# INVESTIGATION OF ELECTRICAL AND PHOTOELECTRICAL PROPERTIES OF ITO-nSi STRUCTURES

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**ABSTRACT**: ITO-nSi solar cells have been obtained by deposition of ITO layers using spray pyrolisis technique onto the surface of nSi wafers with the area up to 48.6*cm*$^2$. The study of current-voltage and capacitance-voltage characteristics indicates that they are abrupt SIS heterostructures with a tunnel transparent $SiO_2$ insulator layer at the ITO-nSi interface. Solar cells with active area up to 48,6*cm*$^2$ have been fabricated. Their quantum efficiency reaches 0,97 at λ=550*nm*. The viability of the developed technology was demonstrated by the fabrication of a number of PV modules composed from 36 solar cells with the output power of 15*W*.

**Keywords**: Silicon, TCO Transparent Conducting Oxides, solar cells.

## 1. INTRODUCTION

Crystalline silicon solar cells currently comprise around 90% of the photovoltaic devices production. By improving known semiconductor processes solar cell costs and performances have improved steadily over the last years. One of the ways of lowering the solar cell cost is the fabrication of solar cells on the base of semiconductor-insulator-semiconductor (SIS) structures obtained by deposition of transparent conductive oxide (TCO) films onto different crystal substrates [1-4].

The aim of these communications is the investigation of electrical and photoelectrical properties of SIS structures on the base of nSi wafers with enlarged area up to 48.6cm$^2$.

## 2. EXPERIMENTAL

The ITO layers are deposited on the nSi crystals surface by spraying of alcoholic solution of $InCl_3$ and $SnCl_4$ in different proportions using the special designed installation which contains four main units: the pulverization system, the system of displacement and rotation of the support on which the substrate is fixed, the system of heating the substrate and the system of the evacuation of the residual products of the pyrolise. The heating system consists of an electric furnace and a device for automatic regulation of the substrate temperature [5].

The alcoholic solution of $InCl_3$ and $SnCl_4$ is pulverized with the aid of compressed oxygen on the silicon wafer substrate where is formed the TCO film composed from the mixture of $SnO_2$ and $In_2O_3$ (ITO). $SiO_2$ insulator films with the thickness from 30*Å* to 100*Å* were obtained on the silicon wafer substrates by different methods: anodic, thermal, or chemical oxidation. The best results have been obtained at the utilization of the two last methods. Ellipsometrical measurement showed that the thickness of the $SiO_2$ insulator layer varies from 30*Å* to 100*Å*.

In our experiments for the fabrication of SIS structures nSi wafers oriented in the (100) plane with different electron concentration from $1\cdot10^{15}cm^{-3}$ up to $6\cdot10^{16}cm^{-3}$ were used as substrates. The ohmic contacts have been obtained by evaporation in vacuum Cu+Sn for the back contact and Al grid for the frontal one.

ITO-$SiO_2$-nSi solar cells with active area of 8.1$cm^2$ and 48.6$cm^2$ have been fabricated.

## 3. RESULTS

The properties of the obtained in this way ITO films depend on the concentration of indium chloride and tin chloride in the solution, the temperature of the substrate, the time of spraying and the deposition speed. ITO films with maximum conductivity ($4.7\text{x}10^3 Ohm^{-1}\cdot cm^{-1}$) and maximum transmission coefficient in the visible range of the spectrum (87%) were obtained from solutions containing 90% InCl3 and 10% $SnCl_4$ and under following condition: substrate temperature 450°*C*, deposition rate 100*Å/s*, spraying time 45*s*.

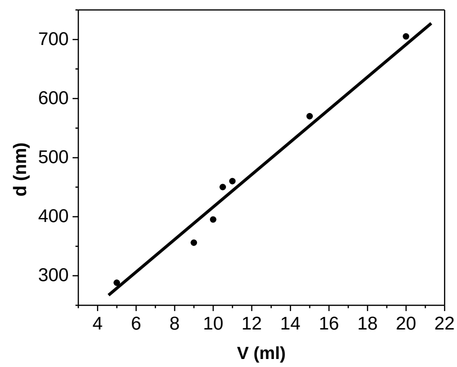


*Fig. 1. Thickness of ITO layers in dependence of the quantity of pulverized solution*

The thickness of ITO layers in dependence of the quantity of pulverized solution has been evaluated from the spectral distribution of the light reflection coefficient from the surface of the deposited layers [5]. In Fig. 1 is presented the dependence of the ITO layer thickness in dependence on the quantity of pulverized solution. It is seen that this relation is linear and the layer thickness varies from 0.3$\mu m$ up to 0.7$\mu m$. The ITO thickness value of 0.35$\mu m$ was chosen for the solar cell fabrication.

The obtained in such a way structures represent asymmetrical doped barrier structures in which the wide band gap oxide semiconductor play the role of transparent metal. Therefore these structures may be considered as Schottky diodes with a thin insulating $SiO_2$ layer at the interface.

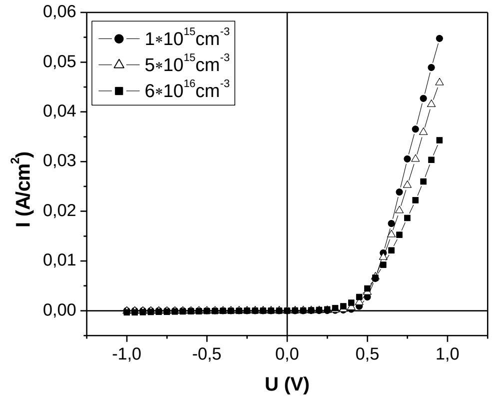


*Fig. 2. The dark I-U characteristics of the ITO-nSi structures for diverse values of electron concentration*

*Table 1.*

| n ($cm^{-3}$) | A | $U_d$ ($V$) | $I_s$ ($A/cm^2$) |
|---|---|---|---|
| $1 \cdot 10^{15}$ | 2 | 0.46 | $1{,}2 \cdot 10^{-6}$ |
| $5 \cdot 10^{15}$ | 2 | 0.5 | $4 \cdot 10^{-6}$ |
| $6 \cdot 10^{16}$ | 2 | 0.5 | $2 \cdot 10^{-5}$ |

The electrical and photoelectrical properties of the ITO-nSi structures have studied in dependence of the electron concentration in the nSi wafers. The dark I-U characteristics of the ITO-nSi structures are presented in Fig. 2. These curves could be described by the usual relation for barrier structures:

$$I = I_S \left\{ \exp\left( \frac{qU}{AkT} \right) - 1 \right\}$$

The values of the diode factor $A$, saturation current $I_s$ and diffusion potential $U_d$ in dependence on the electron concentration in Si wafers are presented in Table 1.

The same values for $U_d$ were also obtained from the C-U characteristics. These results indicate that the obtained ITO-nSi samples are abrupt SIS heterostructures.

The spectral distributions of the quantum efficiency Q of the obtained PV cells have been studied and it is presented in Fig 3. It is seen that in the region of wavelengths from 400 to 870*nm* the value of $\eta$ changes on the limits 0.6-0.97.

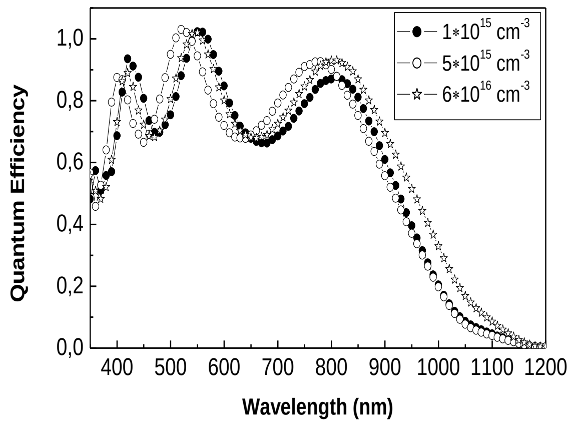


*Fig. 3. spectral distribution of the quantum efficiency of the ITO-nSi solar cells*

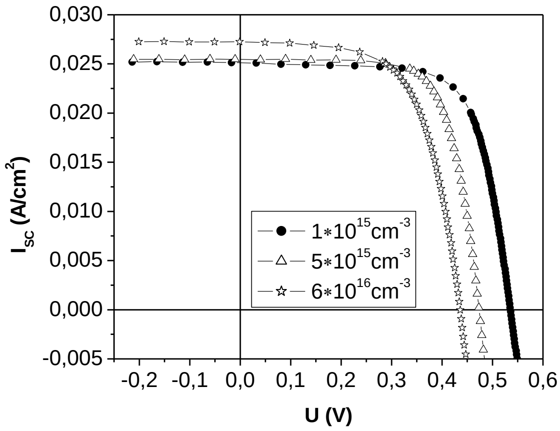


*Fig. 4 Load I-U characteristics of the ITO-nSi solar cells with active area of 8,1cm²*

The obtained ITO-nSi structures were used for the fabrication of photovoltaic converters with the area of 8,1*cm*$^2$ and 48,6*cm*$^2$. The load I-U characteristics for solar cells with active area of 8,1*cm*$^2$ at the AM1.5 illumination conditions are presented in Fig. 4. The respective photoelectrical parameters are summarized in Table 2.

*Table 2.*

| $N_d$ în Si *(cm$^{-3}$)* | $I_{sc}$ *(mA/cm$^2$)* | $U_{cd}$ *(V)* | FF *(%)* | $R_{ser}$ *(Ohm·cm$^2$)* | $R_{sh}$ *(Ohm·cm$^2$)* | $E_{ff}$ *(%)* |
|---|---|---|---|---|---|---|
| $1\cdot10^{15}$ | 25,11 | 0,536 | 71,14 | 2,573 | 0,120E4 | 9,567 |
| $5\cdot10^{15}$ | 25,45 | 0,473 | 71,26 | 2,185 | 1,667E3 | 8,588 |
| $6\cdot10^{16}$ | 27,25 | 0,436 | 63,29 | 2,335 | 1,239E3 | 7,518 |

The efficiency of solar cells with the area of 48,6*cm*$^2$ is 6,979%. The viability of the developed technology for the solar cells obtaining in laboratory conditions was demonstrated by fabrication of the PV modules each of them formed by 36 cells and possessing the active area of 1752*cm*$^2$ and the output power of 15*W*.

## CONCLUSIONS

ITO-nSi semiconductor – insulator – semiconductor structures have been produced with a simple spraying technique. The obtained in such a way structures may be considered as Schottky diodes with a thin insulating $SiO_2$ layer at the interface.

Solar cells on the base of ITO-nSi structures with active area of 8.1$cm^2$ and 48.6$cm^2$ have been fabricated and studied. Their quantum efficiency reaches 0.97 at $\lambda$=550*nm*. At the AM1.5 illumination conditions the efficiency is 9.567% for cells with area of 8.1$cm^2$ and 6.979% for cells with area 48.6$cm^2$. The optimal electron concentration in Si wafers used for the fabrication of solar cells is $(1\text{-}5)\cdot10^{15}cm^{-3}$.

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