CW Single Transverse Mode Operation of GaAs Mushroom Vertical-Cavity Surface-Emitting Lasers

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Vertical-cavity surface emitting lasers (VC-SELS) have been intensively studied in recent years due to their potential applications in fiber communication, optical interconnects, and optical computing. Most applications require a moderate CW power and single mode operation. However, most reported VC-SELS exhibited low CW powers (< 1 mW) and multiple transverse modes. The CW power is mainly limited by the severe ohmic heating which was caused by the high series resistance of p-AlAs/Al0.1Ga0.9As multilayers used in the VC-SELS as distributed Bragg reflectors (DBRs). The multiple transverse modes resulted from a large emitting area (> 5 μm diameter) and the lack of a good current confinement scheme. In this work we demonstrate a GaAs single quantum well vertical cavity mushroom surface emitting laser (MSEL) with a threshold current (Ith) as low as 1.6 mA, a CW power larger than 2.0 mW, and single transverse mode operated up to > 3 Ith. The improved maximum output power is achieved by a reduced series resistance using a selective zinc diffusion process and a relatively higher quantum efficiency (> 20 %). The low threshold current and single transverse mode are attributed to good lateral current confinement in a small constricted region (5 μm diameter) formed by mesa undercutting.

The layer structure shown in Figure 1 consists of a 29.5 pair n-AlAs/Al0.1Ga0.9As bottom DBR, a 300 Å GaAs quantum well active layer sandwiched by an n and a p type Al0.35Ga0.65As cladding layer, a 0.5 μm p-Al0.1Ga0.9As undercutting layer which is selectively etched off to form a constricted region, an extra p-Al0.35Ga0.65As conduction layer for current injection, a 24 pair p-AlAs/Al0.1Ga0.9As top DBR, and finally a 100 Å p-GaAs cap layer. The fabrication of MSELs is briefly described as follows: First mesas/moats were formed by chemical etching; zinc was then diffused for 1-4 hours at 650 °C to selectively disorder the multilayer in the perimeter of the mesa, forming a lower resistance conduction path for current injection. Then the mesa was undercut in the 0.5 μm p-Al0.1Ga0.9As layer to form a 5–10 μm diameter constricted region using a selective solution of Clorox : DI H2O (1 : 5).

The average differential series resistance at the threshold voltage (~ 2.5 V) is 250 and 120 ohms respectively for 10 x 10 μm² devices with one and four hours zinc diffusion. These resistance values are three orders of magnitude lower than that of a monitoring sample without zinc diffusion and about one order of magnitude lower than some previously reported VC-SELS with heterojunction grading. The far-field radiation patterns of a 6 x 6 μm² device are shown in Figure 2. The laser exhibited a very low threshold current of 1.6 mA and a stable fundamental transverse mode up to 3 Ith. The light output power vs. current characteristics of the 6 x 6 μm² and a 10 x 10 μm² device are shown in Figure 3. The threshold current and voltage is 3.0 mA and 2.4 V respectively for the 10 x 10 μm² laser. The maximum CW power of 2.1 mW is achieved on the 10 x 10 μm² laser. This is the largest power ever reported for the same size device. The slope efficiency near threshold is 23 %. For high speed characterization the devices are mounted on a coplanar waveguide substrate. Figure 4 shows a typical characteristic of the modulation response. The relaxation frequency of ~4 GHz is observed at 11 mA dc bias current.

Fig. 1 Schematic diagram of a GaAs SQW mushroom vertical cavity surface-emitting laser.

Fig. 2 Far field patterns of a 6 x 6 μm² device show that a stable fundamental transverse mode is operated up to > 3 I.th.

Fig. 3 L-I curves of devices with (a) 6 x 6 μm² and (b) 10 x 10 μm² active region.

Fig. 4 Modulation frequency response.