Nanocrystalline Sputter-deposited ZnMgO:Al Film and its Application as a Transparent P-Type Electrode in GaN-Based 385 nm UV LED for Significant Emission Enhancement

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One of the significant factors leading to an increase in light emission efficiency in vertical nitride LEDs is the development of transparent electric contacts to the top LED layer. When p-GaN is the top LED layer, the standard ohmic contacts are based on a Ni/Au bilayer, due to their low resistivity. Such a metallization is however opaque and has to be applied as small area contacts leading to issues with nonuniform current flow as well as local degradation. It would be beneficial to replace this contact material with a UV-transparent contact electrode, enabling full area electric contact to the top LED layer for high efficiency light emission.

In this communication we present nanocrystalline, disoriented ZnMgO:Al transparent conducting films grown by room temperature sputtering cosputtering using ZnO:Al and Mg targets. The optical transmission measurements showed that band gap broadening in the films takes place, although not as the expected gradual function of Mg but in bunches. Based on X-ray diffraction (XRD) measurements it was evidenced that the films are textured in the 0001 direction, however the addition of Mg led to significant broadening and loss of intensity of the peak typical of crystalline frustration by the development of secondary material phases in the film. Rutherford backscattering spectroscopy measurements enabled to determine the Mg to Mg + Zn atomic content in the films, which was significantly lower than the 0.43 threshold for ZnO and MgO phase separation. Furthermore, the Mg content determined by RBS was higher than the Mg content resulting from band gap values indicating, that the excess Mg may be in the films as inclusions. The notion of metallic inclusions was also probable due to the lowering of the transmission value with the increase in Mg content. Conventional and high resolution transmission electron microscopy (TEM) studies enabled us to find low atomic mass precipitates in the films, the diameters of which were around 5-10 nm. We identified them as Mg inclusions and determined by means of image analysis that and band gap calculations that 6 to 9% atomic percent of Mg in the films is in these inclusions. Based on reference experiments without Al, where the inclusions and disorientation did not exist, we argue that the presence of Al leads to this effect. The solubility limit of Al in ZnO is ~3 at. %, being close to the concentration in our samples. Since Al supersaturation leads to the creation of Al_2O_3 precipitates, minute amounts of Al_2O_3 could be created in our material, leading to crystalline frustration and disorientation. Any relation of this mechanism to changes in Mg concentrations is however not clear at this point and requires further studies.

Finally, we apply the material as contact electrode to the p-GaN layer in a GaN-based 385 nm UV LED structure. By replacing the Ni/Au ohmic contact to p-GaN in ring geometry by a circular, UV-transparent ZnMgO:Al electrode we obtain a 2,5-fold increase in irradiated power.

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