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Efficiency Enhancement of Silicon Solar Cells by Porous Silicon Technology

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Silicon solar cells produced by a usual technology in *p*-type, crystalline silicon wafer were investigated. The manufactured solar cells were of total thickness 450 μm, the junction depth was of 0.5 μm – 0.7 μm. Porous silicon technologies were adapted to enhance cell efficiency. The production of porous silicon layer was carried out in *HF*: ethanol = 1 : 2 volume ratio electrolytes, illuminating by 50 W halogen lamps at the time of processing. The etching current was computer-controlled in the limits of (6 ÷ 14) mA/cm^2, etching time was set in the interval of (10 ÷ 20) s. The characteristics and performance of the solar cells samples was carried out illuminating by Xenon 5000 K lamp light. Current-voltage characteristic studies have shown that porous silicon structures produced affect the extent of dark and lighting parameters of the samples. Exactly it affects current-voltage characteristic and serial resistance of the cells. It has shown, the formation of porous silicon structure causes an increase in the electric power created of solar cell. Conversion efficiency increases also respectively to the initial efficiency of cell. Increase of solar cell maximum power in 15 or even more percent is found. The highest increase in power have been observed in the spectral range of $\Delta\lambda \cong (450 \div 850)$ nm, where ~ 60 % of the A1.5 spectra solar energy is located. It has been demonstrated that porous silicon technology is effective tool to improve the silicon solar cells performance.

Keywords: silicon, solar cells, porous silicon, efficiency, current-voltage characteristics.

INTRODUCTION

Photoelectric conversion of solar energy into electrical energy is one of the most attractive supplying of ecological energy. So, great interest is seen recently in the research of solar cells and in attempts to improve its efficiency. The highest part of the global solar cells products is of crystalline silicon, in spite of creating new types solar cell. Laboratory-derived silicon solar cell efficiency is of 24.5 %, however the industry cell efficiency does not exceed 20 % [1, 2].

This is not the cheapest or most efficient solar cells, but they remain in the front position for lot of reasons. First of all, silicon is the cheapest semiconductor material. Second, silicon technology is the most advanced, mature, well-developed and least expensive compared to the technology of complex other semiconductor. Silicon is one of the most widespread surrounding materials, one of the most common, environmentally friendly, compatible with human biological life and the environment. The theoretical efficiency limit of silicon solar cells evaluated by 31 %, is a target for cells competitive with other energy sources and acquisition methods. Improvement of solar cell efficiency seeks by reducing losses due to light reflection from the cell surface, optimization of light absorption and the usage of charge carrier generated [3, 4]. There have been attempts to increase the efficiency of silicon solar cells by using a reflectance of porous silicon layers [5, 6]. One such recent work adapted porous silicon to enhance efficiency of epitaxial thin film silicon solar cell [7]. Chirped Bragg reflector were first produced in the conventional p-type silicon substrate. Then epitaxial n-type emitter was grown on the porous silicon structures. Broadband chirped porous silicon reflector effectively returns to the p-n junction badly absorbed photons and thus increases the solar cell efficiency. However, Bragg reflector manufacturing operation is relatively complex. This may result in more expensive production of such solar cell. In this paper, we applied a more simple porous silicon technology to modify and to improve parameters of completed mono-crystalline silicon solar cells. At the same time, we are not limited to reduction of light reflection, as in papers [5, 6], however affect in addition the solar cell volume. The completed monocrystalline silicon solar cells were produced in a manner consistent with the industrial manufacturing process [8]. Current-voltage (*I-V*) characteristic of the porous silicon structures containing solar cell have been measured and its spectral dependence, maximum power dependences were derived of modified silicon solar cell.

EXPERIMENT

Silicon p-type, (100) plane, 450 μm thick mono-crystal wafers have been used in solar cell production. The n-type emitter was made by phosphorus diffusion. The emitter thickness (junction depth) was estimated of (0.5 ÷ 0.7) μm. Continuous lower and grid upper contacts were made of copper by vacuum sputtering. The finished surface of the cells were protected by the a few tens of nanometers thick silicon nitride layer. In the experiments, solar cell panels were cut into (5 × 10) mm^2 samples. The copper wire has been attached to the upper and lower contacts by silver paste. All the metal contacts were protected by chemically resistant and electrically-tight paint. Porous silicon technology operations were carried out in the teflon electro-

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chemical cell. As the anode the lower solar cell contact was used, cathode contacts of the electrolyte made of platinum. The samples were placed in fluorine acid for a few minutes in order to remove the protective layer of silicon nitride, before the manufacturing of porous silicon. Production of porous silicon layer has been carried out in the HF : ethanol = 1 : 2 volume ratio electrolytes. The samples were illuminated by 50 W halogen lamp light during etching. Etching current was controlled by a computer in the limits of $(6 \div 14)$ mA/cm^2, etching time interval was limited in $(10 \div 30)$ s. Electric charge passed through the unit of the area was controlled in the ranges of $(260 \div 420)$ mC/cm^2. Estimated thickness of porous structure was $d \sim (250 - 300)$ nm, porosity was about $(40 - 56)$ %. The simplified scheme of the modified solar cell sample is shown in Fig. 1

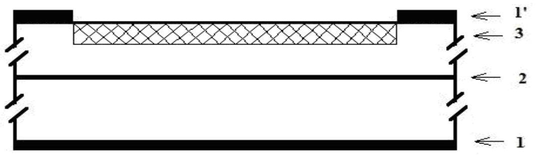

Fig. 1. Scheme of the modified solar cells. 1, 1'– metallic contacts; 2 – p-n junction, and 3 – porous layer

Computerized equipment package consisting of multimeters Tektronix CFG 253, Keithley 2000, Metex MXD 4660, oscilloscopes Tektronix TDS 3032B have been used measuring *I-V* characteristics. Investigation of the spectrally integrated solar cells conversion efficiency have been made using the 35 W Xenon lamp radiation with a spectrum close to 5000 K black body radiation spectra. Halogen 50 W lamp light and diffraction grating monochromator were used during the spectral measurement of *I-V* characteristics.

RESULTS AND DISCUSSION

Quality of the solar cell is determined by a parameter called solar cell efficiency that is simply defined by a ratio:

$$\eta = \frac{P_{\max}}{P_L}, \qquad (1)$$

where $P_{\max}$ is the maximum solar cell power and P_L is power of the incident light. So, solar cell efficiency and $P_{\max}$ are associated by a linear dependence. At constant power of incident, light change in $P_{\max}$ reflects peculiarities in solar cell efficiency and quality of the cell as well. Maximum power created of solar cell can be simply found by measuring its *I-V* characteristic under external biasing as well as measuring current of illuminated solar cell without bias and voltage changing loadings [9]. The past measurements we used to study spectral peculiarities of maximum electric current power created by the solar cell. The dependence of solar cell power versus voltage illuminated by Xenon lamp for two samples is depicted in Fig. 2. The open symbols belong to the samples before modification. The filled symbols reflect the solar cell power after modification it by manufacturing a porous silicon structure. The illumination intensity, so the power of incident light were hold constant during the measurements. The shape of dependence of solar cell electric power on voltage changes noticeably after modification of samples manufacturing porous silicon structure as it is seen in Fig. 2. The change occurs both in the position of $P_{\max}$ as well as in absolute value of the power. The change in position of $P_{\max}$ reflects tuning in the cell resistance. It is no wonder because etching of solar cell reduces the sample effective cross-section area, so it boosts its sequential resistance. More notable change in $P_{\max}$ value was found after modification of the solar cell.

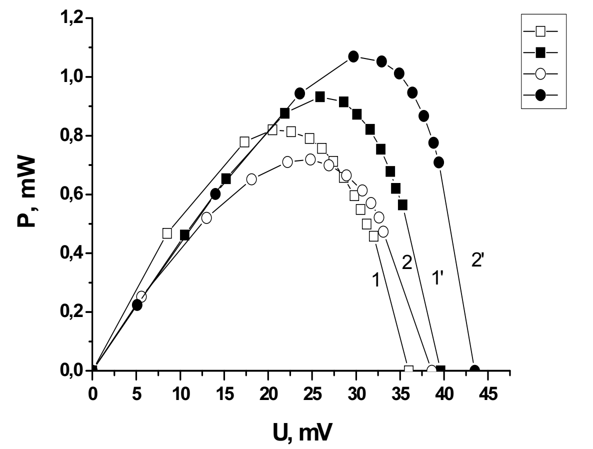

Fig. 2. Power-voltage characteristics of two solar cells under equal illumination: 1, 2 – before the formation of the porous silicon structure; 1', 2' – after the formation of porous silicon

The change in the maximum power is 15 % for the sample 2 and even essentially more for the sample 1, as it is seen in the figure. The first suppose can be made that it is because a reduction of the reflection of incident light by porous silicon layer. However, such supposition is in capability to account the 15 % power $P_{\max}$ increase in sample 2, however it is not capable to explain 1.5 fold increase of $P_{\max}$ in sample 1. So we propose different explanation of the phenomena observed. We suggest that this remarkable increase in power occurs because of better absorbance of incident light and because of the better collection of excited charge carrier, creating after modification of solar cell by manufacturing porous silicon structure. The above explanation has been verified by studying the spectral peculiarities of the power increase. Fig. 3 presents the dependence of solar cell power versus

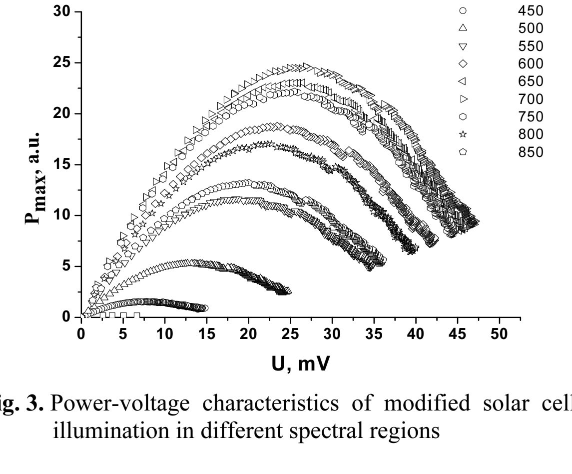

Fig. 3. Power-voltage characteristics of modified solar cells at illumination in different spectral regions

voltage illuminated by the light of halogen lamp passed through a monochromator in different spectral regions, derived of the solar cell load *I-V* characteristic measurement data. It is seen in the figure the shape of dependence $P_{max}(U)$ changes when exciting in different spectral regions. Note that P_{max} value depends on spectral location of the incident light. Fig. 4 represents dependence of P_{max} on the spectral position λ of the excitation light. It is seen in the figure that this dependence is essentially different for modified and unmodified samples.

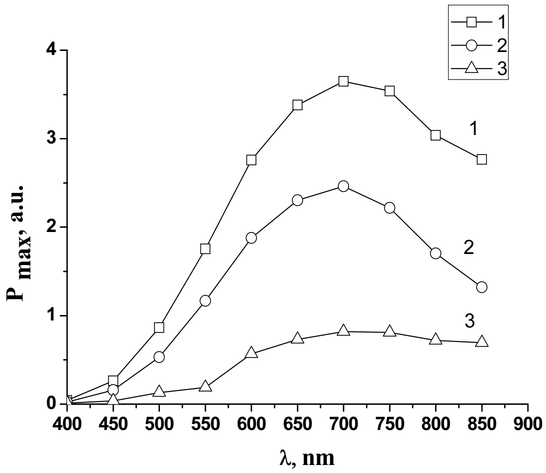

Fig. 4. Spectral dependences of solar cells created power P_{max}: 1, 2 – modified cells, 3 – not modified cell

The power created in spectral region 400 nm ÷ 550 nm is quite weak in all samples investigated because silicon absorption of light in this region is very high. So the charge carriers recombine not reaching the cell p-n junction, excited near the surface. Therefore we will consider the spectral region beginning of wavelength 550 nm, where essential distinction between the initial and modified samples is observed. Size of P_{max} is quite constant in spectral region 600 nm ÷ 850 nm in the initial unmodified samples. We observe absolutely other picture in the samples modified by porous silicon. The modified samples generate considerably, much more power comparing to the unmodified ones in these spectral region. The increase is greater and the spectral region is broader as opposed to the case of selective reflectivity reduction by $\lambda/4$ porous layer [5, 6]. The most increase in power generated is observed at $\lambda \sim 700$ nm, for energy 1.77 eV which is about one-third greater than forbidden energy gap of silicon. The increase in power created is three fold of the sample 2 and four and a half times of the sample 1. The increase of P_{max} is nonmonotonic and decreasing in both directions from the central wavelength 700 nm. So it is difficult to explain such behavior by slowdown of reflectance. We believe the origin of the phenomenon is more complex. We suggest the increase of power generated originates of better absorbance of exciting light and greater collecting factor of charge carriers in silicon solar cells modified by porous silicon structure and technology used.

CONCLUSION

Porous silicon technology was applied to improving completed mono-crystal silicon solar cell. It was shown, the manufacturing of appropriate porous silicon structure significantly enhance the maximum power, delivering by the cell at the equal illumination. The spectral peculiarities of the power increase were studied. It is found, the most increase in power generated is at $\lambda \cong 700$ nm. The increase in power created is three fold in the one of the samples and four and a half times in another at this wavelength. It is suggested, the increase of power generated originates from better absorbance of exciting light and greater collecting factor of charge carriers in silicon solar cells modified by porous silicon structure and technology used.

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