Angular and spectral distribution of laser emission in optical pumped lasers based on InGaN/GaN multiple quantum wells and single heterostructures

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Semiconductor heterostructures grown on high band gap substrates are promising for high power and high efficiency laser diodes operating in the leaky mode regime [1,2]. In our previous work [3], the leaky wave emission was observed in the photoluminescence (PL) and stimulated emission (SE) spectra of InGaN/GaN double and single heterostructures. The main aim of this work is to investigate the angular and spectral distribution of the laser emission from different GaN-based heterostructures to conclude about influence of the active and waveguide layer structures on the type of the laser modes and to establish their optical losses and optical confinement factors.

Undoped single $Ga_{0.86}In_{0.14}N$(30 nm)/GaN, double GaN/$Ga_{0.84}In_{0.16}N$(50 nm)/GaN and multiple quantum well InGaN/GaN heterostructures consisting of ten 3-10-nm thick InGaN active layers and 3.5-15 nm thick barriers were grown by MOVPE at temperatures between 700°C and 1100°C on c-plane sapphire substrates in AIXTRON reactors using TEGa, TMIn and NH_3 and hydrogen as carrier gas. Stimulated emission and PL were excited by radiation of a N_2 laser ($h\nu = 3.68$ eV, $I_{exc} = 10^2 - 3\times10^6$ W/cm^2) at room temperature. The angular dependence of the spectral distribution of the PL and SE were monitored using a special optical fibre system in the plane perpendicular to the heterostructure. The negative angles were selected to be in the direction of substrate.

A 3D graph of the angular and spectral distribution of the laser emission from a MQW structure is shown in Fig. 1 at excitation intensity higher than the laser threshold, $I_{exc}=3.2I_{thr}$. The laser spectra demonstrate a multiple mode structure and the far field patterns consist of two approximately symmetrical spots localised at angles $\alpha = \pm$30-35°. At high excitation power the intensity of the positive spot is higher than the intensity of the negative spot. The laser power is lower for the laser beam passing in the positive direction at $I_{exc}=I_{thr}$. The laser spectra at $I_{exc}=I_{thr}$ consist of one very narrow line with a full width at half maximum of only 0.04 nm (Fig. 2). Many laser lines appear in the spectrum with increasing excitation intensity. The laser spectra of the SH and DH also reveal a multimode structure of the emission. The far field pattern of the SH structure consists of a positive spot at $\alpha = +50°$ and a negative spot at $\alpha = -35°$. Those laser spectra do not depend significantly on the angle of registration. In addition to these directions, an intensive emission at $\alpha \approx$ 2-16° was monitored from the SH laser. Fig. 3 shows the 3D graph of the spectral and angular distribution at $I_{exc}>I_{thr}$ only for those emission spectra which depend on the angle. These emissions were attributed to the leaky modes passing through the substrate edge.

In order to understand the type and number of the lasing modes, the near- and far-field patterns of the laser emission, the values of optical confinement factors and optical loss were calculated for different heterostructures as a function of the mode number. All numerical calculations are performed for the four-layer isotropic waveguide model for the TE modes. The confinement factor for the leaky modes was calculated as a ratio of the emission intensity in the active layers to the intensity concentrated in other layers apart from the substrate. The angular dependence of the wavelength of the leaky mode generation was calculated and has good correspondence with experimental results. Additional results on the far field and near field patterns will be discussed in detail.

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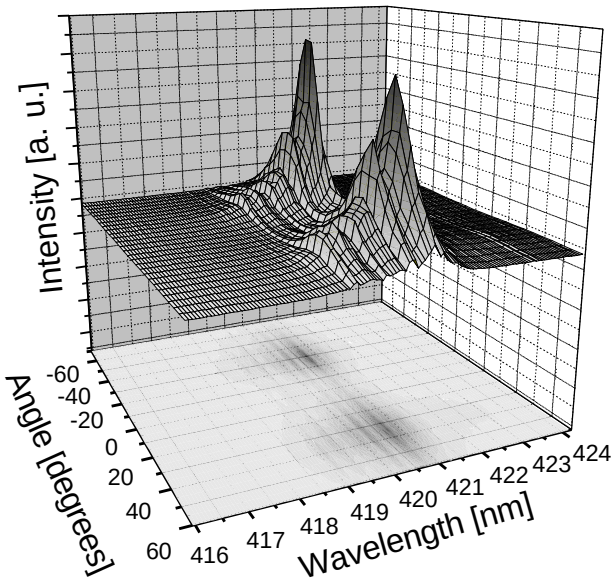

Fig. 1. Angular and spectral distribution of laser emission from a MQW laser at $I_{exc} = 3.2\ I_{thr}$.

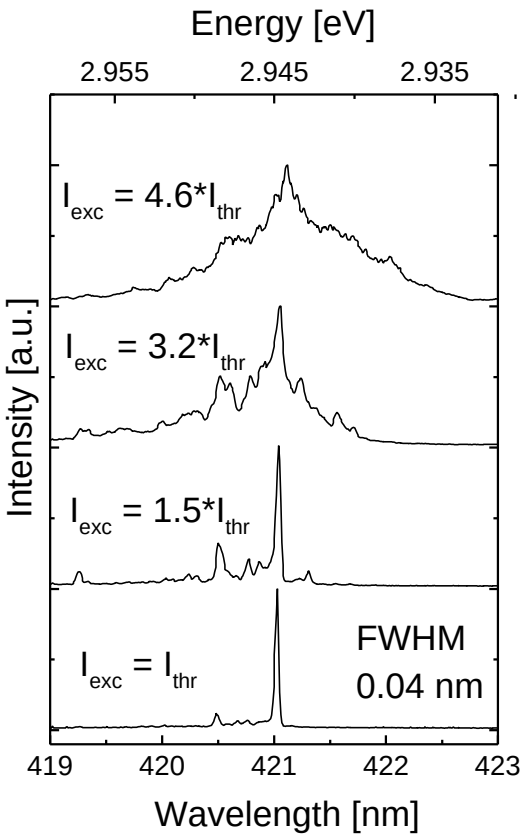

Fig. 2. Laser spectra of a MQW heterostructure at different excitation intensities.

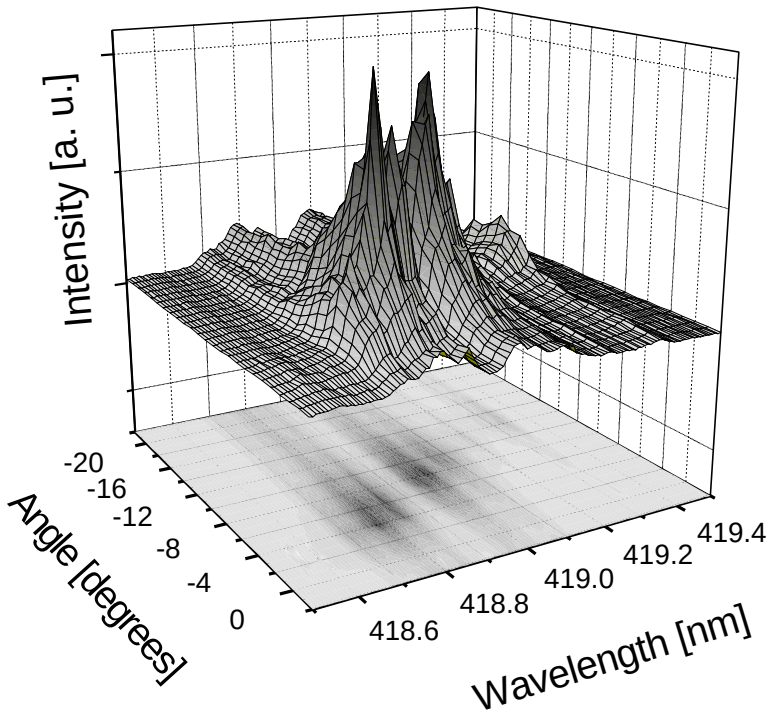

Fig. 3. Angular and spectral distribution of leaky modes emission from SH lasers at $I_{exc} > I_{thr}$.