OPTICAL AND LASER PROPERTIES OF THE INGAN/GAN MULTIPLE QUANTUM WELL HETEROSTRUCTURES

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Laser and optical properties of a series of (InGaN(≤3 nm)/GaN(≤4 nm))*5/GaN:Si(1 μm)/GaN(1 μm) multiple quantum well (MQW) heterostructures were investigated in wide intervals of excitation intensities (I_{exc}) and temperatures. All MQW heterostructures with different composition of the active layers, active, barrier and cladding layer thickness were grown in AIXTRON MOVPE reactors on c-plane sapphire substrates in the 6 × 2 and 11 × 2 inch configurations using triethylgallium (TEGa), trimethylgallium (TMGa), trimethylindium (TMIn) and ammonia (NH_3) as precursors and hydrogen (H_2) and nitrogen (N_2) as carrier gases. The radiation of a pulsed N_2-laser ($\lambda = 337.1$ nm, $t_p = 8$ ns, f = 1000 Hz, $I_{exc} = 10^2 - 10^6$ W/cm^2) was used for lasing and for photoluminescence (PL) measurements over the temperature range from 78 K to 450 K. Tunable dye laser with distributed feedback was used for selective excitation of quantum wells separately from GaN layers.

Laser action under N_2 laser excitation in the transverse geometry of pumping was achieved over the spectral range of 405 – 465 nm depending on the In content in the QWs. The laser threshold at room temperature reached the minimal value of $I_{thr} = 35$ kW/cm^2 for the lasers operated at $\lambda_{las} = 425$ nm and the maximal value of about 150 – 170 kW/cm^2 for the both utmost intervals of the wavelength.

The temperature dependence of the laser thresholds for T = 78 – 450 K for all types of MQWs (violet and blue lasers) reveals two slopes of the characteristics with an inflection point located between T = 200 K and T = 250 K (Figure 1). The violet lasers showed the characteristic temperature changing from $T_0 = 180$ K for low temperature range to $T_0 = 100$ K at high temperatures (Fig. 1,curve 2). The characteristic temperature of the blue lasers at low temperatures had a very high value of $T_0 = 530$ K. It decreased up to $T_0 = 160$ K at high temperatures (Fig. 1, curve 1). This can be attributed to a change in the gain mechanism. The PL parameters at $I_{exc} = I_{thr}$ were used for theoretical simulation of the I_{thr} according to the equation presented in the Fig. 1. This simulation does not explain (Fig 1, curve 3) laser threshold behaviour in the whole temperature interval. This shows that the laser threshold change can not be explained only by the radiative recombination efficiency, its halfwidth and spectral position behaviour. It can be supposed that the localised states created by the In reach clusters (quantum dots) play an important role at low temperatures. The very high value of the characteristic temperature of the blue lasers supports this explanation. The laser spectra maximum shifted to the low energy side with increasing temperature approximately linear with a rate of a 0.05 nm/K (Fig. 2, curve 1). The rate of the spontaneous emission band shift measured under excitation intensity equal to the laser threshold at every temperature was non-linearly increasing with temperature rise in approximately the same way as it is usually observable for the band gap shift (Fig. 2, curve 2).

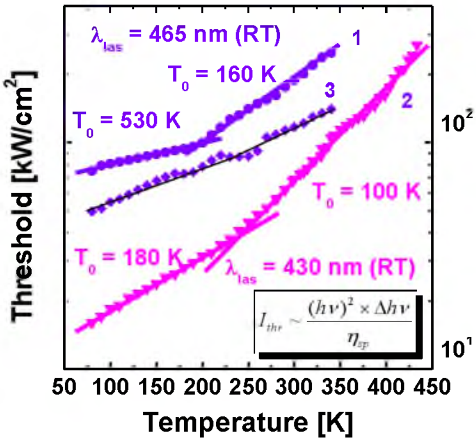

Fig. 1. Laser thresholds of two InGaN/GaN MQWs as a function of temperature (1,2). Curve 3 – approximation of $I_{thr}(T)$ by expression $I_{thr} \sim (h\nu)^2 \cdot \Delta h\nu / \eta_{sp}$ for the blue laser with $\lambda_{las} = 465$ nm.

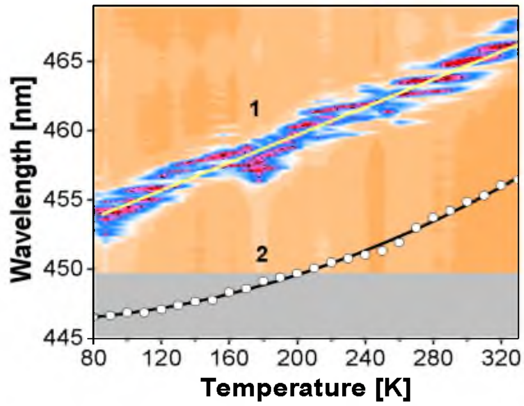

Fig. 2. 2D graph of laser spectra (1) and spontaneous emission peak position at $I_{exc} = I_{thr}$ (2) in temperature interval of 80 - 330 K.

An influence of the excitation intensity on the laser spectrum structure and position, laser power and efficiency as well as on the luminescence characteristics was investigated at room temperature. The laser spectrum centre shifts to the long wavelength side with increasing excitation intensity by 2-5 nm depending mainly on the cavity quality.

In order to understand the reasons of the laser spectra shift with excitation intensity and in order to reveal the exciting and inherent light influence on the laser mode structure and position, measurements of the PL and laser spectra at excitation by a narrow stripe and by a focused radiation of the N_2 laser were carried out and compared with the temperature dependencies of the laser and PL spectra. It was shown that the PL peak position shifts only to the short wavelength side (Fig. 3, curve 2) at the same time when the laser lines move to the long wavelengths (Fig. 3, curve 1). On the base of these results, it was concluded that the large shift of the laser spectrum in the I_{exc} interval of 100 – 1000 kW/cm^2 is due to a considerable thermal overheating of the active region which occurs in turn exclusively at the expense of the inherent InGaN/GaN laser radiation. The maximal value of the overheat reaches of 40 – 100 K depending on the cavity quality and so on the laser light density inside cavity.

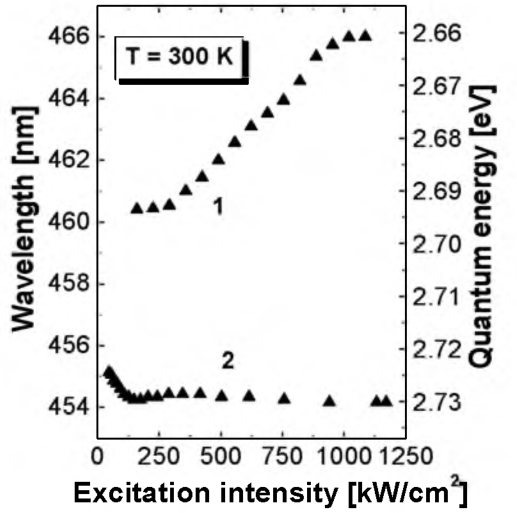

Fig. 3. Spectral position of the laser emission centre (1) and spectral position of the PL band from sample surface at excitation by focused N_2 laser beam (2) as a function of excitation intensity.

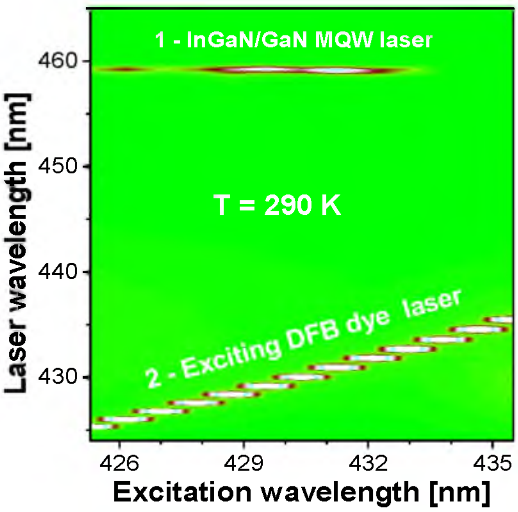

Fig. 4. 2D graph of InGaN/GaN MQW laser spectra (1) and exciting DFB dye laser spectra (2).

Figure 4 shows 2D graph of InGaN/GaN MQW laser spectra (band 1) obtained under wavelength tunable DFB dye laser excitation (band 2) at room temperature. No wavelength shift is observed as it is seen from the Figure as the excitation moves to the long wavelength side. A comparison of this result with PL and laser spectra excitation for this structure allows to think that the main gain mechanism in InGaN/GaN MQW laser at room temperature is recombination of nonequilibrium carriers in the electron-hole plasma.