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FEMTOSECOND LASER INDUCED SPECTRAL RESPONSE ENHANCEMENT OF PHOTOVOLTAIC CELLS

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Abstract

The evidence of the effect of irradiation time of femtosecond laser pulses on the spectral response of a Silicon photovoltaic cell had been investigated experimentally. The femtosecond laser used in this work is with wavelength of 800 nm, frequency of 80 MHz and 80 fsec. Photovoltaic cells under study have broad spectral response ranging from the visible to near infrared (400-1000) nm. Different irradiation time (1, 3 and 9 min) has been used for irradiating photovoltaic cells. The responsivity of the photovoltaic cell is enhanced due to irradiation time. All treatments and measurements have been done at room temperature. The observed enhancement is related to the appearing of sub-pico (nano) structured groves. Results show the responsivity depends on appearing (micro-nano) structure.

1. Introduction

Silicon is an important technological material on which most of the

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semiconductor and solar cell industries are dependent. A bandgap of 1.07 eV leads to efficient detection of visible light and conversion of sun light into electricity. There is a wide range of interest in improving the responsivity of silicon detectors in the visible and the near-infrared (near-IR) regions of the electromagnetic spectrum [1]. In order to increase the responsivity of actual solar cells many different ways are currently being developed by researchers. Through the focus of work on the nano and micro-structuration of the surface [2], the use of antireflection coatings [3], or the use of absorption of nano particles [4]. Kübarsepp et al. [5] observed the effect of UV radiation on the responsivity of silicon photodiodes. In the near UV, the relative changes can be as great as 0.5% when photodiodes are irradiated at wavelengths near 250 nm. Over the past several years, researchers have advanced the development of a surface structuring technique to enhance the absorption of radiation both below and above the bandgap of silicon [6]. Through the use of femtosecond or nanosecond lasers to form microstructures along the exposed silicon surface, absorption of silicon can be as high as 90% at wavelengths region from 250 to 1100 nm [7]. The beneficial effect of the microstexturized Si obtained by femtosecond laser is demonstrated by Halbwax et al. [8] which shows that the photocurrent intensity is increased more than 30% in the laser treated regions. Rabha and Bessaïs [9] used a chemical vapor etching method to perform front porous silicon (ps) layer of Si solar cells. This ps surface could explain the reduction of the reflectivity value, as a result of decreasing of the optical reflectivity of this structure. It is about 8% in the 450-950 nm wavelength range.

In the present work, we improve the method used to interpolate the responsivity of photovoltaic Si in the visible and near -IR regions by using femtosecond laser. When femtosecond laser pulses are focused by high numerical aperture objectives $(NA > 1)$, the laser radiation is confined to a very small focal volume, creating photon densities high enough to induce multiphoton absorption at the laser focus, even in normally transparent materials.

2. Experimental Part

The experimental procedure is done by two steps; the first step is the response measurement of the samples, the arrangement of the optical system used in detecting the response spectrum as shown in Figure 1.

The spectrum response of the samples was measured by standard method using computerized monochromatic before and after irradiation process. Xe lamp was used as a light source, aligned to incident on monchromator. The system instrumentation was controlled by a pc via the RS232 interface. The output of the monochromator was directed to output windows. One beam was directed to a calibrated detector and the other to the sample under test.

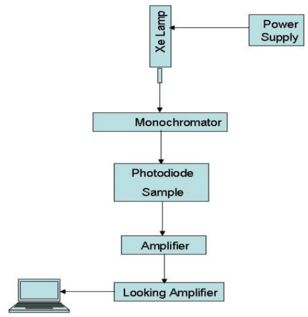

Figure 1. Schematic diagram of measurements response spectrum.

The second step is the photovoltaic cell (sample) irradiation by femtosecond laser pulses. Figure 2 shows a schematic diagram of the experimental setup. The sample was irradiated by a tunable mode- locked Ti: sapphire laser that operates at 800 nm, 80 MHz frequency with full pulse duration of 80 fs for the experiment in this work.

The laser beam is expanded by a beam expander and then delivered and focused onto the surface of a silicon workpiece by means of a 80 mm focal length lens. Irradiated sample is positioned by a three-dimensional (3D) linear image stage. A digital camera was utilized to observe the sample movement during the irradiation of the cell. The time response of the irradiated and uniradiated samples has been measured. A scanning Electron Microscopy (SEM) image of the structure was obtained in air environment. Line scan was performed at a fixed scan speed.

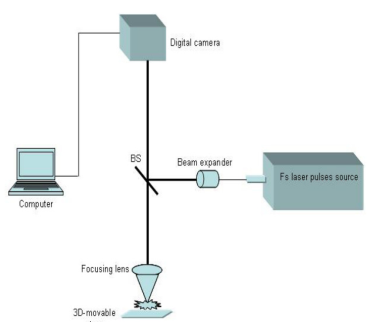

Figure 2. Diagram of the femtosecond laser experimental set-up.

3. Results and Discussion

A commercial silicon photodiodes is used for measurements of wavelength ranging from 400 to 1000 nm. The effect of the irradiation of ultrashort laser pulses on the spectral response is shown in Figure 3. The spectral response of photovoltaic solar cell is reported in the 400-1000 nm spectral region. It reveals the dependence of the spectral response on irradiated time. All the measurements are done at room temperature. The responsivity of unirradiated sample at visible range (400-800 nm) is constant. The responsivity increases with irradiated time upto 540 sec. The photovoltaic is enhanced from 0.2 to 0.8. At 470 nm the responsivity was 0.17 A/W. Since the response is falling off rather rapidly at 775 nm, the interpolation in this region could be practical implication of this is that virtually effective in the visible region.

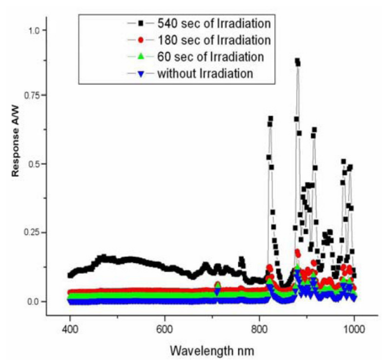

Figure 3. Spectral response of irradiated and unirradiated solar cell.

The responsivity changes are 0.04-0.17 A/W higher in the visible region, at the levels 400-775 nm. Apparently, an irradiation for 540 sec leaves the large concentration of the atoms in a unique nonequilibrium configuration that leads to high gain and photoresponse in both the visible and near -IR. The silicon solar cell performance was studied with irradiated by femtosecond laser. It was shown that the cell efficiency was increased about 5% compared to unirradiated sample.

Optimized irradiated samples exhibit high responsivity compared with commercial silicon photodiodes in the visible and the near -IR ranges. SEM image of the samples had been obtained in air environment. One line scan was performed at a fixed scan speed. A periodic structure was formed and observed in nanometer range. The SEM image shows a semi periodic structure known as ripples or grooves in submicrostructer and was found after laser irradiation as shown in Figure 4.

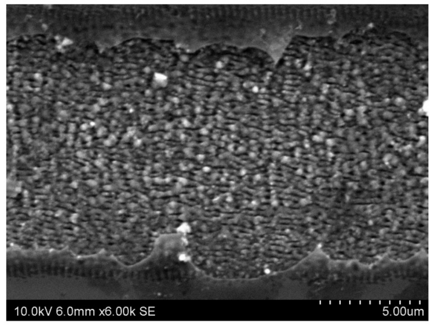

Figure 4. SEM photo of the irradiated cell by femtosecond laser.

The beneficial effect of the texturizations is demonstrated by Figure 5, which shows that the photocurrent intensity is clearly increased in the laser treated regions.

The real photocurrent of the non-laser treated surface should be smaller $(20\,\mathrm{nA})$ and therefore the gain becomes higher. Additional measurements will give better quantitative results.

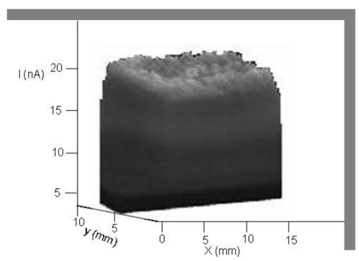

Figure 5. Photocurrent in the laser treated zones.

4. Conclusion

The investigation the responsivity of Si photodiodes for the visible and near -IR by irradiated the samples with femtosecond laser had been done. This approach presents a simple way to improve the silicon solar cell efficiency and response. It happened by irradiating the silicon surface with a series of femtosecond laser pulses. It leads to produces micro-spikes on silicon surface that strongly reduced the incident solar reflection. We have in this study created a photovoltaic structure. This technique helps to improve the responsivity and the conversion efficiency of the photovoltaic cell.

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