Semiconductor and optical properties of Ge-doped ZnO thin films grown by ALD method

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Atomic Layer Deposition (ALD) method allows the precise thickness control, as well as gives high-quality films with thickness uniformity. It is commonly utilized in the deposition of thin films of metal oxides including ZnO. Zinc oxide is a transparent *n*-type semiconductor with a direct band gap Eg equal to 3.4 eV [1]. Due to the simplicity in its synthesis by ALD method, it can be found in various applications, e.g. thin film transistors [2] or light-emitting diodes [3].

So far, only one paper describing synthesis of Ge-doped ZnO (Ge:ZnO) by ALD was published by Chalker [4]. In this work, Ge:ZnO thin films were synthesized using the semi-industrial scale ALD reactor at mild temperature conditions. The detail characterization of the deposited thin films, with a focus on semiconductor and optical properties as well as surface studies, was performed using methods such as XPS, SEM equipped with EDS, and XRD, UV-VIS spectroscopy, Hall effect measurement etc. Due to the possible industrial application, the influence of Ge doping on the electronic and optical properties of layers was analyzed.

Applied procedure allows the successful deposition of Ge:ZnO thin films using the ALD method with Ge content from 0 up to 40%. Scaling up the process in semi-industrial reactors requires the re-establishment of deposition parameters for each material. To remove the organics from partially decomposed precursor, the additional pulse of water is required. Moreover, increase of precursor pulse time allows the uniform distribution of gas flow through the chamber, and in consequences, homogeneous deposition of thin films. In this work, the sample thickness along the length of the chamber, i.e. 70 cm, do not vary. The electronic and optical properties of the layers are significantly influenced by doping ZnO with just a few percent of Ge. The electrical conductivity decreases above 5% of doping, thus marking the optimal doping level for the best electrical performance. The Ge-doped ZnO films showed also a higher transmittance in the visible region along with a reduction in the value of refractive index indicating reduced reflection losses than undoped ZnO.

Fabrication of mentioned films using the industrial system highlights their possible application in the electronics or optoelectronics.

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