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 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 nm^2. Silver island films look the same.

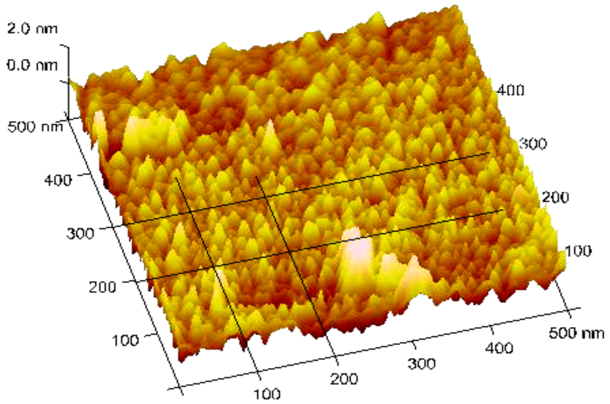

Fig. 4 AFM image of the gold film of 2 nm thick on the glass substrate.

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

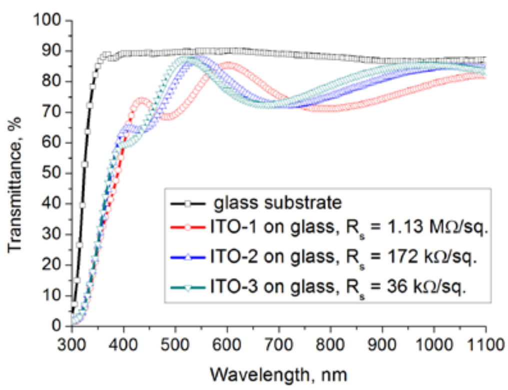

Fig. 5 Transmittance characteristics of ITO thin films of different thickness.

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.

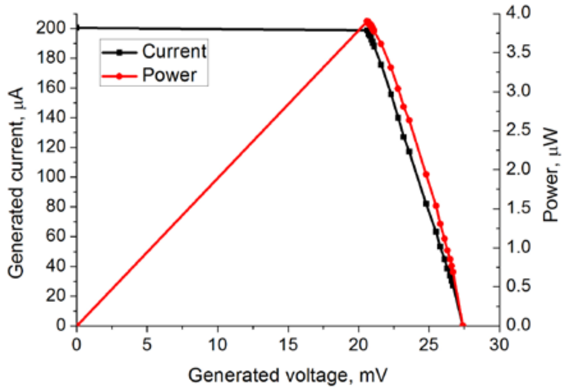

Fig. 6 I-V and PV characteristics of the Al/ITO/Si/Al photovoltaic structure.

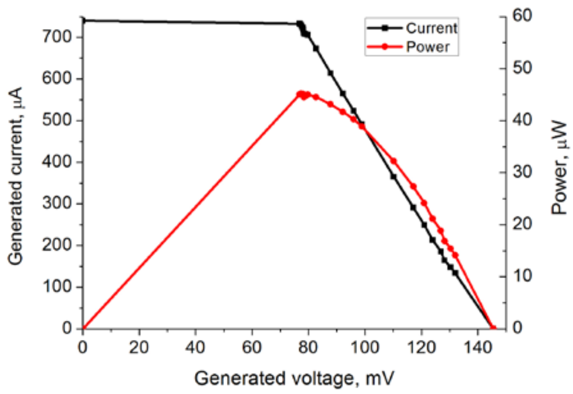

Fig. 7 I-V and PV characteristics of the Al/ITO/Au/Si/Al photovoltaic structure.

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 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 illustrate 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, $w = \sqrt{\frac{2\varepsilon_0 \varepsilon_r V_0}{q N_A}}$, 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, V_{0Si}, on the junction Si-Au and V_{0ITO} on the junction Au-In_2O_3 were provided by the same way as it was done by E.M. Nasir [6].

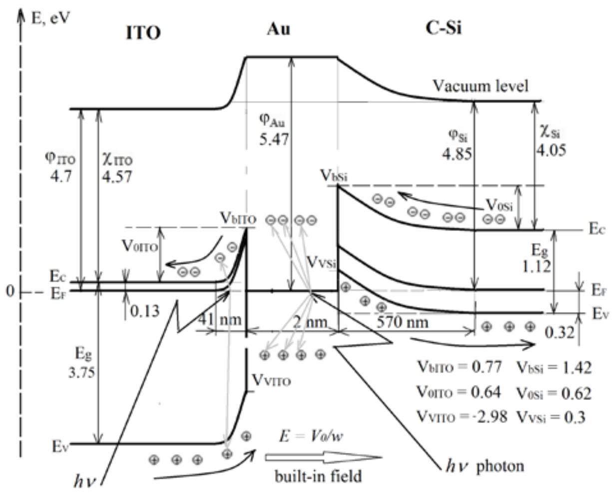

Fig. 8 A schematic energy diagram for the experimental PV cell.

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: $w = w_{Si} + w_{ITO}$. 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 $E = V_b/w$ produced by the built-in potential, V_b, in the depletion region. Thus, all the gold particles form a set of forward-biased nano-diodes Schottky.

Under solar light irradiation, *hv*, we 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.

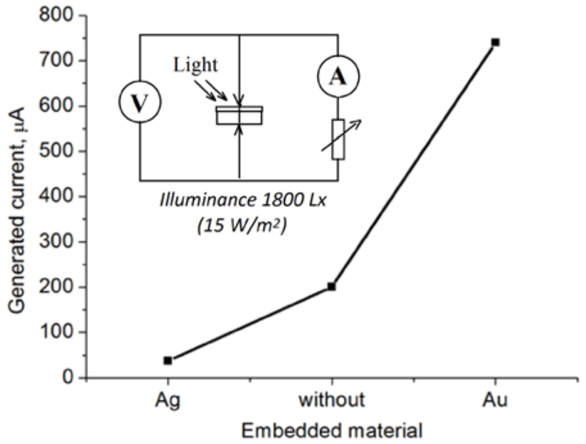

Fig. 9 Comparison of the short-circuit current in different PV structures.

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 experimentally investigated the effect of type of interlayer island metal films embedded into the P/N junction on the properties of PV structures. It was shown that non-continuous thin films deposited using sputtering in the triode system realizing the plane plasma discharge of low pressure appear the surface plasmon resonance behavior under illumination at light of visible spectrum. The type of metal films defines a photovoltaic structure behavior. The gold island film prepared by the triode sputtering and embedded into the P/N junction of the photovoltaic structure has appeared significant increase in the PV cell efficiency.

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