Photoacoustic Properties of Thin Film Zinc-Stannate

T. Ivecić1a, M. V. Nikolić2b, D. L. Young3c, D. Vasilijević-Radović4d, D. Urošević5e

1Institute of Technical Sciences of SASA, Knez Mihailova 35, 11000 Beograd, Serbia and Montenegro
2Center for Multidisciplinary Studies of the University of Belgrade, Kneza Višeslava 1, 11000 Beograd, Serbia and Montenegro
3National Renewable Energy Laboratory, Golden, Colorado 80401, USA
4Institute of Microelectronics and Single Crystals, Njegoševa 12, 11000 Beograd, Serbia and Montenegro
5Mathematical Institute, SASA, Knez Mihailova 35, 11000 Beograd, Serbia and Montenegro

tamara@itn.sanu.ac.yu, maria@itn.sanu.ac.yu, david_young@nrel.gov, dana@nanosys.lthm.bg.ac.yu
draganu@uring.mi.sanu.ac.yu

Abstract. Thin films of single-phase zinc-stannate (Zn$_2$SnO$_4$) were grown by rf magnetron sputtering onto glass substrates. Transmission in the visible range was measured allowing determination of the energy gap and thickness of analyzed thin film samples using interference fringes. The photoacoustic phase and amplitude spectra of all samples were measured as a function of the laser beam modulating frequency using a transmission detection configuration. Fitting of experimental data enabled calculation of thermal diffusivity, the coefficient of minority carrier diffusion, their mobility and lifetime.

Fig. 1 XRD pattern of a typical Zn$_2$SnO$_4$ thin film sample after annealing. Transmission results of a typical Zn$_2$SnO$_4$ thin film sample after annealing are given in fig. 3. Film thickness and index of refraction were calculated using the interference fringes observed on fig. 3. The refractive index of the thin film was first calculated using the following equation [1]:

$$n_r^2 = (n_i^2 + n_m^2)/2 + 2 nr_n n_m T_{max} - T_{min}/n_i^2$$

where $n_i$ is the refractive index of air, $n_m$ is the refractive index of glass and $n_r$ is the refractive index of the film,

$$T_{max} = T_{min}/2$$

where $T_{max}$ and $T_{min}$ are the maximum and minimum of the transmittance versus the wavelength given in fig. 3.

Fig. 2 AFM image of a Zn$_2$SnO$_4$ thin film 600 nm thick a) plan-view, b) 2D.

The value obtained for the refractive index was $n_r = 3.4$. The film thickness for each sample was calculated using the value obtained for the refractive index and the classical equation for interference fringes:

$$2nd = m\lambda$$

where $d$ is the film thickness, $m$ is the fringe order and $\lambda$ is the wavelength. The values obtained were in the range of 316-600 nm (the sample given in fig. 3).

The direct band gap for each sample was calculated from the absorption edge. It lead to be 0.325 eV for the sample 600 nm thick (fig. 3). The energy gap was calculated to be: $E_0 = 2E_0 \lambda = 3.181$ eV. The values obtained for two film thicknesses are given in table 1. It is well known that the optical direct energy gap for Zn$_2$SnO$_4$ is about 3.35 eV. In our case the higher value of the energy gap is the consequence of a strong Burstein-Moss shift. The free carrier concentration of a sample with a film thickness of 643 nm was determined in [2] as $3.3 \times 10^{20}$ cm$^{-3}$, so we expect this value to be higher for the thinner film with a higher energy gap.

The results obtained for the mobility and carrier mobility for two different film thicknesses are given in table 1. One can see that mobility was slightly higher for the thinner film. Both obtained values are in accordance with the ones calculated in [2] for different film thicknesses using the four-coefficient method for determining transport properties and the transport theory. Low mobility values and carrier concentrations are responsible for the high resistivities of Zn$_2$SnO$_4$ films. According to [2] incomplete crystallization of thin-film samples reflected in a larger full width at half maximum of XRD intensity peaks of thin films compared to the bulk spotty target could account for low mobility values. Minority carrier mobility is a parameter whose values could be useful for characterizing solar cell materials, as the minority carriers in characterizing solar cell materials, as the minority carriers in

Table 1 Calculated parameters for Zn$_2$SnO$_4$ thin films

<table>
<thead>
<tr>
<th>Sample thickness</th>
<th>$D_1$ (m$^2$/s)</th>
<th>$D$ (m$^2$/s)</th>
<th>$\alpha$ (m$^2$/s)</th>
<th>$\sigma$ (m$^2$/s)</th>
<th>$\rho$ (cm$^2$/Vs)</th>
<th>$E_0$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 nm</td>
<td>0.1 $\times 10^{-5}$</td>
<td>0.50 $\times 10^{-10}$</td>
<td>4 $\times 10^{-2}$</td>
<td>682</td>
<td>0.2 $\times 10^9$</td>
<td>0.5 $\times 10^{-10}$</td>
</tr>
<tr>
<td>316 nm</td>
<td>0.1 $\times 10^{-5}$</td>
<td>0.63 $\times 10^{-10}$</td>
<td>2.10 $\times 10^{-2}$</td>
<td>1195</td>
<td>0.5 $\times 10^9$</td>
<td>0.2 $\times 10^{-10}$</td>
</tr>
</tbody>
</table>

The obtained values for the mobility and carrier mobility for two different film thicknesses are given in table 1. One can see that mobility was slightly higher for the thinner film. Both obtained values are in accordance with the ones calculated in [2] for different film thicknesses using the four-coefficient method for determining transport properties and the transport theory. Low mobility values and carrier concentrations are responsible for the high resistivities of Zn$_2$SnO$_4$ films. According to [2] incomplete crystallization of thin-film samples reflected in a larger full width at half maximum of XRD intensity peaks of thin films compared to the bulk spotty target could account for low mobility values. Minority carrier mobility is a parameter whose values could be useful for characterizing solar cell materials, as the minority carriers in absorber materials can be indicators of device performance.

References


Acknowledgements

The authors would like to express their gratitude to Prof. M. Nikolic for many helpful conversations and S. Dutic for the X-ray measurements. This research was performed within projects 1832 and 6150 financed by the Ministry of Science and Environmental Protection of the Republic of Serbia.