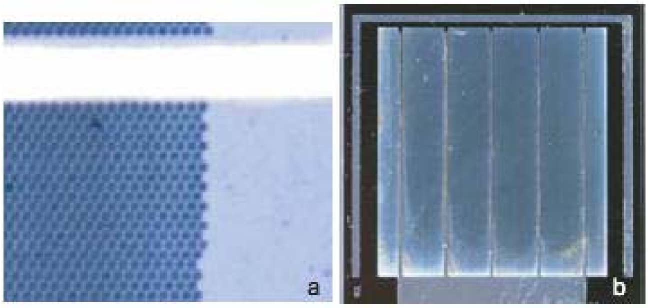

Fig. 5. Solar cells with the microfabricated surface a) – surface detail b) – entire cell

3 Device Characterisation

The main optoelectrical solar cells parameters measured for the structure performances are:

Open circuit voltage, V_{oc} obtained in 400 - 424 mV range, indicating a clean technological process so the shunt resistance decreases. V_{oc} values were obtained using a digital multimeter and a radiation source supplied by a stabilized voltage. Illumination of the structures was 2.3m W/cm^2.

Short-circuit current I_{sc} measured in the same conditions as V_{oc} - the values are in the 1-1.2 mA range.

The global *sensibility, S,* based on the I_{sc} values was 0.47 A/W - the specific value for the sillicon photovoltaic devices (0.2 - 0.3 A/W), the sensitivity increases, especially in the near IR range, due to texturisation, as the spectral characteristics shows.

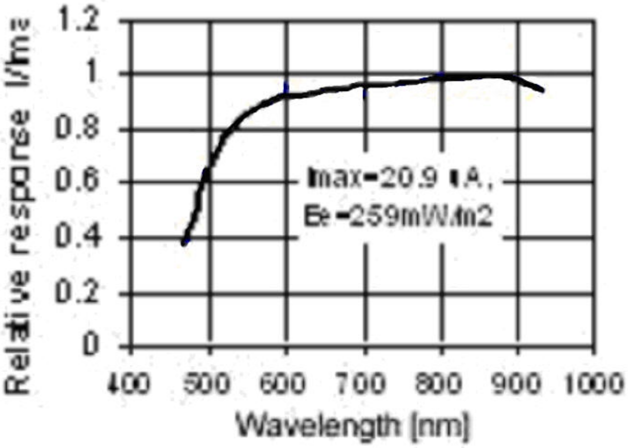

Fig.6 Spectral characteristic of the model

We performed the texturised solar cell *spectral characterization,* by measurements of the photocurrent in photovoltaic regime (I_{SC}), using interferential filters, a light source and a radiometer / photometer for light incidence on the device. The cells response, in the range of 0.35-1.1 μm, was characterized using an incandescent lamp, and the wavelengths were selected using interferential filters with 25 nm / division.

The spectral characteristic is shown in fig. 6.

The solar cell presents a flat spectral response in 550 – 925 nm range and the width at half of the height is in 0.47- 1.11 μm.

I-V characteristic of the solar cell was traced on the characteristic tracer and Fig. 7 shows a tipical characteristics for the implemented model. The characteristics form in the IV-th quadrant indicates a photovoltaic power source.

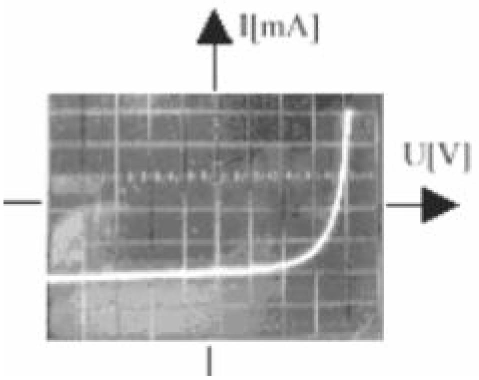

Fig.7. I-V characteristic of the exposed cell characteristic tracer image
Scale: 0.1 V/div. horizontally; 0.5 mA/div. vertically

The conversion efficiency is known as the most important parameter of the solar cell. Without taking into account the semiconductor material used, we can obtain higher conversion efficiency by optimizing the fabrication and design processes. Optimizing the structure of the solar cell means the reduction of different types of losses in such a way that the efficiency comes near its theoretical value. One of the most important losses is the loss in reflection at the incident surface. The structure obtained by texturing the surface leads to the magnification of the absorbed fraction from the incident radiation in such a way that the characterization of the conversion efficiency was replaced with the optical characterization of cell surface, determining the output power and the fill factor.

The conversion efficiency of photovoltaic cells depends strongly on the light that may reach the active cell layer. The photogenerated current achieves a level much smaller than the maximum for solar spectrum standard at the surface of the Earth because of the losses by reflection. Surface texturing procedure is one of the methods used to reduce the surface reflections. We determinate the spectral dependency of reflectivity on a textured surface in order to evaluate the reflection properties. In our tests and experiments, we used the SPECORD SP 42 spectrophotometer that has a module for reflexion measurements and an automatic orientation test equipment, based on a developpment board with an high density FPGA circuit [7]. The obtained specter is presented in figure 8 where we superposed the reflectivity at the surface of untextured silicon for comparison.

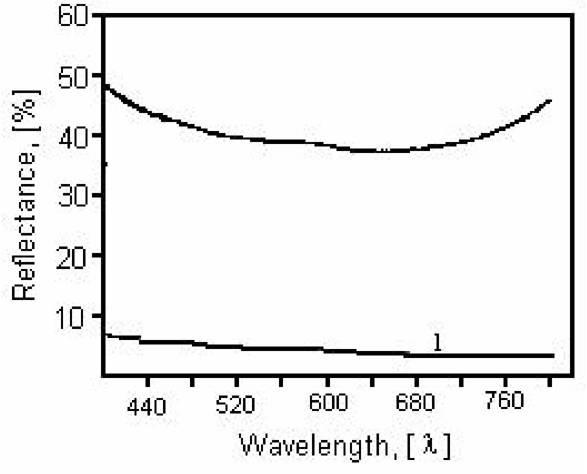

Fig.8 Spectral dependence of the reflectivity for different conditions texturised surfaces:
1-isotropic etching in HNO_3: HF: CH_3COOH;
2- monocristallin silicon non-texturised surface.

From the figure we can see the significant decrease of reflectivity, with 35%, applying the texturisation procedure by anisotropic etching in HNO_3:HF:CH_3COOH. Such a decrease of the reflectivity leads to less losses at surface by contributing to an improved cell conversion efficiency.

The conversion efficiency, which was evaluated in the incandescent bulb illumination conditions at 2.3 mw/cm^2, is 16.71%.

The fill factor is defined as a ratio between the output power and the product I_{sc}xV_{oc} , giving indications about the losses in the desired structure of a series resistance not very small or a shunt resistance not very large. In our measurements this factor was over 0.7.

Output power P was determined form the characteristic I-V and has the value 0.35 mW at an illumination of 2.3 mw/cm^2.

4 Conclusion

I-V solar cells characteristics was performed with an characteristic tracer. The characteristics form in the IV-th quadrant indicates a photovoltaic power source.

To 2.3mW/cm^2 illumination the data are:
- Spectral range: 350-1100 nm;
- Open circuit voltage, V_{oc}: 400 – 424 mV;
- Short-circuit current I_{sc}: 1-1.2 mA ;1-1,2mA
- Sensitivity: 0.47 A/W;
- Output power: 0.38 mW

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