Plasma-assisted MBE of AlGaN layers and QW structures for high efficiency sub-300-nm emitters

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Plasma-assisted molecular beam epitaxy (PA MBE) is considered as one of the most promising epitaxial technologies for implementation of AlGaN-based heterostructures for the semiconductor ultraviolet (UV) photonics with a minimum operating wavelength λ=210 nm. In this paper we consider the formation of the UV-emitting $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ (x,y=0-1, y>x) nanostructures in both bulk AlGaN layers and intentional quantum wells (QWs) grown by PA MBE at the metal-rich conditions.

First, the strong dependence of the internal structure of bulk $Al_yGa_{1-y}N$ layers on periodical variation of the F_{III}/F_N flux ratio, resulting from the substrate rotation, is discussed. Influence of the rotation speed on the emergence of monolayer(ML)-thick Ga-enriched compositional irregularities in the layers in the growth direction is confirmed by a high-angle annular dark-field scanning transmission electron microscopy (HAADF STEM) as well as by measurements of optical adsorption and photoluminescence (PL). Both back-reflection and edge PL measurement geometries are used, with the latter demonstrating a sub-300-nm stimulated emission from the 100-nm-thick AlGaN layers having periodically spaced Ga-enriched 1-ML-thick insertions. A relatively low threshold power density of 240kW/cm^2 at λ=287nm is obtained for such AlGaN layers with the average Al content of 70 mol%, while the homogeneous layers show no stimulated emission.

Then, fabrication and properties of $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ SQW and MQW structures with different QW thickness (0.5-2.5nm) and morphology (2D-3D) are presented, with the QWs being fabricated by a sub-monolayer digital alloying (SDA) method as nominal superlattices $\{GaN/Al_yGa_{1-y}N\}_N$ (N=2-10) with thicknesses of GaN wells and $Al_yGa_{1-y}N$ barriers varying from 0.5 to 4 ML. It is demonstrated that relatively low growth temperatures (~700°C) and fast (<0.5s) manipulation of the metal fluxes at the metal-rich conditions enable one to control the QWs growth on the atomic scale and change their morphology from continuous to quantum-disk-like one with the minimum disk thickness and diameter of 1ML and a few tens of nanometers, respectively. As a result, these QW structures exhibit a different degree of the charge carrier localization with the maximum value of internal quantum efficiency (IQE) (estimated as the PL intensity ratio at RT and 10K) of about 80% for the 3D-continuous QW morphology. Surprisingly, the lowest threshold power densities of stimulated emission and the highest intensities of electron-beam excited luminescence at λ=230-300 nm are achieved in the QW structures with the quantum-disk morphology, exhibiting the IQE value of 30-40% [1].

The experiments are compared with the calculated parameters of charge carriers and excitons in such QWs, obtained by using a 6-band k-p model taking into account the effects of stresses and internal polarization fields. Finally, the optimum design and PA MBE growth conditions of both bulk AlGaN layers and QW structures demonstrating efficient lasing or spontaneous emission in the sub-300 nm wavelength range are discussed.

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References:

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