On the feasibility of fundamental-mode operation in unstable-resonator GaInN lasers

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Fundamental-mode operation is necessary in order to fully realize the advantages of the short wavelength in GaInN lasers, in applications such as digital versatile disk and laser printers. A limitation to fundamental-mode operation over a reasonably wide excitation range is the formation of filaments in the lateral (perpendicular to epitaxial growth) dimension. [1,2] Filamentation occurs because of self-focusing of the intracavity laser field in the semiconductor gain medium. After the onset of filamentation, the lateral dimension of the fundamental laser mode is constricted, so that overlap with the gain volume is substantially reduced. The inversion that is not depleted by the fundamental mode then becomes available to the higher order lateral modes, thereby increasing the likelihood of multimode operation. Furthermore, filamentation gives rise to high intracavity intensities, which increase the possibility of material damage. In this paper, we investigate a solution to the problem of filament that is based on the use of an unstable resonator. To determine the extent to with an unstable resonator can counter the strong filamentation effects in a nitride gain medium, we use the Crank-Nicholson method to numerically solve the wave equation for the intracavity laser field. [2] The local saturated intensity gain G and carrier-induced refractive index δn_g are obtained from a semiclassical laser theory that is based on the semiconductor Bloch equations, with collisions treated at the level of quantum kinetic equations in the Markovian limit. [3] Figure 1 illustrates the formation of a filament in a 10μm stripe width laser. The optical resonator consists of plane uncoated facet mirrors of reflectivities $R_1=R_2=0.18$, separated by 500μm. We consider a 4 nm $Ga_{0.8}In_{0.2}N/GaN$ quantum well gain region. The figure shows the changes in the lateral intensity distribution with increasing injection current. For excitations $J/J_{th} \leqq 1.2$, where J_{th} is the threshold current density, the lateral intensity distribution extends over the entire stripe width (solid curve). The dashed and dotted curves for J/J_{th} = 1.6 and 2.0 show the narrowing or filamentation of the lateral intensity distribution at higher excitations. These narrow intracavity field distributions do not make effective use of the available gain. Figure 2 shows the lateral field distributions with increasing injection current for the same GaInN laser as in Fig. 1, but operating with a negative-branch resonator consisting of a plane mirror and a concave mirror of

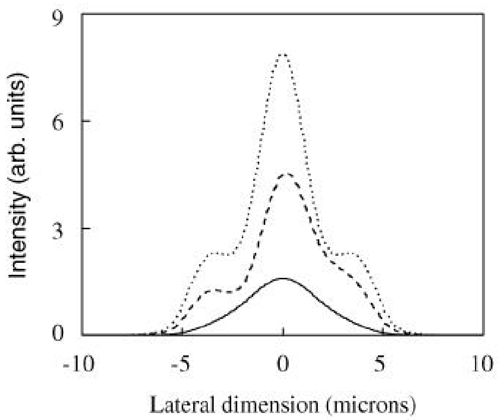

Fig. 1. Lateral intensity distribution at output facet for 10 μm stripe width GaInN quantum well laser operating with plane facets. The excitation levels are J/J_{th}= 1.2 (solid curve), 1.6 (dashed curve) and 2.0 (dotted curve).

radius of curvature ρ_2=400 µm. To enhance the effects of the curved facet, we increase the facet reflectivities to R_1 = R_2 = 0.8. A more uniform intensity distribution, that overlaps better with the broad gain region, and does not contain sharp intensity peaks that may cause material damage, is obtained at excitations up to greater than twice the lasing threshold. Figure 3 depicts the far-field intensity distributions for the two lasers at twice threshold. We note that the intensity variations in the unstable resonator near-field do not lead to noticeable degradation of the far field. In the calculations of the far fields, we removed the aberrations due to tilt and defocus, as they are easily correctable with conventional optics. In summary, a wave-optical model that is coupled to a microscopic gain theory is used to investigate the feasibility of using an unstable resonator to counter the effects of filamentation in a nitride gain medium.

While high-power single-mode operation has been demonstrated in conventional near-infrared semiconductor lasers operating with a wide range of unstable resonator configurations, our investigation found the nitride lasers to be more sensitive to resonator geometry because of the stronger filamentation tendency of the gain medium. A parametric study shows that for an GaInN quantum well laser, a negative-branch unstable resonator is preferred over the commonly used positive-branch one, in terms of insensitivity to mirror curvatures, and enabling fundamental-mode operation far above lasing threshold in a broad-area stripe geometry. This work was supported in part by the U. S. Department of Energy under contract No. DE-AC04-94AL85000.

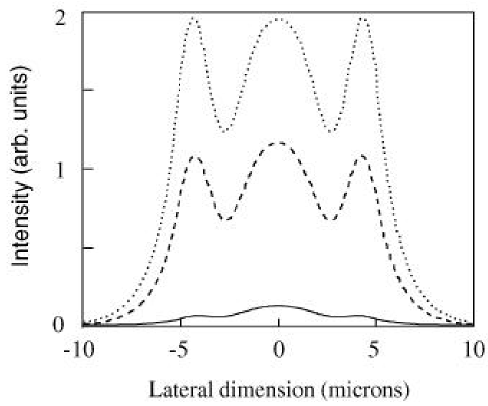

Fig. 2. Lateral intensity distribution at output facet for 10 µm stripe width GaInN quantum well laser operating with unstable resonator. The excitation levels are J/J_{th}= = 1.1 (solid curve), 1.5 (dashed curve) and 2.0 (dotted curve).

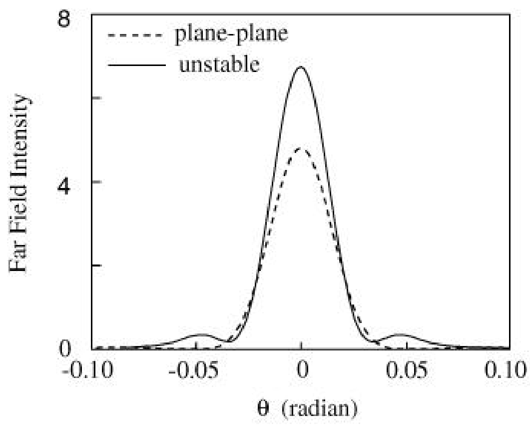

Fig. 3. Far-field intensity distributions for lasers in Figs. 1(dashed curve) and 2 (solid curve), operating at J/J_{th} = 2.0.

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