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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[1-3] 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/$Al_xGa_{1-x}As$ 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 (I_{th}) as low as 1.6 mA, a CW power larger than 2.0 mW, and single transverse mode operated up to > 3 I_{th}. 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/$Al_{0.1}Ga_{0.9}As$ bottom DBR, a 300 Å GaAs quantum well active layer sandwiched by an n and a p type $Al_{0.35}Ga_{0.65}As$ cladding layer, a 0.5 μm p-$Al_{0.1}Ga_{0.9}As$ undercutting layer which is selectively etched off to form a constricted region, an extra p-$Al_{0.35}Ga_{0.65}As$ conduction layer for current injection, a 24 pair p-AlAs/$Al_{0.1}Ga_{0.9}As$ 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 ^{O}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-$Al_{0.1}Ga_{0.9}As$ layer to form a 5-10 μm diameter constricted region using a selective solution of Clorox : DI H_2O (1 : 5).

The average differential series resistance at the threshold voltage (~ 2.5 V) is 250 and 120 ohms respectively for 10 x 10 μm^2 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 μm^2 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 I_{th}. The light output power vs. current characteristics of the 6 x 6 μm^2 and a 10 x 10 μm^2 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 μm^2 laser. The maximum CW power of 2.1 mW is achieved on the 10 x 10 μm^2 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 wavequide substrate. Figure 4 shows a typical characteristic of the modulation response. The relaxation frequence of ~4 GHz is observed at 11 mA dc bias current.

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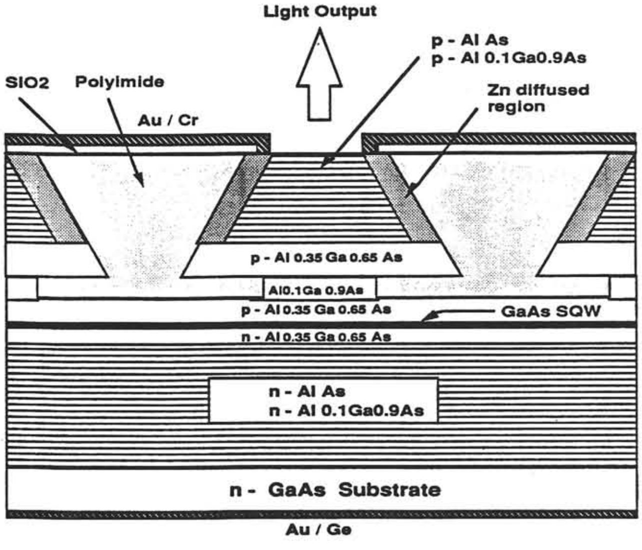

Fig. 1 Schematic diagram of a GaAs SQW mushroom vertical cavity surface-emitting laser.

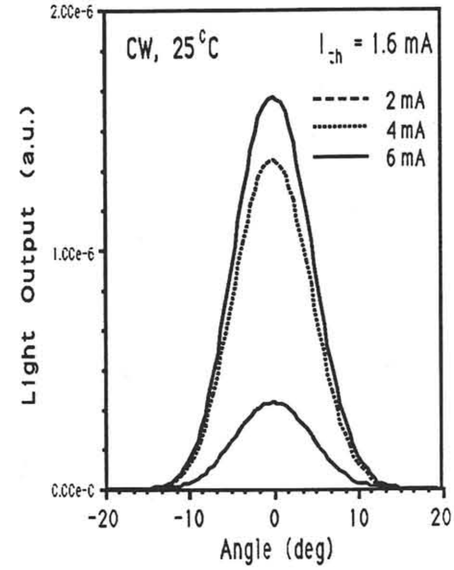

Fig. 2 Far field patterns of a 6 x 6 μm^2 device show that a stable fundamental transverse mode is operated up to > 3 I_{th}.

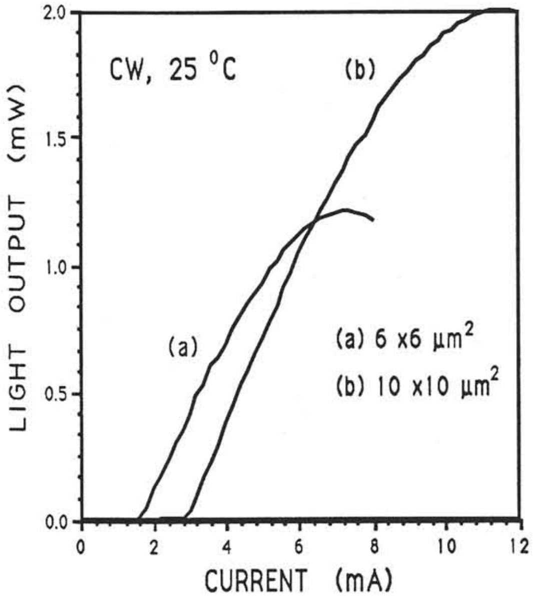

Fig. 3 L-I curves of devices with (a) 6 x 6 μm^2 and (b) 10 x 10 μm^2 active region.

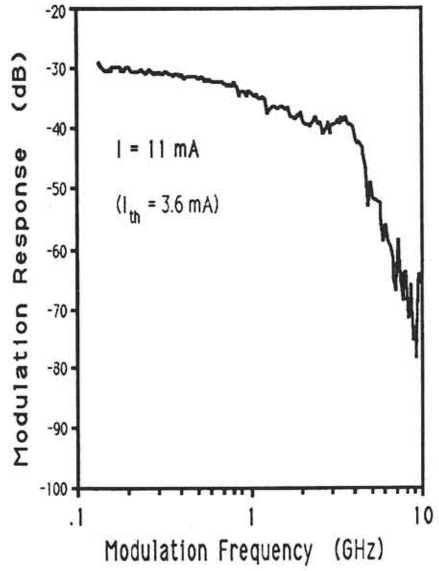

Fig. 4 Modulation frequence response.