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Efficiency Enhancement of Photovoltaic Silicon Cell by Ultrashort Laser Pulses

We present an experimental evidence of the effect of the femtosecond laser pulses on the spectral response of the Silicon photovoltaic cell. The response of this device is covering the visible to near infrared spectral region. The responsivity of the photovoltaic solar cell is enhanced from 0.18A/W to 0.25A/W and/or the conversion efficiency increase from about 9% to about 14% due to irradiation effect. All treatments and measurements are made at room temperature. Results show that the responsivity is enhanced and the nano-structured groves of the 700-900 nm range are observed.

Keywords: Efficiency, Ultrashort pulses, Photovoltaics, Nanostructure
Received: 9 March 2009, **Revised**: 15 April 2009, **Accepted**: 22 April 2009

1. Introduction

Silicon is the most commonly used semiconductor in optoelectronic devices and silicon photodiodes are often used in industrial applications are reliable devices for light to electricity conversion. High operations Silicon photodiodes are preformed between their spectral responsivity. These features are especially important in the field of optical radiometry in which measurements of photometric and radiometric quantities have to be done with a high level accuracy.

The description of high accuracy interpolation of quantum yield of Silicon photodiode detectors in the near UV is presented by Kübarsepp et al [1]. The results of the of the quantum yield calculations and of measurements obtained by use of a Silicon trap detector are presented and compared. Since the year 1969 the amorphous Silicon plays a crucial role in producing lower cost-effective solar cells. However, the solar cells made from this material tend to have lower energy conversion efficiency than bulk silicon.

Carey et al [2] investigated the I-V characteristics and responsivity of photodiodes fabricated with silicon that was micro structured by use of femtosecond laser pulses in a Sulfur-containing atmosphere [2]. The Silicon surfaces irradiated with high intensity nanosecond laser pulses in the presence of Sulfur-containing gases have near unity absorption from near UV (250nm) to NIR (2500nm) at photon energies well below the bandgap of ordinary Silicon [3].

Microstructures developed spontaneously on Silicon surface under the cumulative short laser pulses irradiated in different ambient atmosphere [4,5]. The experimental results reveal that the ambient atmosphere and the laser pulse duration play key roles on the microstructures formation. In the present work, the experimental procedure to enhance the efficiency of a bare silicon solar cell from 9% to 14% is explained and the enhancement through out demonstrating the effect of femtosecond laser irradiation on Silicon surface is presented.

2. Experimental Procedure

As standard mechanism of spectral measurements (Fig. 1), the spectral response of the samples is measured after and before the irradiation process using femtosecond laser source and a calibrated detection unit. The system instrumentation is controlled from a PC via RS232 interface. The output of the monochromator is directed to two output windows, to the calibrated detector and the other to the sample under test. During the system operation a broad band light source is passed through a monochromator signaling out the desired frequency of the light to illuminate the photodiode.

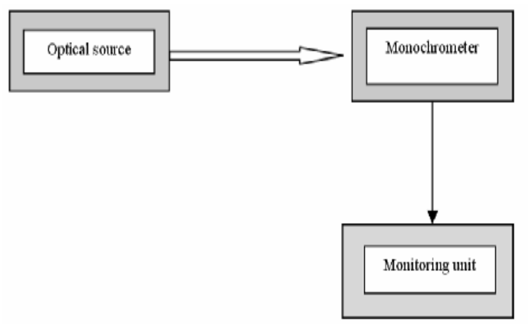

Fig. (1) The spectral measurement setup

The intensity of the light is measured with a calibrated detector and stored on the PC. The

 ISSN 1813-2065

photovoltaic devices current is measured with the semiconductor parameter analyzer and the results are stored on the PC. The measurement is then repeated over a range of wavelength between 400-900nm.

The sample understudy was irradiated by a tunable mode-locked Ti:sapphire oscillator laser source with 100fs pulse duration, 80MHz frequency at 800nm wavelength of operation. The sample was irradiated by this laser and a focusing objective with high numerical aperture was used in air environment. The laser beam was expanded by a 1x4 beam expander and it was focused on the target by means of 100mm focal length lens. The irradiating beam was directed normal to the anode side of the sample. The irradiation processes created numerous defect sites and modified the sample surface.

The behavior is identical at different wavelengths, 532nm and 810nm. The time response of the irradiated and unirradiated samples to nanosecond laser pulses has been taken into account. The output of the sample is connected by 50Ω to an oscilloscope for collecting data. Scanning Electron Microscope (SEM) images of the structures obtained in air environment. One line scan was performed at a fixed scan speed. A periodic structure (lines) was formed and observed in the range of 700-900nm range. The SEM images shows a semi periodic structure known as ripples or grooves in submicrostructure and were found after laser irradiation, Fig. (2).

As a conclusion, we believe that the use of this approach leads to enhance the spectral response of photovoltaic cell. The low intensities defining the laser irradiation drastically change the scale of the surface reshaping process, promoting the formation of nanostructures and the interaction between surface roughness and/or smoothness lead to increase the number of pulses contributing certainly to rapid nano-channels formation with very small spacing.

This approach leads to a new generation of photovoltaic solar cells and could be used to enhance a photovoltaic material responsivity and hence the conversion efficiency. Although the efficiency of the amorphous Silicon based solar cells were increased from 7% to about 9% during the last 40 years utilizing different methods, the stepping to 14% efficiency is considered as a big step by only rearranging the micro crystal structure of the cell surface utilizing ultrashort laser pulses which should be still economically reasonable in a large scale production.

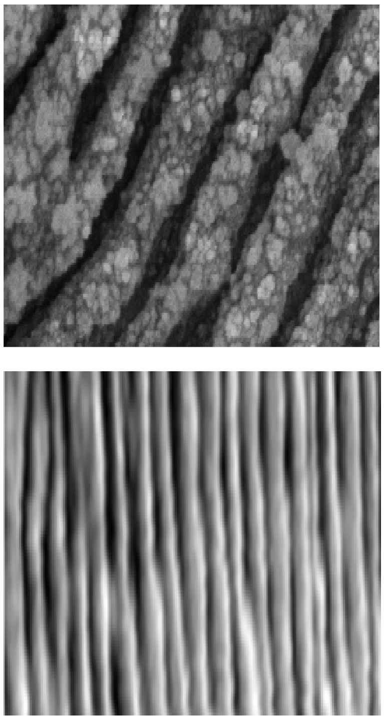

Fig. (2) The periodic structured of the irradiated cell, by a 100fs laser pulses, 800nm wavelength, 4μm length (above) and 12μm length (below)

3. Results and Discussion

Effects of the irradiation of the spectral response for samples before and after ultrashort laser pulses irradiation are shown in Fig. (3). This figure shows the dependence of the responsivity versus wavelength and the role of the laser effects at room temperature.

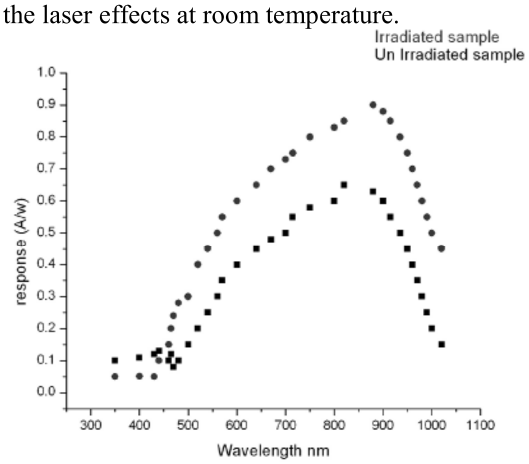

Fig. (3) The spectral response of the irradiated (upper curve) and unirradiated (lower curve) photovoltaic solar cells

The relative response increased after the irradiation processes. From this figure one can observe that the efficiency of the irradiated sample is enhanced clearly compared to unirradiated sample at the wavelengths longer than 500nm. The responsivity of the photovoltaic cell hence is increased from 0.18A/W to 0.25A/W due to irradiation effect. The conversion efficiency of the irradiated cell is calculated using the well known equation

$$\eta = \frac{IV}{AI_o}$$

where I is the current value, V is the voltage, I_o is the solar intensity and A is the solar cell area.

The results show that the measured efficiency for the bare Silicon solar cell was 9% before irradiation and tend to be 14% after that; however the area under the response curves as shown in Fig. (4) indicating that the total response of the irradiated samples at different wavelengths.

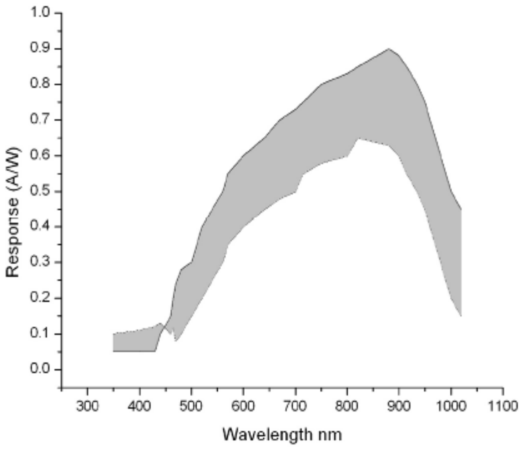

Fig. (4) The comparison of the spectral response curve of irradiated and unirradiated solar cells

The ratio of the total quantum yield obtained before and after irradiation yield a 1.43 times increases in the total efficiency of the solar cell along the whole spectral wavelength range of the working solar cell. On the other hand, the gain response curves as a function of the bias voltage for irradiated sample at different wavelength are shown in Fig. (5).

4. Conclusions

In summary, we have demonstrated how we can perform sub-microstructure of photovoltaic cell by means of irradiating the sample by femtosecond laser pulses. The responsivity and the conversion efficiency of the photovoltaic cell are enhanced by this technique.

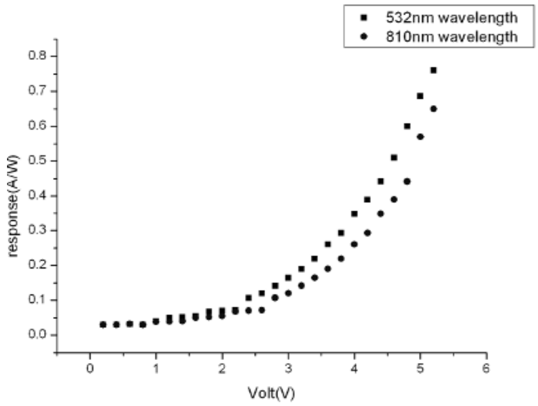

Fig. (5) The gain response of irradiated and unirradiated samples at two different wavelengths

Acknowledgment

Authors acknowledge M. Bellini and A. Zavatta for their help during the irradiation the samples. K.A.N. acknowledges ICTP for the financial support in the framework of the TRIL program.

References

[1] T. Kubarsepp., P. Karha., and E. Ikonen, *Appl. Opt.*, 39 (2000) 1.
[2] J.E. Carey et al., *Opt. Lett.,* 30 (2005) 1773.
[3] C.H. Crouch et al., *Appl. Phys. Lett.*, 84 (2004) 1850.
[4] Z. Jingtao et al., *SPIE*, 10, 1117/12, 57 (2005) 1965. Lasers in Material Processing and Manufacturing II. Edited by Deng, ShuShen; Matsunawa, Akira; Yao, Y. Lawrence; Zhong, Minlin. Proc. of the SPIE, Vol. 5629 (2005) 276-283.
[5] R.A. Myers et al., *Appl. Opt.*, 45 (2006) 35.