Shallow acceptor states in ZnO:N grown under oxygen-rich conditions

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Zinc oxide is a widely investigated semiconductor, because of a broad range of its possible applications. However, its wide application in electronics and optoelectronic is hindered by well-known difficulties with stable and reproducible *p*-type doping. Present studies indicate that complexes of an intentional dopant with native point defects and impurities unintentionally introduced during the growth provide shallow acceptor levels and play a crucial role in conversion conductivity towards *p*-type. It becomes more and more clear that in order to achieve an acceptor conductivity in ZnO it is equally important to effectively introduce a dopant as well as to play with growth conditions in a way that ensures appropriate interaction of dopant, native defects and unintentional impurities. Temperature of growth seems to be a critical issue in obtaining the *p*-type ZnO as it decides on a type and number of dominant native point defects in a material. Oxygen-rich conditions, which are beneficial for achieving the *p*-type conductivity, can be reached at very low (about 100^{o}C) temperature of growth [1].

In this paper we report on optical properties of ~2μm thick ZnO:N films that were obtained under oxygen-rich conditions and, after a short annealing, show a stable *p*-type conductivity with hole concentration of $4.5x10^{16}$ and $\mu = 17.4$ cm^2/Vs. [2].
Low temperature photoluminescence spectra of an as grown ZnO:N sample reveal a dominant donor-related peak at 3.36 eV as well as acceptor-related emissions at 3.302 and 3.318 eV. Annealing at 800^{o}C of a ZnO:N sample leads to conversion of conductivity from *n* to *p*-type, which is accompanied by a considerable enhancement of PL at 3.302 eV. Analysis of temperature dependent PL measurements discover a different origin of two acceptor-related bands. It has been found that the PL band at 3.302 eV can be assigned to donor-acceptor pair (DAP), whereas this at 3.318 eV to free electron to acceptor (FA) transitions. Based on temperature dependence of the FA transition acceptor binding energy has been determined as 119.3±1 meV [3]. LT CL images of *p*-ZnO:N show a complicated picture of acceptor- and donor-related emissions; after annealing acceptor- and donor-related lines are gathered along micro-columns. CL images confirm that in ZnO:N films obtained at LT under oxygen-rich conditions acceptor-related emission is neither related with grain boundaries nor with stacking faults, which was previously observed for ZnO grown at much higher temperature (450^{o}C). It offers some hope that a homogeneous p-type ZnO material can be achieved at least at the nm scale.

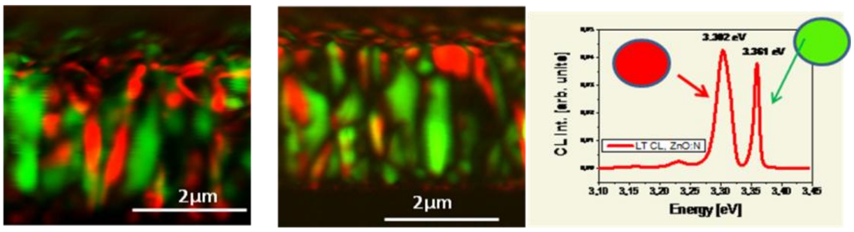

Fig. 1. LT CL images of an annealed ZnO:N sample.

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[2] E. Guziewicz, E. Przezdziecka et al., ACS Appl. Mat.Int. **9**, 26143 (2017).
[3] E. Przezdziecka et al., J. Luminescence **198**, 68 (2018).