Low Divergence Edge-Emitting Laser with Asymmetric Waveguide Based on One Dimensional Photonic Crystals.

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The efficient coupling of laser radiation from a semiconductor diode to single-mode or multimode fiber is critical in the performance / cost ratio in applications from pump laser diodes for optical amplifiers to industrial and medical optical power delivery systems. Several approaches to waveguide engineering have been proposed to increase the modal spot size. Two major schemes can be distinguished: either a low-index layer is inserted into the confinement layer or a high-index layer is inserted into the cladding layer. However such designs use traditional waveguides and the vertical far-field angle of the lasers is above 13-18º. More recently, an idea of using an asymmetric waveguide based on a periodic GaAs-AlGaAs structure been proposed to realize stable single-mode lasing with an arbitrary modal spot size [1]. In the frame of this approach the waveguide is designed as a one-dimensional photonic crystal with an irregularity (defect). The active area (InGaAs quantum wells) is placed inside the defect. Only the fundamental mode is localized near the GaAs defect layer, while all other modes are extended through the multilayer structure and leak to the substrate. In this work we address the properties of the laser with ultrabroad (>10 μm) waveguide based on photonic band crystal (PBC) with defect.

The epitaxial structure was grown using metal-organic chemical vapor deposition (MOCVD). The thickness of the GaAs layers and $Al_{0.8}Ga_{0.2}As$ barriers were 800 nm and 80 nm, respectively. 20-nm wide linearly-graded AlGaAs interfaces were used to provide low series resistance of the device (<10^{-4} /cm^2). The PBC defect region with a thickness of 900 nm was placed close to the p-doped 1180 nm-thick (Al,Ga)As injector layer (p~$5.1 x 10^{17}$ cm^{-3}). The total thickness of the PBC waveguide with the defect layer was 9.3 μm to completely localize the fundamental mode and provide filtration of all high-order modes having much higher leaky loss in the GaAs substrate. The PBC region was n-doped up to ~ $4.8 x 10^{17}$ cm^{-3}. High-reflection (R_{HR} ~90%) and anti-reflection (R_{AR} ~ 10%) coatings were deposited on the rear and the front facets, respectively.

The structure showed maximal output power of 10.5 W in pulsed mode and 1.73 W in CW mode. The differential efficiency for a 1350 μm-long device was 85 %. The full-width half-maximum (FWHM) of the beam in vertical direction was 13-14º and did not depend on the injection current. The horizontal beam divergence angle was 6º.

Further optimization of the PBC design allowed us to achieve FWHM of the far field pattern as small as 4.8º at currents exceeding the threshold by 10-20%.The far field pattern only slightly broadens up to 5.5-6º at highest injection currents.

[1] N.N. Ledentsov and V.A. Shchukin, *SPIE Optical Engineering* **41**, 3193 (2002).