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Infrared and conductive properties of TCO films deposited by magnetron sputtering at different temperatures

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Abstract. Low-emissive Transparent Conductive Oxide (TCO) coatings, such as Indium Tin Oxide (ITO) films, can be used to reduce radiative losses that affect Hybrid photovoltaic-thermal (PV-T) devices. This work shows the optical properties of ITO deposited by magnetron sputtering on a glass substrate with and without thermal heat treatment at different temperatures. All the analyses conducted include UV-VIS and infrared regions, up to 20 µm.

1 Introduction

Solar energy has immense potential for meeting global thermal and electrical energy demands [1]. Hybrid photovoltaic-thermal (PV-T) devices, insulated by a high vacuum envelope, have emerged as a promising solution to address these challenges. When properly designed, these devices can harness solar radiation across the entire solar spectrum (0.2 to 2.5 µm) and simultaneously generate heat and electricity, maximizing energy yield per unit area. Low-emissive Transparent Conductive Oxide (TCO) coatings, such as Indium Tin Oxide (ITO) films, have to be developed and employed to exploit the advantages of high vacuum insulation fully [2]. The lowest thermal emittance value achieved to date (ε=0.21) was obtained using ITO film [3]. However, thermal emittance values lower than 0.21 are desirable to reduce the thermal radiation losses and increase the total energy production. The high vacuum PV-T is expected to provide up to two times the revenue and carbon savings compared to current commercial solution.

A novel hybrid flat plate photovoltaic-thermal collector under high-vacuum (HVPV-T) was modeled in MATLAB [4] to investigate its performance to satisfy the huge thermal energy demand of industry at temperatures around 100°C. up to 120 °C while generating additional electrical energy. The results indicate that the HVPV-T can be more efficient and it require less collector areas respect to the stand alone solution already with a thermal emittance of 0.21. However, the thermal energy production of the proposed HVPV-T system can be dramatically improved by reducing the thermal emittance of the TCO layer.

This study explores the relationship between the optical and conductive properties of ITO films and their dependence on coating conditions, and thermal treatments. All the analyses conducted include UV-VIS and infrared region, up to 20 µm, filling the current gap in the literature, which limits the optical analysis to 1.5 µm or less [5], since the main interest so far has been photovoltaic conversion.

2 Preliminary results

ITO films were deposited on a glass substrate by magnetron sputtering using Argon as sputtering gas and in the presence of an oxygen flux. The sputtering system is equipped with four sputtering cathodes (two DC and two RF) and the four sample holders supported by a rotating disc that allows to place the holder under the desired target position.

The deposited films are comprehensively characterized in terms of transport and optical properties. The refractive indices were measured up to 1.7 µm by ellipsometric measurement, whereas the transmissivity and reflectivity were measured up to 25 µm at different points to control the film uniformity.

It is well known that heating the thermal treatment and/or deposition at high temperatures may improve the transparency and conductivity of ITO films. The sample was therefore divided into four parts, three of which underwent a heat treatment at different temperatures for 1 hour under vacuum: T_1 = 250 °C, T_2 = 300 °C, and T_3 = 350 °C. Figure 1 presents the results for the sample without and with thermal treatments, including the reflectivity and transmissivity spectra from the UV to the MIR regions. From this data can be extracted the absorptivity spectrum reported in Figure 2. Since at

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thermal equilibrium absorptivity and emissivity are equal the thermal treatments result in a lower emissivity, which in turn correspond to a lower thermal emittance (that is computed as spectrally averaged emissivity in the range from 2.5-25 μm).

Similar or better results can be achieved by depositing the TCO film on a substrate heated at high temperatures. The sample holder temperature is controlled by a PID regulation of halogen lamps placed under the sample holder. The sample holder is made of copper bulk which is a high reflective, low emittance material: to enhance the heating of the plate by absorbing the radiated power of the halogen lamps, a multilayer thin film selective absorber ($Cr_2O_3/Cr/Cr_2O_3$) [6] was deposited on the side facing the lamp. The selective coating allows to absorb the radiation emitted by the lamps keeping the thermal emittance below 0.1, minimizing the thermal power radiated by the sample holder. Such scheme allows the sample holders to reach high temperatures with a minimal thermal load and keeps the holders free to rotate.

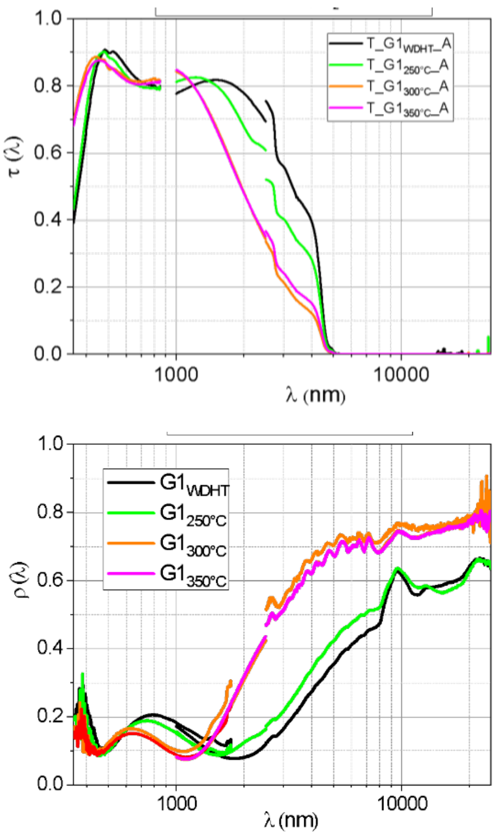

Fig. 1. Reflectivity (top), transmissivity (bottom), spectra from UV to MID IR region of a sample with different treatments.

These quantities, eventually integrated on the proper wavelength region, and the measured refractive index, provide the data required to calculate the optical and thermal efficiency of the PV-T cell, enabling its optimitations.

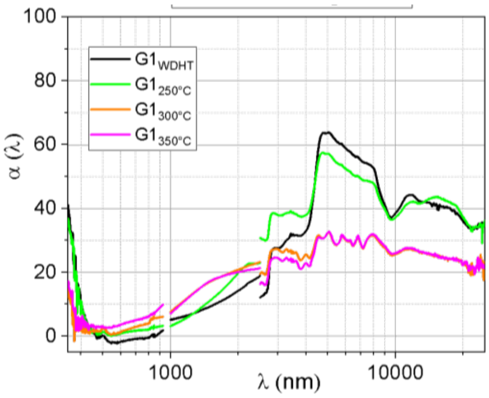

Fig. 2. Absorptivity/emissivity spectra from UV to MID IR region of a sample with different thermal treatments.

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