On the mechanism of high internal quantum efficiency of AlGaN-based DUV-LEDs grown on the AlN templates with dense macrosteps

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For numerous potential applications such as sterilization, water purification, phototherapy [1], and solar-blind optical wireless communication (OWC) [2,3], AlGaN light-emitting diodes (LEDs) have attracted increasing attention. Since the use of AlN underlayer for AlGaN growth is a key technology to achive better performance of AlGaN LEDs, such as the device lifetime, optical output power, and external quantum efficiency (EQE), preparation of the AlN layer is one of the current issues. Our approach is based on the use of a sapphire substrate with a vicinal angle of 1.0° toward the sapphire $[10\bar{1}1]$ direction, which leads uneven AlN surfaces with dense macrosteps and is suitable to grow deep ultraviolet (DUV) LED structures with AlGaN quantum wells (QWs) [4,5]. The surfaces of the AlN template and AlGaN cladding layer on the AlN layer are formed with dense macrosteps having average step heights and terrace widths of approximately 10 nm and 300 nm, respectively, where the estimated threading dislocation density is 5×10^{8} cm^{-2}.

In this presentation, the microscopic structural and optical characteristics of AlGaN LED structures grown on the AlN templates with dense macrosteps are shown to discuss the origin of their high IQE. The cross-sectional transmission electron microscope observations under the high-angle annular dark field scanning mode and microscopic energy dispersive X-ray spectroscopy revealed that the AlGaN cladding layer under the AlGaN QW layer had a microscopic compositional modulation, which originates from the macrosteps at the AlN template surface. Moreover, Ga-rich portions in the cladding layer behaved as current micropaths, and the micropaths are connected with the carrier localization structure formed in QWs. The in-plane cathodoluminescence (CL) spectroscopy showed a significant inhomogeneity of the CL characteristics. The gentle slopes at the sample surface showed brighter emissions with a lower peak photon energy, confirming the carrier localization. This carrier localization structure in the QWs combined with the current micropaths in the cladding layer can increase the IQE as well as EQE of AlGaN LEDs [6]. Simultaneously, such the structure works as an ensemble of self-organized micro-LEDs with low electric capacitance resulting into the realization of Gbps-class DUV solar-blind OWC [2,3].

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