Study of $(Ga_xIn_{1-x})_2O_3$ thin films produced by aerosol deposition method

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ABSTRACT

Thin films of the $(Ga_xIn_{1-x})_2O_3$ compound have been prepared on Si substrates by the aerosol deposition method with variation of the Ga concentration (x) from 0 to 0.95. Indium chloride ($InCl_3$) and gallium nitrate ($Ga(NO_3)_3$) were used as precursors. The morphology, chemical composition, and crystal structure of the obtained films have been investigated by scanning electron microscopy (SEM), energy dispersive X-ray (EDX) and X-ray diffraction (XRD) analysis. The vibration modes have been deduced from Raman spectroscopy measurements to gain additional data concerning the crystallographic structure of phases constituting the deposited films. The optical absorption spectra were analyzed at room temperature in order to determine the bandgap as a function of the x-value in thin films. The photoresponse of films was investigated under the radiation with wavelength from the ultraviolet (UV), visible, and infrared (IR) spectral intervals. The performed investigations demonstrated the polycrystalline nature of films, consisting of high quality nanocrystals, ensuring a gradual increasing of the bandgap from 3.50 eV to 4.85 eV with increasing the x-value from 0 to 0.95, and a predominant photoresponse in the UV spectral range.

Keywords: Thin films, metal oxide alloys, SEM, absorption spectra, UV irradiation, photoresponse.

REFERENCES

[1] Bierwagen, O. „Indium oxide - A transparent, wide-band gap semiconductor for (opto) electronic applications" Semicond. Sci. Technol., 30, 024001 (2015). https://doi.org/10.1088/0268-1242/30/2/024001.

[**2**] S.I. Stepanov, S. I.; Nikolaev, V. I.; Bougrov V. E.; Romanov, A. E. „Gallium oxide: Properties and applications - A review", Rev.Adv. Mater. Sci., 44, 63-86 (2016).
[3] Pearton, S. J.; Yang, J.; Cary, P. H.; Ren, F.; Kim, J.; Tadjer, M. J.; Mastro, M. A. „A Review of Ga_2O_3 Materials, Processing, and Devices". Appl. Phys. Rev. 5, 011301 (2018). https://doi.org/10.1063/1.5006941.
[4] Gonçalves, G.; Barquinha, P.; Pereira, L.; Franco, N.; Alves, et. All. „High Mobility a-IGO Films Produced at Room Temperature and Their Application in TFTs". Electrochem. Solid-State Lett., 13, H20−H22 (2010).
[5] Huang, W.-L.; Hsu, M.-H.; Chang, S.-P.; Chang, S.-J.; Chiou, Y.- Z. „Indium Gallium Oxide Thin Film Transistor for Two-Stage UV Sensor Application". ECS J. Solid State Sci. Technol. 8, Q3140−Q3143 (2019).
[6] Kim, Y. G.; Kim, T.; Avis, C.; Lee, S.-H.; Jang, J. „Stable and High-Performance Indium Oxide Thin-Film Transistor by Ga Doping". IEEE Trans. Electron Devices, 63, 1078−1084 (2016).
[7] Hartwin Peelaers, Daniel Steiauf, Joel B. Varley, Anderson Janotti, and Chris G. Van de Walle. „$(In_xGa_{1-x})_2O_3$ alloys for transparent electronics". Phys. Rev. B 92, 085206 – Published 31 August (2015).
[**8**] Mohamed, H. „Transparent Conductive Gallium-doped Indium Oxide Nanowires for Optoelectronic Applications". J. Korean Phys. Soc., 62, 902-905 (2013).
[9] Tarsa, E. J., English, J. H., & Speck, J. S. et. All. „Pulsed laser deposition of oriented In_2O_3 on (001) InAs, MgO, and yttria-stabilized zirconia". Applied Physics Letters, 62(19), 2332–2334 (1993). https://Doi:10.1063/1.109408.
[10] Dive, A., Varley, J., & Banerjee, S. „In_2O_3−Ga_2O_3 Alloys as Potential Buffer Layers in CdTe Thin-Film Solar Cells". Physical Review Applied, 15(3) (2021). https://doi:10.1103/physrevapplied.15.034028.
[11] Swallow, J. E. N., Palgrave, R. G., Murgatroyd, P. A. E., Regoutz, A., Lorenz, M., Hassa, A.,Veal, T. D. „Indium Gallium Oxide Alloys: Electronic Structure, Optical Gap, Surface Space Charge, and Chemical Trends within Common-Cation Semiconductors". ACS Applied Materials & Interfaces, 13(2), 2807–2819 (2021). https://doi:10.1021/acsami.0c16021.
[12] Alexandra Papadogianni, Takahiro Nagata and Oliver Bierwagen. „The electrical conductivity of cubic $(In_{1-x}Ga_x)_2O_3$ films ($x \leq 0.18$): native bulk point defects, Sn-doping, and the surface electron accumulation layer". Jpn. J. Appl. Phys., 61, 045502 (2022). https://doi.org/10.35848/1347-4065/ac4ec7.
[13] Wang, C. Y., Kirste, L., Morales, F. M., Mánuel, J. M., et. All. „Growth mechanism and electronic properties of epitaxial In_2O_3 films on sapphire". Journal of Applied Physics, 110(9), 093712 (2011). https://doi:10.1063/1.3658217.
[14] Stepanov, S., Nikolaev, V., Pechnikov, A., Scheglov, M., Chikiryaka, A., Chernykh, A., Polyakov, A. Y. „Halide Vapor Phase Epitaxy of In_2O_3 and $(In_{1-x}Ga_x)_2O_3$ on Sapphire Substrates and GaN/Al_2O_3 Templates". Physica Status Solidi (a), 218(3), 2000442 (2020). https://Doi:10.1002/pssa.202000442.
[15] Kuang, Y., Ma, T. C., Chen, X. H., Li, J.,Ye, J. D. „Misfit epitaxial strain manipulated transport properties in cubic In_2O_3 hetero-epilayers". Appl. Phys. Lett., 117(10), 102104 (2020). https://Doi:10.1063/5.0021344.
[16] Kokubun, Y., Abe, T., & Nakagomi, S. „Sol-gel prepared $(Ga_{1-x}In_x)_2O_3$ thin films for solar-blind ultraviolet photodetectors". Physica Status Solidi (a), 207(7), 1741–1745 (2010). https://doi:10.1002/pssa.200983712.
[17] Kranert, C., Lenzner, J., Jenderka, M., Lorenz, M., von Wenckstern, H., Schmidt-Grund, R., & Grundmann, M. „Lattice parameters and Raman-active phonon modes of $(In_xGa_{1-x})_2O_3$ for $x < 0.4$". Journal of Applied Physics, 116(1), 013505 (2014). https://doi:10.1063/1.4886895.
[18] Demin, I. E., & Kozlov, A. G. „Effect of composition on properties of In_2O_3–Ga_2O_3 thin films". Journal of Physics: Conference Series, 858, 012009 (2017). https://doi:10.1088/1742-6596/858/1/012009.
[19] Chen, K.-Y., Yang, C.-C., Su, Y.-K., Wang, Z.-H., & Yu, H.-C. „Impact of Oxygen Vacancy on the Photo-Electrical Properties of In_2O_3-Based Thin-Film Transistor by Doping Ga". Materials, 12(5), 737 (2019). https://doi:10.3390/ma12050737.
[**20**] Jiayong Gan, J.; Lu, X.; Wu, J.; Xie, S.; Zhai, T.; Yu, M.; Zhang, Z.; Mao, Y.; , Wang, S. C. I.; Shen, Y.; Tong, Y. „Oxygen vacancies promoting photoelectrochemical performance of In_2O_3 nanocubes". Sci. Rep., 3, 1021 (2012).
[21] Kranert, C.; Sturm, C.; Schmidt-Grund, R.; Grundmann, M. „Raman tensor elements of β-Ga_2O_3". Sci. Rep., 6, 35964 (2016).
[**22**] Varley, J. B.; Weber, J. R.; Janotti, A.; Van de Walle C. G. „Oxygen vacancies and donor impurities in β-Ga_2O_3". Appl. Phys. Lett., 97, 142106 (2010).
[23] Fabi Zhang, Jinyu Sun, Haiou Li, Juan Zhou, Rong Wang, Tangyou Sun, Tao Fu, Gongli Xiao, Qi Li, Xingpeng Liu, Xiuyun Zhang, Daoyou Guo, Xianghu Wang & Zujun Qin. „Band-gap tunable $(Ga_xIn_{1-x})_2O_3$ layer grown by magnetron sputtering". Frontiers of Information Technology & Electronic Engineering volume 22, 1370–1378 (2021). https://doi:10.1631/FITEE.2000330.