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Use of Embedded Metal Nanostructures for Solar Cells

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***Abstract*— Thin island metal motion pictures embedded in the p-n semiconductor crossing point of a photovoltaic structure engage out and out change their viability. A kind of metal portrays this change. In this work we show our outcomes of test trials of creation photovoltaic heterostructures ITO/C-Si with thin metal motion pictures introduced into the semiconductor crossing point. We associated such metals as gold and silver which can show up the limited surface plasmon resonation impacts, when the islet estimations are a couple of nanometers. We found that the gold nanoparticle in a general sense improves the photovoltaic change profitability when the silver nanoparticles keep the photocurrent age. Made photo control in the examples with embedded gold island films was more to around 10 times than without this interlayer. All metal island motion pictures and ITO maker films were prepared using low-weight triode dc sputtering system.**

***Keywords*— Metal Island films, Localized surface plasmon-polariton, Diode Schottky, Solar cells.**

I. INTRODUCTION

The capability of photovoltaic (PV) converters is obliged as a result of high electrical and optical adversities [1]. A champion among the most choosing components of optical mishaps is the luminosity or radiative recombination which also limits the possible profitability [2]. The reality of the situation is, each held photon can invigorate only a solitary join of charged particles, an electron and an opening. In like manner, with a particular true objective to out and out form the capability of daylight based cells, it is vital to extend the amount of charged particles that are created by absorption of a photon. A way to deal with manufacture different electrons invigorated by light is use of metal nanoparticles talented to outline a restricted surface plasmon resonation [3] or SPR. It is understood that the photon devoured by a gold particle empowers a gathering of charged transporters, electrons and openings, due to polarization of the atom [4]. In this manner, the SPR can be considered as a wellspring of additional electrons got by maintenance of "hot" or high-essentialness photons.

Inside a p-n convergence of the diode photovoltaic structure there is an amazing intrinsic electric field. The gold nano-particles imbedded into the silicon p-n crossing point will be under effect of this electric field. For instance, the gold has a work more vital than the work limit of the silicon, each of gold nano-particles outlines a Schottky contact with the n-sort silicon and an Ohmic contact with the p-sort silicon. In this way, each and every gold particle introduced into the p-n crossing point shape a course of action of forward-uneven nano-diodes Schottky which are in the implantation mode. Under daylight based light these nano-diodes should mix additional electrons, empowered in the gold nano-particles, in the conductive band of the silicon and additional free holes in the valence band of the silicon [5]. One of approaches to manage collects more affordable and more capable PV structures is to use the heterostructures instead of p-n convergences worked from a comparable material. By thusly, one can execute from the creative chain such methodology as molecule implantation or scattering. Consequently, in the PV structures in light of utilization of p-sort silicon wafers, a n-sort silicon maker, masterminded by molecule implantation, scattering or atomic layer epitaxy, may be changed on the another semiconductor layer with portrayed electron center. Normal cases for such structures are n-ZnS/p-Si and n-ZnS:Al/p-Si heterojunction [6], or ITO/A-SI:H/SI heterostructure [7]. Here, the ITO (In2O3-SnO2) layer was used as a maker on the PV heterostructure.

The target of this work is to investigate likelihood to improve an efficiency of the PV structure using dainty island metal film. Here, we demonstrate the results of our exploratory trials.

2. EXPERIMENTAL DETAILS

Metal island thin movies and ITO producer coatings were kept by a triode sputtering technique in the low-weight plasma release [8]. The ITO sputtering target was made of

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indium oxide and tin oxide in the proportion In2O3:SnO2 = 90:10. Aluminum cathodes were set up by vacuum dissipation technique. The photovoltaic structures were set up on the (100) surface of the single-crystalline p-sort silicon substrates with resistivity of ~5-9 Ω·cm. The glass slides were connected as witness substrates to quantify and think about the optical properties of developed thin movies. Every testimony of metal and ITO thin movies was given on both silicon and glass substrates. Figure 1 speaks to a side perspective of the developed thin film structure. We utilized gold and silver island thin movies to create the plasmon reverberation under light illumination.

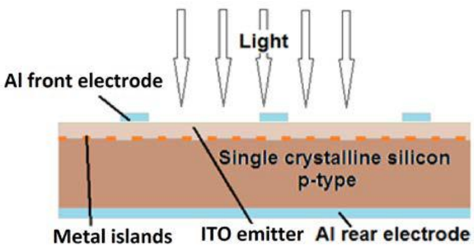

Fig. 1 Experimental PV structure.

External view of the prepared samples is shown in figure 2. The sample represents a multilayer system grown on the single-crystalline substrate of p-type. The front surface of the substrate is coated in series by gold island interlayer with approximate thickness of 2 nm and transparent conductive In2O3-SnO2 (ITO) thin film with rough thickness of 200 nm. A sheet resistance of Au, Ag, and ITO films was measured using a standard 4-point method. Optical characterization of all films was done at wavelength of 200-1100 nm using the UV-2800 UV/VIS spectrophotometer of UNICO. The surface structure was studied using the SPM DI300 in AFM contact mode and the computerized metallurgical microscope "Nicon-Optiphot 100" with optical magnification of up to ×1600.

Fig. 2 External view of the PV sample.

In order to compare the influence of metal islands imbedded into the semiconductor junction of solar cell on their parameters, we prepared a series of the same pairs of samples. In the pair, one of the samples was prepared with gold or silver island film, and the second one was built without a metal film. All the rest of parameters of the samples remained the same. To obtain the I-V and P-V characteristics of our PV-structures, they were measured at the same conditions at constant temperature of 200C under illumination of an incandescent lamp (its radiation spectrum significantly biased in the IR range) on the distance of 10 cm providing maximum light intensity of ~1800 Lx that relates to approximately 15 W/m2.

3 RESULTS AND DISCUSSION

Figure 3 represents the transmittance spectra measured on thin gold and silver island films. Also, the spectrum of pure glass substrate presented here.

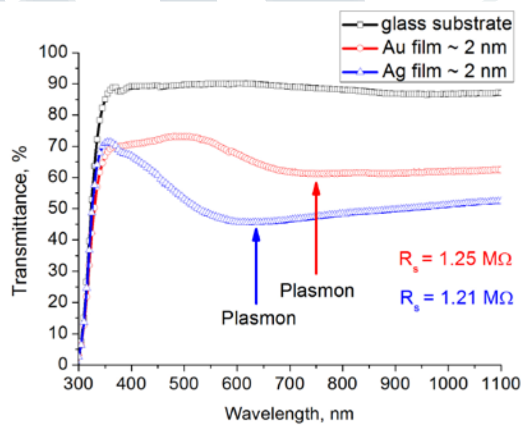

Fig. 3 Transmittance spectra of island metal thin films.

As shown, both gold and silver films deposited during short time represent the large absorption peaks situated through visible part of spectrum. These peaks characterize arising the plasmon behaviour of electrons in the thin metal islands. The thicker films deposited by this method not show such absorption peak since the localized plasmon-polaritons disappear in the coalescing films [9]. Deepness, largeness and location of absorption peaks fully defined by the material of metal, and shape and dimensions of islands. Our thin metal films were non-continuous and they were consisted of disks with diameter of 12-14 nm and height of 2-3 nm. Their sheet resistance is sufficient high. These films were embedded into the p-n

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junction formed by ITO thin film deposited on the silicon surface. Figure 4 represents the AFM 3D topography of thin island gold film with thickness of 2-3 nm. This film consists of islands regularly distributed on the substrate surface and contains approximately 30 islands on the area of 100×100 nm2. Silver island films look the same.

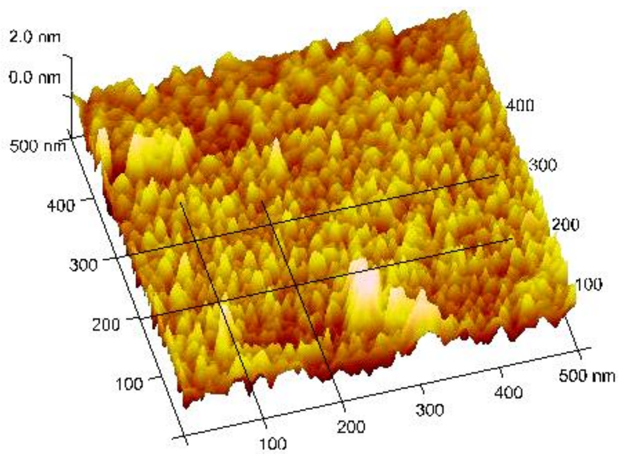

Fig. 4 AFM image of the gold film of 2 nm thick on the glass substrate.

Figure 5 represents the transmittance characteristics of ITO thin films of different thickness on glass.

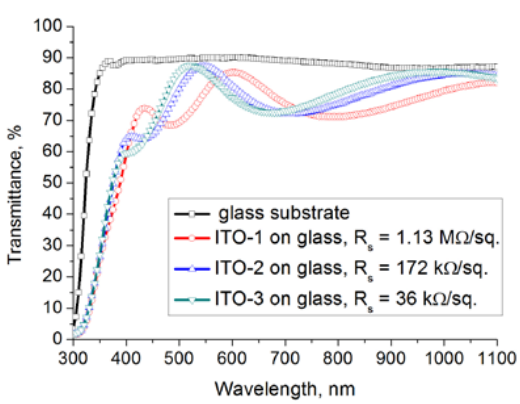

Fig. 5 Transmittance characteristics of ITO thin films of different thickness.

All these films present interferential behaviour. We applied the films with the sheet resistance of 36 kΩ/sq for preparation the emitters in the photovoltaic structures. All these films have good transmittance in the visual spectrum. The I-V characteristics were measured using a variable load resistor. The load resistance was varied in the interval from 1 Ω up to 900 Ω. Figure 6 and 7 present I-V characteristics measured for samples with two different structures: (a) Al/ITO/Si/Al and (b) Al/ITO/Au/Si/Al. The P-V characteristics were calculated on the base of measured I-V characteristics.

As shown in figures 6 and 7, the generated power in the structure with embedded gold interlayer is in 10 times more than in the structure without it. In the samples with gold interlayer, the metal islands form different types of contact with emitter and base of the P/N structure.

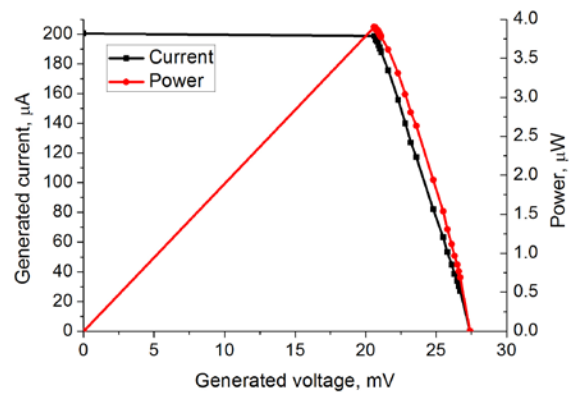

Fig. 6 I-V and PV characteristics of the Al/ITO/Si/Al photovoltaic structure.

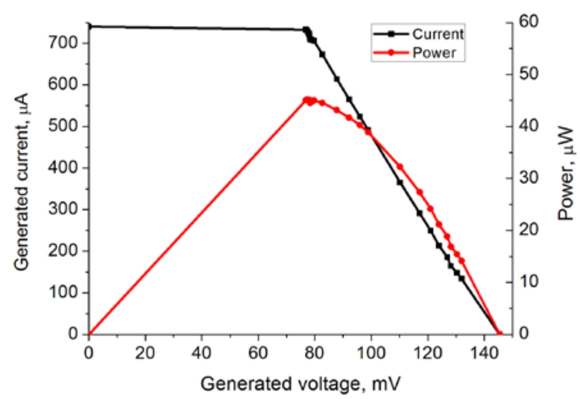

Fig. 7 I-V and PV characteristics of the Al/ITO/Au/Si/Al photovoltaic structure.

As known, the type of contact depends on the type of semiconductor, P or N, and the difference between the work functions between contacting materials [10]. The work function of the gold is higher than the work function

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of the ITO. Therefore, the gold islands create Schottky contacts with the emitter and Ohmic contacts with the base of the diode P/N structure. At the same time, a natural high-strength electrical field is built-in in this P/N junction and our Schottky nano-diodes are undergo high electrical field. On the other hand, a light irradiation of the grown thin-film gold islands generates localized SPR inside the gold particles in the visible range of light. Under the built-in electrical field, the directly biased nano-diodes Schottky emit their excited additional electrons in the conducting band and the holes in the valence band of the P/N structure. This way, we obtain a significant increase in the short-circuit current and open circuit voltage of the device.

We tried illustrating this increasing by using the schematic energy band diagram. To create this diagram, we parameters of applied materials shown in the table 1. Here are the reference data and our measured and calculated results.

Table 1.

Parameter	C-Si	Au	ITO	Source
Work function, φ, eV		5.47	4.7	[11] [12]
Mobility, μ, $cm^2/V{\cdot}s$	410		50	[1] [13]
Bandgap, Eg, eV	1.12		3.75	[1] [14]
Relative permittivity, ε_r	11.9		3.95	[1] [14]
Electron affinity, χ, eV	4.05			[15]
Film thickness, d, nm		~2	~200	*
Sheet resistance, Ω/sq		1.25M	36k	*
Charge carrier concentration, n/p, cm^{-3}	$2.5{\cdot}10^{15}$	$5.9{\cdot}10^{22}$	$1.7{\cdot}10^{17}$	**
Depletion width, w, nm	41		570	***

* Our measurements;

** Calculation, $n = \frac{1}{q\mu\rho}, cm^{-3}$;

*** Calculation, $w = \sqrt{\frac{2\varepsilon_0\varepsilon_r V_0}{qN_A}}$, cm.

Figure 8 represents the schematic energy diagram built using electrical and optical properties of deposited gold and ITO thin films. Calculation of a built-in potential, V0Si, on the junction Si-Au and V0ITO on the junction Au-In2O3 were provided by the same way as it was done by E.M. Nasir [6].

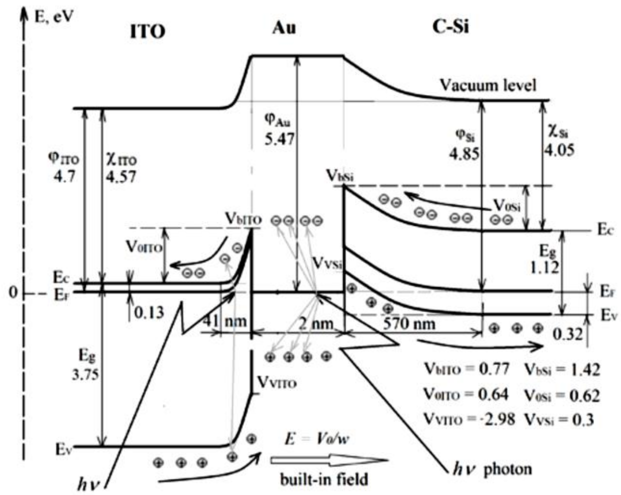

Fig. 8 A schematic energy diagram for the experimental PV cell.

This diagram illustrates the behaviour of p-n heterojunction with embedded gold island film under illumination. As it was mentioned above, the metal (gold) particle with a work function greater than the work function of the emitter ITO layer of n-type and greater than that of p-type base crystalline Si is embedded inside the depletion region with width w. This width is a sum of depletion regions in the ITO-Au contact and in the Au-Si contact: w = wSi + wITO. Therefore, it forms a Schottky contact with the emitter ITO layer and an Ohmic contact with the base (p-type silicon). This particle is subjected to a strong electric field E = Vb/w produced by the built-in potential, Vb, in the depletion region. Thus, all the gold particles form a set of forward-biased nano-diodes Schottky.

Under solar light irradiation, hv, we are seeing two mechanisms of absorption: first one is a usual absorption of the photon in the active part of the solar cell producing one pair electron-hole, second mechanism is an absorption by the gold particle producing localized SPR in gold particles. Excited electrons from the metal particles-islets are injected into the conducting band of the semiconductor due to the resonance energy exceeding the Schottky barrier. These additional electrons will be collected by emitter electrode of the PV cell, thus increase the load current. So, each photon absorbed by the gold particle produces a group of charged carriers due to polarization of the gold and injects them into the conductive (electrons) and valence (holes) bands of the ITO and silicon. Therefore, we obtain the amplification effect or the photon amplifier generating additional charged carriers utilized in the grown structure. Parallel connection of a plurality of nano-diodes Schottky to the silicon p-n junction leads to increase in the voltage generated by the system Using the additional charged carriers generated within the gold particles and injected into the semiconductor environment, we can increase the useful electricity.

It is of interest to compare influence of different metals on the PV cell efficiency.

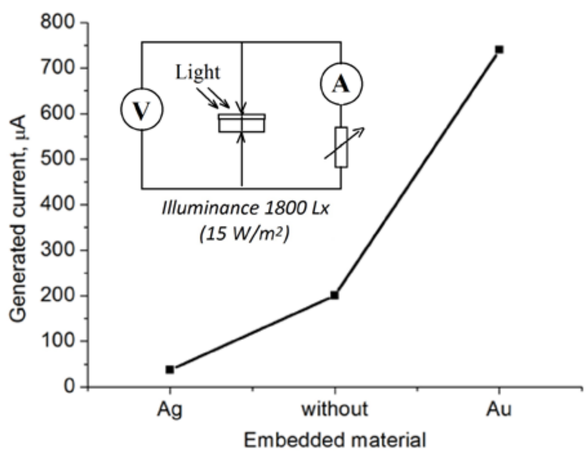

Fig. 9 Comparison of the short-circuit current in different PV structures.

Figure 9 presents measured short-circuit currents for different PV structures. Here, we compare three different structures: the system with embedded silver island film, the system without an interlayer, and the system with the gold interlayer. Insert in figure 3 illustrates a principal measuring scheme. Firstly, we measured a short-circuit current and an open-circuit voltage generated by grown PV-systems under the same illumination. After that, we measured I-V characteristics by change of loading resistance. As shown in figure 9, the silver layer prevents to the spread of the generated charged carriers and promotes their rapid recombination. We explain this effect by the formation of Ohmic contact between the silver particles and ITO emitter.

4. CONCLUSION

In this paper, we likely looked into the effect of kind of interlayer island metal films introduced into the P/N crossing point on the properties of PV structures. It was exhibited that non-predictable thin motion pictures continued using sputtering in the triode structure understanding the plane plasma arrival of low weight show up the surface plasmon resonation lead under lighting up at light of unmistakable range. The sort of metal films portrays a photovoltaic structure direct. The gold island film organized by the triode sputtering and introduced into the P/N convergence of the photovoltaic structure has appeared to be gigantic addition in the PV cell profitability.

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