MICROSTRUCTURE AND OPTICAL PROPERTIES OF ITO THIN FILMS INVESTIGATED FOR HEAT MIRRORS IN SOLAR COLLECTORS

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The aim of this work is preparation of RF sputtered ITO thin films for application as heat mirrors in solar thermal collectors. The alteration of optical properties and behavior in IR spectra of additionally treated films was investigated. The films were deposited on silicon and glass substrates by RF sputtering on vacuum installation A-400 VL. For deposition of films were used targets with composition indium-tin 90:10 and 95:5 mol%. The films microstructure was studied by TEM and SEM. Optical and electrical properties as well as microstructure of the films change considerably after heat treatment.

The measurements in IR range of as-deposited ITO layers and heat treated ones were performed by Fourier transform infrared spectrophotometer Shimadzu Prestige 21. The as-deposited ITO films showed 45% in the Infrared, and after annealing at 5000C additional treatment, the films showed reflection in IR range not exceeding 60% at longer wavelengths. The films have high visible transmition measured with CARY 5E – spectrophotometer.

Keywords: thin films, indium-tin oxide, IR properties, heat mirrors, solar energy conversion.

1. INTRODUCTION

ITO thin films have been studied extensively for optoelectronic device applications because of their unique transparent and conducting properties. ITO is a highly degenerated n-type wide band gap (3.3–4.3 eV) semiconductor with low electrical resistivity [1,3].

In many applications for effective use of solar energy the modern technology requires layers with high reflection in IR range and high transparency in the visible [4]. These coatings are usually deposited on the inside surface of the frontal window of solar collector and in combination with non-selective absorber this represents equivalent circuit of one selective absorber [5]. Expect for photothermal conversion the heat mirrors are widely used in modern buildings as low-emissive glass windows.

The heat mirrors have high transmitance in the solar spectrum (0.3-2.5 μm) [6]. The investigation carried out confirms the relationship in the modern Materials Science between the composition, technological parameters and additional treatment, and microstructure and properties of the materials. The study tries to explain the obtained experimental results and to finds the trends for improving them.

The purpose of this work is to obtain ITO thin films with high transparency in the visible (0.3-2.4 μm) and high reflection in the Infrared range (2.5-15 μm). We investigated the correlation of the films structure and optical properties of ITO thin films with the technological process parameters-target composition and annealing temperature.

2. EXPERIMENTAL

For deposition of ITO films the RF sputtering vacuum installation A-400 VL Leybold was used. The influence of technological factors as oxygen pressure, time of deposition and electrical parameters of the sputtering process were studied and strictly controlled. Two type targets with 90:10 and 95:5 mol % (In:Sn) were used. The films were deposited on glass substrates at room temperature. In our research the as-deposited amorphous ITO films were subjected to various annealing temperatures to obtain various degrees of the amorphous and crystalline phases of the ITO films.

The microstructure of the films was studied by TEM and selected area electron diffraction (SAED) using TEM-400, Philips transmission electron microscope. The surface of the layers was investigated by SEM. The substrates for RF sputtering deposition of non-annealed thin film samples for direct TEM observations were fresh fractured surfaces of NaCl crystals.

To identify the optical properties of films the methods of UV-VIS and IR spectrometry were used. The measurements in the Infrared of as-deposited ITO layers and heat treated ones were performed by Fourier transform infrared spectrophotometer Shimadzu Prestige 25. The transmitance in the visible range was measured with CARY 5E spectrophotometer.

3. RESULTS AND DISCUSSION

As it is seen in Fig.1a the TEM micrographs and SAED patterns show the initial amorphous structure of the investigated layer.

After "in situ" heat treatment of the films by electron beam in the microscope, where the temperature arises up to 270 – 300 °C, structural evolution was observed and the formation of separated nano- and microcrystals (Fig. 1b) is followed by the appearance of polycrystalline structure (Fig. 1c).

As-deposited films have predominantly amorphous structure. After heat treatment at 250 °C and higher, the structure of ITO films was changed, a polycrystalline structure was observed.

The microstructure is strongly connected with the electrophysical properties of the films. It was established that the annealing of the ITO films influences their electrical and optical properties.

The transmitance and reflection in visible and near IR of as-deposited and heat treated films with different concentration of dopand (Sn) are showed on figures (2,3).

The investigated films have low sheet resistance (25Ω/□ for 90:10mol % and 20Ω/□ for 95:5mol %). After heat treatment at 500 °C the sheet resistance of samples decreases, (20Ω/□ for 90:10mol % and 17Ω/□ for 95:5mol % respectively). Similar results by other scientists, working with different targets and technologies of deposition and heat treatment at 600 °C were obtained [2,7]. Our results and the studied literature, show that the electrical parameters of ITO films can to be improved by using different dopands and treating methods of films.

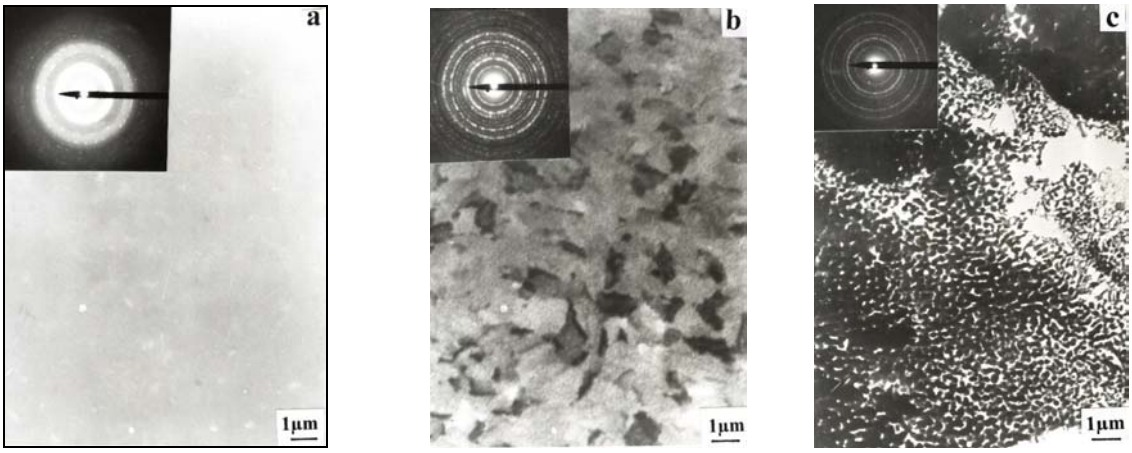

Fig. 1. TEM micrographs and SAED patterns of thin ITO films:
a) amorphous structure before "in situ" electron beam heating;
b) separated nano- and microcrystals obtained after the first steps of "in situ" electron beam heating;
c) polycrystalline structure due to longer "in situ" electron beam heating of the film.

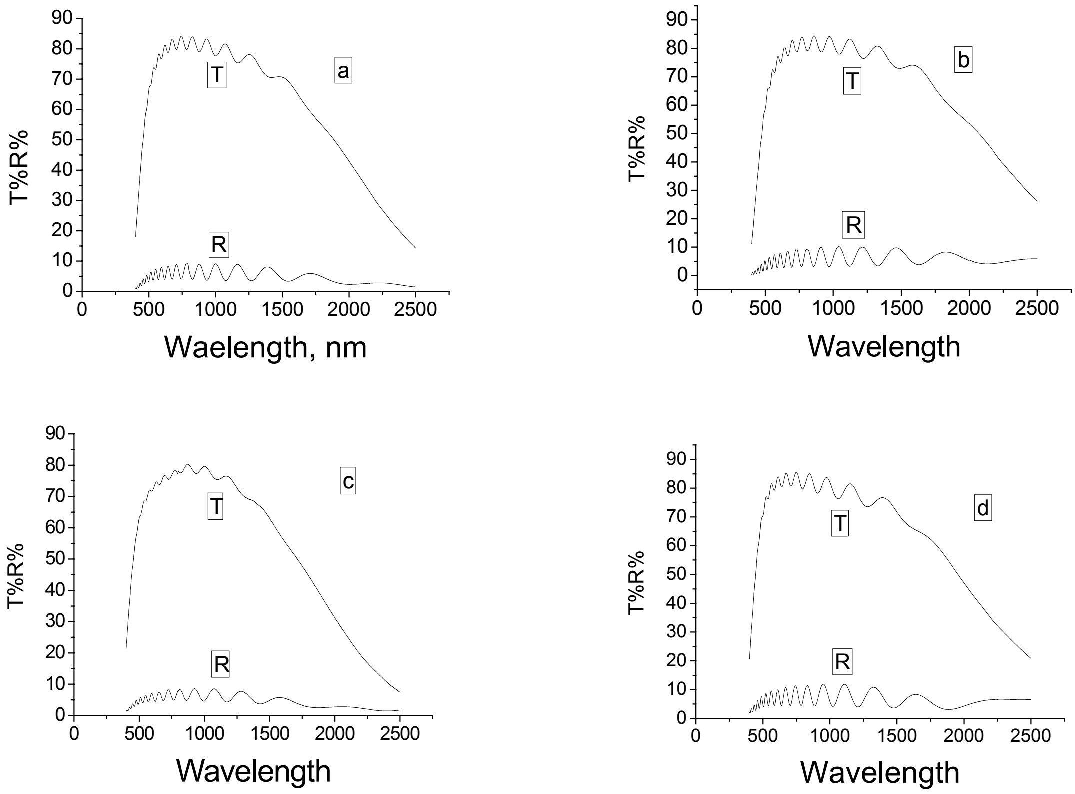

Fig.2. Transmition and reflection in visible and near IR range.
a) as-deposition 90:10 mol % film;
b) heat treated at 500 °C 90:10 mol % film;
c) as-deposition 95:5 mol % film;
d) heat treated at 500 °C 95:5 mol % film.

Fig. 2 shows that all investigated films independently of their dopands and their microstructure have high transparency in the visible range. But all efforts were directed to obtaining layers with high reflection in the infrared. The infrared reflectance of the investigated layers showed strong dependence on the content of dopands and on the microstructure of the films.

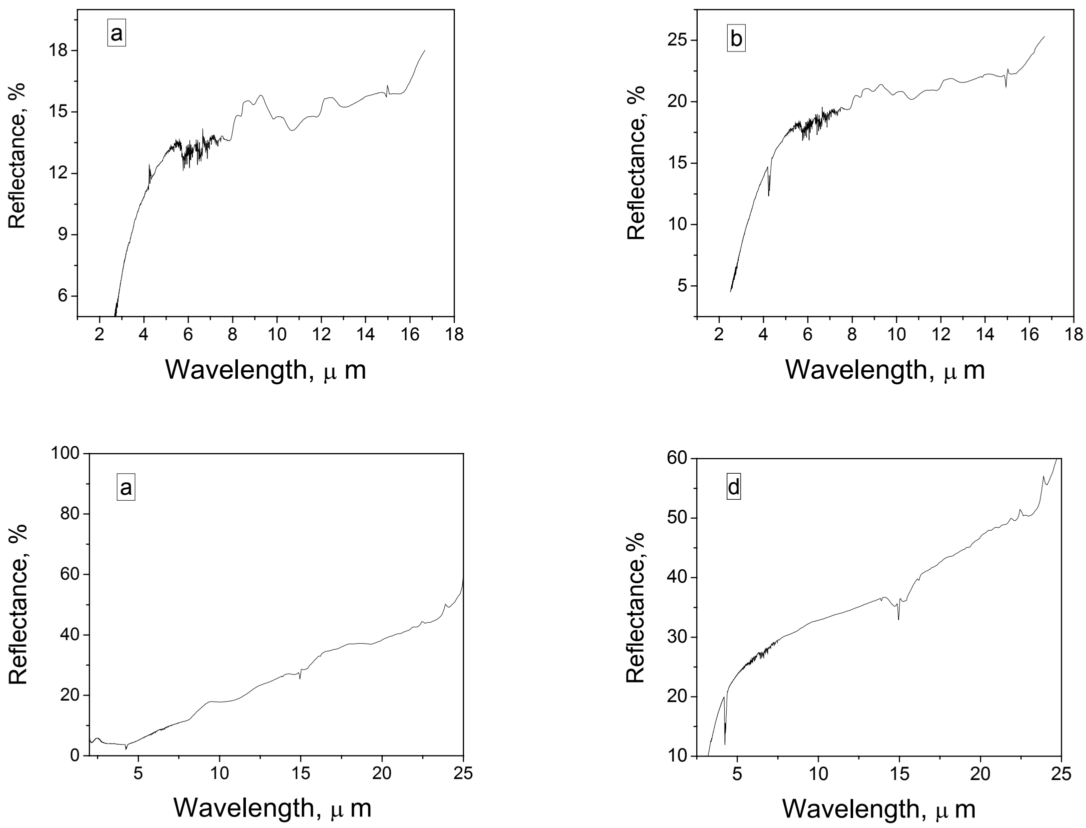

Fig.3. Reflection in IR range:
a) as-deposition 90:10 mol % film;
b) heat treated at 500 °C 90:10 mol % film;
c) as-deposition 95:5 mol % film;
d) heat treated at 500 °C 95:5 mol % film

Fig. 3 shows that the obtained ITO films by target with composition 90:10 mol% (In:Sn) have low reflection in the IR range. All films were processed by heat-treatment with different temperatures. The films with composition 95:5 mol% (In:Sn) display dependence on heat-treatment at 500 °C. With that composition the reflection in IR range reached 60 % for the longer wavelengths.

4. Conclusion

ITO films with increased reflection in the infrared were sputtered employing target 95:5 mol % and low sheet resistance. The obtained ITO thin films have high transparency in the visible, exceeding 80%. According to these optical and electrical parameters, films after proper optimization could find broad application in photothermal converters, display technique, etc.

5. REFERENCES

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