STRUCTURAL, OPTICAL, AND ELECTRICAL CHARACTERIZATION OF SOL-GEL PROCESSED SCREEN-PRINTED CdO:Li FILM**

Vipin Kumar*, Renu Kumari, Dhirendra K. Sharma, Kapil Sharma, Sweta Shukla, Akansha Agrwal

Department of Applied Sciences, KIET Group of Institutions, Delhi NCR Ghaziabad, India; e-mail: vipinkumar28@yahoo.co.in

Lithium (2 wt %)-doped cadmium oxide (CdO:Li) film was grown on a glass substrate via a sol-gel processed screen-printing set-up. Through X-ray diffraction, it was demonstrated that the CdO:Li film exhibits reflections from the (111), (200), (220), (311), and (222) CdO cubic phase planes. The SEM image showed irregularly shaped, interconnected, and agglomerated grains on the entire film. The optical diffuse reflection study revealed that the film has a direct transition of the band gap at 2.50 eV. The refractive index of the film varies with photon energy and gains maximum value (~2.3) at 1.5 eV. The electrical attributes of the film were inspected by Hall measurement. It was noticed that the film conveyed n-type conductivity with low resistivity of the order of 10^{-3} $\Omega \cdot cm$.

Keywords: *sol-gel screen-printing, band gap, refractive index, resistivity.*

СТРУКТУРНЫЕ, ОПТИЧЕСКИЕ И ЭЛЕКТРИЧЕСКИЕ ХАРАКТЕРИСТИКИ ЗОЛЬ-ГЕЛЬ ПЛЕНКИ CdO:Li, ИЗГОТОВЛЕННОЙ МЕТОДОМ ТРАФАРЕТНОЙ ПЕЧАТИ

V. Kumar*, R. Kumari, D. K. Sharma, K. Sharma, S. Shukla, A. Agrwal

УДК 539.216.2

Отделение прикладных наук группы институтов KIET, Дели, Газиабад, Индия; e-mail: vipinkumar28@yahoo.co.in

(Поступила 8 декабря 2021)

Пленка оксида кадмия (CdO:Li), легированного литием (2 мас.%), выращена на стеклянной подложке с помощью установки золь-гель трафаретной печати. Рентгенодифрактограмма пленки CdO:Li демонстрирует отражение от плоскостей (111), (200), (220), (311) и (222) кубической фазы CdO. СЭМ-изображения показывают, что пленка состоит из взаимосвязанных и агломерированных зерен неправильной формы. Из спектра диффузного отражения определен прямой переход запрещенной зоны при 2.50 эВ. Показатель преломления пленки изменяется с энергией фотонов и достигает максимального значения (~2.3) при 1.5 эВ. Методом Холла установлено, что пленка обладает проводимостью n-типа с низким удельным сопротивлением ~10^{-3} *Ом · см.*

Ключевые слова: *золь-гель трафаретная печать, ширина запрещенной зоны, показатель преломления, удельное сопротивление.*

Introduction. Thin films of transparent conducting oxides (TCOs) are important in optoelectronics because of their high transparency and excellent electrical conductivity. TCOs such as In_2O_3, SnO_2, ZnO, TiO_2, and CdO have recently been thoroughly investigated [1]. CdO is highly recognized among these TCOs owing to its unique combination of outstanding electrical conduction and optical transmission, which manifests itself in a variety of applications such as smart windows, flat panel displays, solar cells, and gas sensors [2]. CdO exhibits *n*-type conduction with its wide direct band gap of 2.2–2.8 eV [3].

**Full text is published in JAS V. 90, No. 1 (http://springer.com/journal/10812) and in electronic version of ZhPS V. 90, No. 1 (http://www.elibrary.ru/title_about.asp?id=7318; sales@elibrary.ru).

Doping with specific metal ions such as In, Al, Sn, and F one can tune the optical and electrical properties of CdO [4]. According to these reports, a rise in the band gap and electrical conductivity of CdO is possible by doping it with a dopant having a smaller ionic radius [5]. CdO thin films were deposited using a variety of deposition set-ups [2–5]. In this study, a 2 wt% Li-doped CdO film was deposited on a glass substrate using a novel sol-gel processed screen-printing set-up. The screen-printing procedure using sol-gel has numerous advantages over other methods. It is environmental-friendly, cost-effective, simple, and quick, and has the ability to coat a large surface area. In this procedure, the gel was prepared using a standard sol-gel process, and the prepared gel was then used for film deposition on a glass (clean) substrate using a screen-printing set-up. The deposited CdO:Li film was investigated for its electrical, optical, and structural properties toward its commercial applications. It should be mentioned here that the doping of lithium ions in CdO has been scarcely explored.

Experimental. Cadmium acetate dihydrate (98%) and 2 wt% lithium acetate dihydrate, taken as host precursor and dopant precursor respectively, were dissolved in 20 mL of the ethylene glycol solvent. Drop-by-drop monoethanolamine (MEA) was introduced to the solution. The obtained solution was stirred continuously at 80°C for 2 h. Further, the solution was retained under environmental conditions for 3 days. Before depositing the film, the substrate (glass) was cleaned via acetone and then dried for 10 min at room temperature. The gel thus formed was further used to deposit the film on a substrate (cleaned glass substrate) via a screen-printing set-up. After that, the substrate was dried using a hot plate at 100°C to evaporate the water content and the solvent. Finally, the film was sintered (fired) using a tube furnace at 500°C for 10 min to evaporate the undesired organic residuals. The thickness of the film (by the gravimetric method) was observed to be 3μm.

The structure of the Li doped CdO sample was characterized by an XRD (Rigaku ultima-IV) diffractometer. The surface morphology of the film was investigated via an (Oxford ZE155, EV018) scanning electron microscope. The optical features of the film were observed via a UV spectrophotometer within the wavelength region 300–800 nm. The electrical features of the film were probed via a Hall Effect (Ecopia, HMS-5000) set-up. The silver paste was used for making the metal electrodes on the film. The magnetic field strength was 0.55 Tesla.

Results and discussion. The phase conformation of the prepared CdO:Li film was governed by X-ray diffraction. Figure 1 exposes the XRD pattern of the CdO:Li film. It is apparent from Fig. 1 that the XRD pattern carries only five peaks matching with (111), (200), (220), (311), and (222) planes. These peaks communicate the cubic phase (JCPDS-card No. 05-0640) and the polycrystalline nature of CdO. No peaks were seen matching with lithium or lithium oxide in the pattern, which confirms the successful fusion of Li ions into the CdO lattice. The lattice constant (a) of the CdO:Li film evaluated from XRD data was 4.654 Å. The outcome of the lattice parameter was in good harmony with the previously detailed value of the lattice parameter [6]. To evaluate the average crystallite size (D), the Scherrer formula [7] was used. The average crystallite size evaluated was ~34 nm.

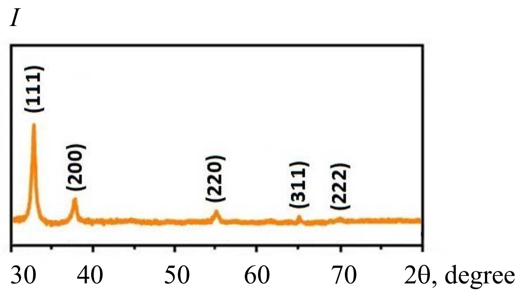

Fig. 1. X-ray diffraction of the 2 wt% Li-doped CdO film.

SEM is an excellent way toward the surface morphology characterization of the produced sample which conveys productive information concerned with the character and size of the grains (particle) on the surface of the sample. Figure 2 shows the scanning electron micrograph of the CdO:Li film. The image appears to be non-uniform on the surface, and the particles were within the nanometer scale. The grains were interconnected, irregularly shaped, and highly agglomerated on the whole film. As a result of the agglomeration of small grains, it is very complex to determine the exact grain size from SEM.

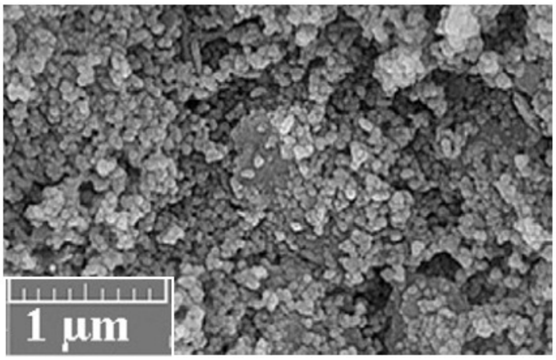

Fig. 2. SEM image of the 2 wt% Li-doped CdO film.

Tuning of the band gap has been of key importance in the development of modern devices. Optical characterization of CdO:Li film at room temperature was executed by diffuse reflectance. Figure 3 shows the diffuse reflection spectrum of the CdO:Li film, which exhibits a wide absorption band within the 400–550 nm range. Fundamental absorption communicates the excitation of electrons from the valence band to the conduction band, which can be employed to find out the band gap [8]. The band gap of the CdO:Li film can be estimated via the reflection spectra employing the Kubelka–Munk function $F(R\infty)$ [9]:

$$F\left(R\infty\right)=\frac{\left(1-R\infty\right)^2}{2R\infty},$$

where $R\infty$ denotes the reflectance of the film.

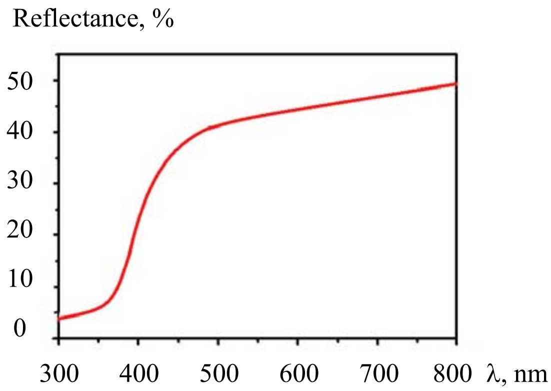

Fig. 3. Diffuse reflectance spectrum of the 2 wt% Li-doped CdO film.

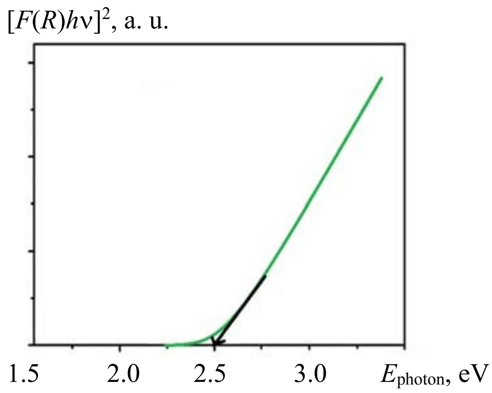

Fig. 4. Band gap plot of the 2 wt% Li-doped CdO film.

Figure 4 shows the plot of $[F(R\infty)\text{ Energy}]^2$ versus [Energy]. The band gap of the CdO:Li film was estimated from the intercept (linear fit) of the absorption edge to $[F(R\infty)\text{Energy}]^2 = 0$, which is found to be 2.50 eV. The observed band gap (2.50 eV) of the CdO:Li film in this study is higher than the band gap of bulk CdO (2.3 eV). The rise in the band gap can be credited to broadening of the Burstein–Moss band gap [10]. The estimated result is in agreement with the band gap result for 2 wt % Yttrium (Y)-doped CdO film [11]. For using TCO films in solar cells, the higher value of the band gap is always desirable [12].

To further understand the optical features of materials, the refractive index is a vital parameter. The refractive index (n) of CdO:Li film was computed by equation [13]:

$$n=\left(1+\sqrt{R\infty}\right)\Big/\left(1-\sqrt{R\infty}\right).$$

Figure 5 shows the dependence of the refractive index (n) of the CdO:Li film on the photon energy (E_{photon}). The refractive index first increases and attains a maximal value of ~2.3 at a photon energy of 1.5 eV. After attaining the maximal value, the refractive index starts decreasing. The obtained result of the refractive index is comparable with the result described for the CdO:Al film [14].

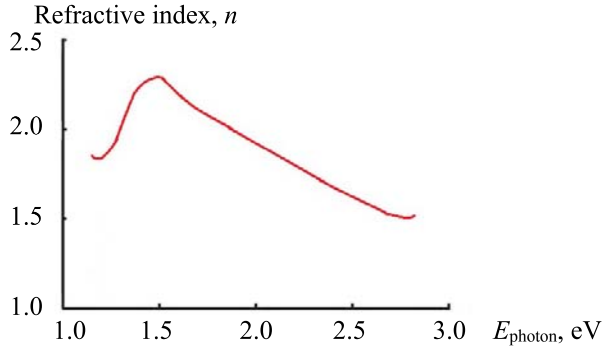

Fig. 5. Dependence of the refractive index on the photon energy for the 2 wt% Li-doped CdO film.

The negative Hall coefficient of the CdO:Li film conveyed *n*-type conductivity. The doped CdO film typically has higher conductivity than undoped CdO [15], which is attributed to the fusion of dopant ions into the CdO lattice. For the CdO:Li film, Hall measurements revealed the resistivity of the order of 10^{-3} Ohm · cm, mobility of the order of 34.23 cm^2/Vs, and carrier concentration of the order of 10^{20} cm^3. The high magnitude of the carrier concentration here may be attributed to the successful fusion of Li ions into the CdO lattice.

Conclusions. A sol-gel processed screen-printing set-up was used to successfully grow CdO:Li(2 wt%)-doped film. The XRD pattern of a CdO:Li film communicates a cubic phase and a polycrystalline nature. The optical characterization of a CdO:Li film reveals a direct transition of the band gap at 2.50 eV. The film refractive index varies with the photon energy and reaches its maximal value (2.3) at 1.5 eV. The electrical characterization of the CdO:Li film revealed *n*-type conductivity and resistivity of the order of 10^{-3} Ohm · cm. Lithium ions were completely fused into the CdO lattice. The results obtained here indicate that the CdO:Li film can be used for commercial applications.

Acknowledgements. All the authors convey their earnest gratitude to the honorable director, KIET Group of Institutions, Dr. (Col) Amik K. Garg, for the motivation to realize this research work.

REFERENCES

1. I. A. Tambasov, M. N. Volochaev, A. S. Voronin, N. P. Evsevskaya, A. N. Masyugin, A. S. Aleksandrovskil, T. E. Smolyarova, I. V. Nemtsev, S. A. Lyashchenko, G. N. Bondarenko, E. V. Tambasova, *Phys. Solid State*, **61**, 1904–1909 (2019).
2. S. Ilican, M. Cagler, Y. Cagler, F. Yakuphanoglu, *Optoelectron. Adv. Mater. Rapid Commun*., **3**, 135–140 (2009).
3. R. Kumari, P. Singh, V. Kumar, *J. Mater. Sci. Mater. Electron*., **29**, 8989–8994 (2018).
4. A. A. Dakhel, *Solid State Sci*., **13**, 1000–1005 (2011).
5. P. Velusamy, R. Rameshbabu, K. Ramamurthi, *AIP Conf. Proc*., **1731**, 080022 (2015).
6. R. Kumari, V. Kumar, *J. Solgel Sci. Technol*., **94**, 648–657 (2020).
7. N. N. Jandow, M. S. Othman, N. F. Habubi, S. S. Chiad, K. A. Mishjil, I. A. Al-Baidhany, *Mater. Res. Express*, **6**, 116434 (2019).
8. T. Ahmad, S. Khatoon, *J. Mater. Res*., **28**, 1245–1253 (2013).
9. R. A. Zargar, S. Chakrabarti, J. M. Shahabuddin, J. Kumar, M. Arora, A. K. Hafiz, *J. Mater. Sci. Mater. Electron*., **26**, 10027–10033 (2015).
10. K. Usharani, A. R. Balu, V. S. Nagarethinam, *Surf. Eng*., **32**, 829–833 (2016).
11. S. Ahmed, M. S. I. Sarkar, M. M. Rahman, M. Kamruzzaman, M. K. R. Khan, *Heliyon*, **4**, e00740 (2018).
12. Z. Biju, H. Wen, *J. Semicond*., **34**, 053003 (2013).
13. R. A. Zargar, M. Arora, R. A. Bhat, *Appl. Phys. A*, **124**, 36 (2018).
14. M. K. R. Khan, M. A. Rahman, M. Shahjahan, M. M. Rahman, M. A. Hakim, D. K. Saha, J. U. Khan, *Curr. Appl. Phys*., **10**, 790–796 (2010).
15. A. A. Dakhel, *J. Mater. Sci*., **46**, 6925–6931 (2011).