ENHANCEMENT OF SILICON SOLAR CELLS BY SURFACE PLASMONS

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Abstract

Thin-film solar cell technologies are a promising approach for applications of photovoltaic and have the potential for producing cheaper devices in a large scale. In order to perform all of this, we have to build very good thin film solar cells. There is a very strong need to increase the absorption of light from the sun in crystalline silicon in order to reduce the thickness of a crystalline Si-solar cell from 300-500 µm to a few µm. One method, which is under strong discussion in these days, is to make use of resonance absorption of light in surface plasmons. The idea is to deposit metallic nanodots on the surface of a standard solar cell. The nanodots size and density must then be optimized relative to the wavelength of the light to give rise to maximal absorption. At the end, we successfully achieved a very good efficiency of these films solar cells.

Key-word: photovoltaic, solar cells, silicon, surface plasmons

Permbledhje

Realizimi i sistemeve të paneleve fotovoltaike me efiçencë të lartë, që do të kenë një interes të veçantë në drejtim të promovimit të kësaj teknologjie, arrihet vetëm duke ndërtuar qeliza diellore shumë të mira përsa i përket karakteristikave fizike.

Qelizat diellore të holla prej silici janë një arritje e madhe për aplikimet në fushën e fotovoltaikëve. Teknologjia e tyre përbën nje potencial në prodhimin e paisjeve jo të kushtueshme në një shkallë shumë të gjerë. Për këtë, nevojitet shtimi e absorbimit të rrezatimit dritor nga silici kristalin ndërkohë që zvogëlojmë trashësinë e qelizave diellore të silicit nga 350-500 µm në disa µm.

Një mënyrë e cila po diskutohet shumë aktualisht, dhe qëllim i studimit tonë, përqëndrohet tek përdorimi i absorbimit të rezonancës së dritës në plasmonet e sipërfaqeve. Pra, ideja është depositimi i nanogrimcave metalike në sipërfaqen e një qelize diellore standarte. Madhësia e këtyre nanogrimcave, si dhe densiteti i tyre duhet të optimizohen në lidhje me gjatësinë e valës së dritës rënëse, në mënyrë që të përfitojmë absorbim maksimal të dritës, e për pasojë përmirësimin e celulave në studim.

Qëllimi ynë, ai që të arrinim një efiçencë sa më të mirë të këtyre qelizave diellore, u përmbush me sukses.

Introduction

We know that excitation of metallic structures can lead to oscillations of the conduction electrons, known as surface plasmons. These surfaces can result in selective photon absorption and scattering, and the giant enhancement of electromagnetic fields [1].

Suface plasmons are those plasmons that are confined to surfaces and than interact strongly with light resulting in a polariton. They can be excited in wavelength regions where the material has a negative real part of the dielectric constant. For light to couple to the surface plasmons, the metal surface must be rough on the scale of wavelength of the light, to accommodate the necessary change in momentum [2]. The excitation of surface plasmons by light is denoted as a surface plasmon resonance (SPR) for planar surfaces, or localized plasmon resonance (LSPR) for nanometer-sized metallic structures [6]. In this study we used such structures in order to improve the absorption and emission of light from thin planar layers, by coupling light with the waveguide modes of the planar layer. Light trapping using surface plasmons avoids the increase in surface area of conventional techniques [3].

Silicon nanocrystals can produce two or three electrons per photon of high-energy sunlight. By generating these multiple electrons, solar cells made of silicon nanocrystals could convert at a very high percentage of the energy in light into electrical power [4].

In this work we find that the surface plasmons can increase spectral response of thin film cells over almost the entire solar spectrum [5]. At wavelengths close to the band of Si we observe a significant enhancement of the absorption for thin films, and also for wafer-based structures. The final results are report as below.

Methods and experimental techniques.

In this work metallic nanostructures were fabricated and applied to glass and silicon substrates. Then electrical and optical properties are measured. These nanostuctures are applied to solar cells. The sample used for experiment investigations was made of '**n**' type of silicon, (100) orientated and 100 µm of thickness.

Two methods are used for producing the metal island structures. We try two different depositions of metal nanoparticles in the silicon wafers in thin layers of silver. For the formation of metal islands using annealing, 10nm, 15nm, and 20nm of silver was deposited, then annealed in N_2 atmosphere in different temperatures and time.

The first one was ECON evaporation under the nitrogen N_2 atmosphere. The

nanoparticles we formed but depositing different thickness of layers of silver. These layers were uniform and the velocity of deposition was 0.5Å\s. Mass deposition differs from 10 nm of silver, 15 nm, and 20nm of silver uniform layers on silicon wafers under the pressure of 10-5 Torr. Then, we annealed all these samples in different temperatures (200˚C, 250˚C and 300˚C), different time (50 min, 10 min, 3 min) of annealing, collapsing together to form islands. Annealing was done under the N_2 atmosphere, flow rate of which was up to 50 lit\h. These samples were annealed in a VECSTAR Furnace, Model 83.

After annealing we did AFM (atomic force microscopy measurements) for all these samples. The AFM technique (RASTERSCOPE 3000) is used to have pictures of surfaces topography of all samples prepared, grain analysis, plane correction etc. Some of the results for AFM measurements are shown below (Figure 1).

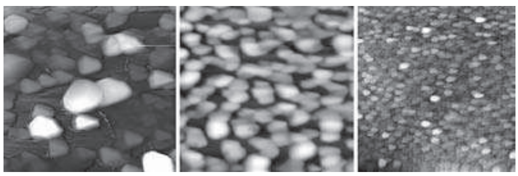

Figure 1. In this figure are shown respectively: a) 20nm of Ag, 250˚C for 50 min; b) 15nm of Ag, 250˚C for 2 min; c) 10nm of Ag, 250˚C for 10 min

We cut these wafers on 10x10mm^2.These silicon crystals, have been kept at room temperature for some time, so they form a thin SiO_2 layer, about 3 nm thick, called natural SiO_2 layer. All the different thickness of silver was deposited on this thin SiO_2 layer, and that was done in order to see the effect of particle size in enhancement.

As we see from these pictures, and many others done for all samples that we prepared, the silver nanodots have non-uniform spread and now a well defined shaped, and furthermore they are very big. Some of these samples, was annealing for the second time in order to see if they increase or decrease in sizes. As we accepted they are increased very much becoming bigger and bigger.

The second way of preparing other samples was evaporating them on Thermal Evaporator.

This evaporation is done under the pressure of 10^{-6}Torr. After evaporation we did the AFM for all these samples, before annealing. Then after annealing these samples of 10,15 and 20nm of silver under the nitrogen, in 200˚C ; 250˚C for 10 min, or 50 min, and doing AFM of them, we try to anneal these samples for the second time, but in a shorter time (3 ore 10 min) and higher temperatures as 250˚C and 300˚C.

These experiments were preceded for the samples with natural oxide SiO_2 and 25 nm of SiO_2.Then we did AFM of these samples again, in order to see what happens with the sizes of nanocrystals.

The evaluation of images taken from AFM was done using the SPIP (Scanning Probe Imaging Processor). Images below show the results taken from this step (figure 2).

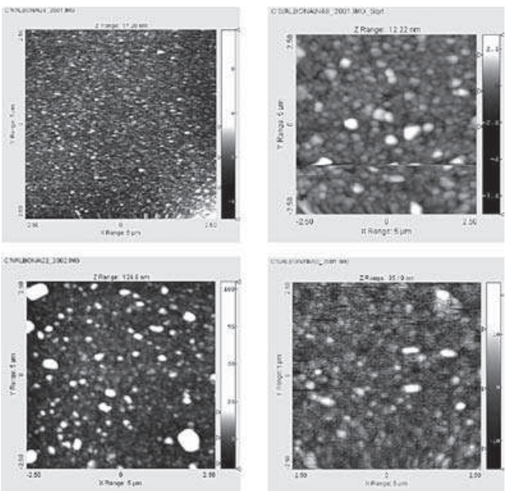

Fig.2. In this figure are shown: a) 10nm Ag/25nm SiO_2 before annealing; b) 20nm Ag/25nm SiO_2 (200°C, 10 min); c) 20nm Ag/3nm SiO_2 (200°C, 10 min); d) 15nm Ag/3nm SiO_2 (200°C, 10 min)

Results taken from above, were not so good, the sizes were very big so, after the conclusion that thermal evaporating is more convenient, we obtained some other samples of 10, 15 and 20 nm silver on natural and 25 nm of silicon oxide. The evaporation under the technique BALZERS, lasts 1 minute under the pressure 10^{-6} Torr.

After evaluation all images taken till in this moment, we decide that will use the Thermal evaporation technique for our samples. Then we will anneal them on 125˚C, 150˚C, and 175˚C. Then we will use magnetron-sputtering technique (ACT ORION SPUTTERING SYSTEM) for the SiO_2 thickness on silicon wafers. Sputtering technique under T=200^0C for 1000 seconds under the pressure 3mTorr. The velocity of sputtering was 0.25 Å/sec, and a motor power of 50 watt.

Then we decide to anneal our samples in lower temperatures, 125˚C, 150˚C, and 175˚C for 50 min. The images (figure 3) are taken from SPIP evaluation of AFM images taken from these images.

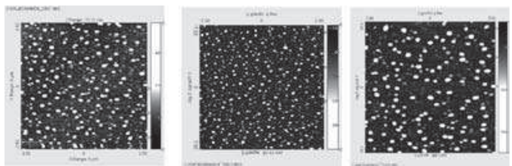

Fig. 3 In this figure are shown: a) 10nm Ag/25nm SiO_2 (150°C, 10 min); b) 10nm Ag/ 25nm SiO_2 (125°C, 10 min); c) 10nm Ag/25nm SiO_2 (175°C, 50 min)

Then after MESA ETCH we did our diodes, after that we evaluate electrical and optical properties. The optical and electrical measurements are done in the region of interest, except that of UV where metal tends to absorb very good. So we expect to see an absorption enhancement in optical measurements.

To evaluate measurements we use a program Lab view 7.1.

We used samples of 10, 15 and 20 nm Ag on natural silicon oxide and thicker silicon oxide, resulted 44 nm of thickness, measured by ellipsometer EL X_02C.

Electrical measurements (I-V measurements)

For all diodes obtained from the samples evaluated we did I-V measurements to see if they were good diodes. From the measurements they results to be good enough. But as we see in the figures (PL) we see that there is not much difference between the photocurrent in diodes before and after annealing. This means that there is no great enhancement on photocurrent given from these samples [7]. These shows that silver nano-crystals are cannot absorb as well the monochromatic light given by lamp. We used a filter of LJ1695L1 (F=50mm, H=30mm, L=42mm) for the focusing of the second order –diffraction line. After RBS spectra's for the samples taken in evaluation results that a percentage of iron is induced in the samples.

For an electromagnetic field of semiconductor arising form a surface plasmon excitation in a proximate metal nanoparticle the duration of an interaction between the field and semiconductor is determined by the lifetime of the surfaced plasmon excitation. For a p-n diode increase of absorption by nanoparticles, will be seem at an increase of photocurrent response at wavelengths that correspond to the wavelength of nanoparticles surface plasmon resonance.

The basic device structure is done by p-n junction diode. It is n-type Si (100) wafer with receptivity p =1/R=1/100 (10-2Ωcm)

Samples #3047 made by John, as it was shown above, consist on a p^+ layer grown in MBE (Molecular Beam Epitaxy) Growth rate was max 5 Å/s, under the temperature of 458 grades Celsius.

Here are presented two of these I-V curves for the final samples #3047 taken in evaluation. (Figure 4)

We analyzed the performance by monitoring the open-circuit voltage *V*oc and the short circuit current *I*sc. Normally, it is determined from the current-voltage *I-V* relationships, with *I*sc and *V*oc as important characteristics. The delivered power is computed using *P=IV*. It seems that they are good enough, and this is shown from the power of current obtained.

PHOTOCURRENT MEASUREMENTS

These measurements are done using ORIEL 257 & KEITHLY 617.

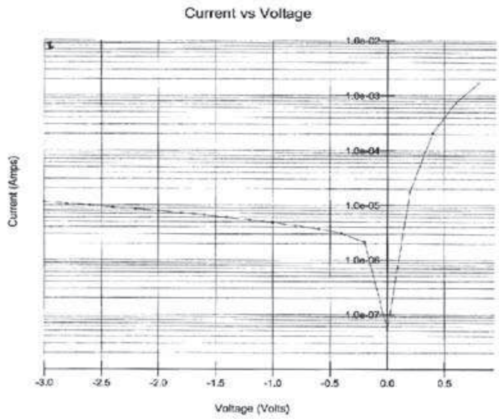

Fig.4. 10nm Ag/25nm $SiO_{2\ annealed}$ at 125 degrees

The diode-IV characteristic has been measured and photo-current measurements as a function of light-wavelength has been performed on the as-grown diodes, demonstrating that the diodes are well suited for these investigations [9]. We deposited Ag nanodots on these diodes and determine optimal size and density distributions with respect to the photo current by combining AFM and photo-current measurements.

The photocurrent and extinction spectra were measured using a 100 Watt Quarts Tungsten halogen lamp as an illumination source and a grating monochromatic (grating 2) with more then 1200 groove/mm grating, providing monochromatic light at wavelength of 300 nm till 1200 nm. For measurements at wavelength of 580 nm or longer, were employed filters (filter 5), so we could eliminate illumination from the second order diffraction line. For measurements of extinction spectra, monochromatic light transmitted through the sample was incident on a Si photo-detector, from which the current signal is directed to the lock-in amplifier.

The final samples # 3047 were prepared in MBE, sputtered in Magnetron Sputtering and then evaporated in Thermal Evaporation concluding in 10 nm, 15 nm and 20 nm of silver layers on 25 nm SiO_2. The same procedure was attended to anneal these samples, and then evaluate the particles sizes and photocurrent obtained by these samples.

Spectra's from Ag 10 nm, 15 nm, and 20 nm are shown as below in fig. 5.

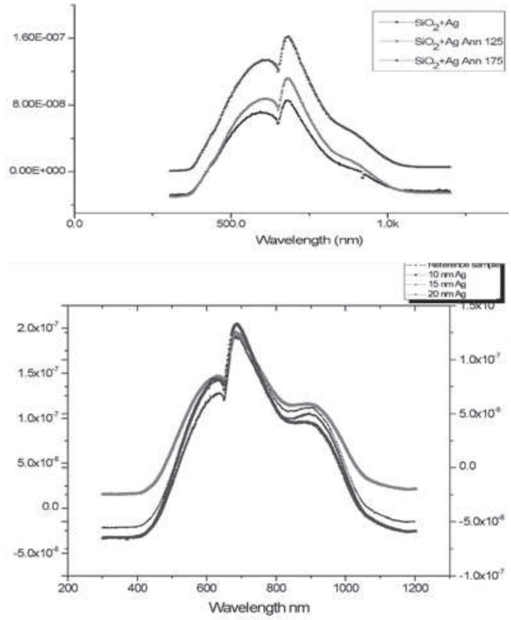

Fig. 5 a) Photocurrent enhancement from a 25 nm SiO2 thick layer solar cell, for particle with to 10 nm mass thickness of Ag annealed in different temperatures, and one sample not annealed; b) Photocurrent enhancement for different mass thickness of silver particles, annealed in 150 degrees, compared with reference sample (no Ag and natural SiO_2)

To further investigate the effect of increasing the size of the nanoparticles[8], silver of varying mass thickness was deposited on Si wafer and optically characterized by measuring the absorption in Si from the sample after annealing.

For such diodes, increased optical absorption due to present of silver nanodots will be manifested as an increase in photocurrent response at wavelengths [9] corresponding to the Ag nanocrystals surface plasmon resonances. Fig. 6 shows an enhancement in photocurrent depending to the size of silver particles.

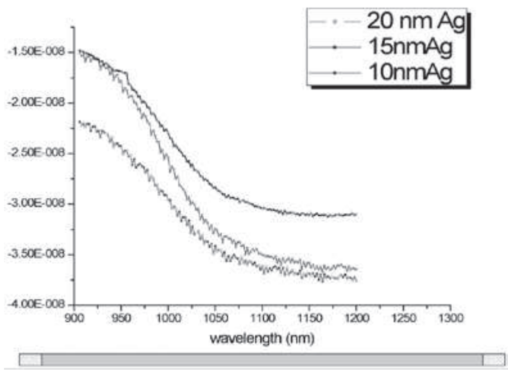

Fig. 6 El enhancement plot for particle sizes corresponding to different mass thickness of Silver, shows an enhancement for larger particle sizes

CONCLUSIONS

the experimental investigation of the current-voltage response of illuminated p-n junctions in forward and reverse polarity enables for the experimental evaluation of the produced photocurrent as a function of the applied bias and given illumination level.

We can see from the results above that the layer of silver particles can have an increase in emitted light. Hereafter we have an increase in photocurrent, thus an increase in efficiency of solar cells. The investigation of surface plasmons effect on silver nanoparticles, as a mean of improving the efficiency of thin-film and solar cells are preceded. Hence, surface plasmons offer a promising way to improve the efficiency of thin-film solar cell structures, avoiding the problem of increased recombination, which occurs when silicon is textured directly. So if we reduce the thickness of silicon around 15 nm, we will have a very good light trapping provided by the metal nanoparticles in the visible region and infrared region. This is shown in our measurements as well. Enhancing absorption at wavelength corresponding to the solar radiation spectrum could increase efficiency of thin films devices.

The same analysis done for "n" type silicon could be better to be performed also in the future for the "p" type silicon samples.

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