Design and Fabrication of A Micro-Cavity Laser with Transparent Micro Loop Mirror

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Abstract: We describe a linear laser with micro loops as end mirrors. FDTD simulation is used to design the mirror and laser cavity. Initial fabrication result with threshold of ~0.4mA is presented.

OCIS codes: 140.3580 Lasers, solid-state; 140.2020 Diode lasers

1. Introduction

Microcavity lasers are of interest for planar integration due to their low lasing thresholds and small sizes. Current planar microcavity lasers are in the form of ring or disk cavities. Compares to ring or disk cavity, linear cavity has the advantage that the spontaneous emission into the lasing mode will be largely into one mode instead of two (i.e. clockwise and counter-clockwise), leading to high spontaneous emission coupling factor β[1,2]. Higher β value will lead to lower lasing threshold. In addition, for practical applications, linear cavity will enable us to achieve single-ended output, leading to higher output power. To achieve a single-ended output, one mirror of the laser needs to have high reflectivity while the reflectivity of the other mirror shall be relatively low. Deposited Au mirrors or DBR gratings are typically used to achieve the high reflectivity mirrors at one end. However, planar DBR grating is difficult to achieve high reflectivity or micro-size cavity due to low refractive-index contrast, and Au mirrors tend to be lossy. In this paper we discuss a new approach of using a micro loop mirror as high reflectors. We will also show that by combining a directional coupler with the micro loop mirror, the reflectivity value can be adjusted to reach the desired value for optimal output power.

2. Theory and Design

The high reflectivity micro loop mirror is formed by connecting the two arms of a Y-splitter with a curved single mode waveguide. The loss comes from two parts: the first part is the loss from the Y junction, which strongly depends on the Y-junction angle; the second part is the bending loss from the curved waveguide, which depends on the curvature of the waveguide. Finite differential time domain method [3] is used to evaluate the loss and we find that for core/cladding refractive index contrast of 3.3 and 1, curvature > 1.5um and Y-junction angle <20 degree gives reflection>98% at the wavelength of interest.

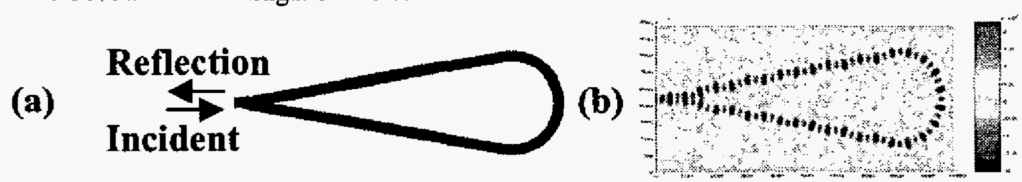

Fig. 1. (a) High reflection loop mirror with 20 degree angle and 3um diameter waveguide loop, (b) FDTD pattern of the electrical field when launching in CW wave at wavelength 1.55um.

For the output end, a directional coupler is combined with the curved single mode waveguide loop. Following typical coupler equations, with input A_1, the output B_1 and B_2 are (Fig.2):

$B_1 = \sqrt{1-c^2}\,A_1, B_2 = -jcA_1$, where $c = \sin(\pi L / 2L_0)$, with L_0 being the full coupling length of the coupler.

Connecting the two output end and let the coupler length L' deviate slightly from ½ of the full coupling length L_0 as $L' = L_0/2 + \Delta L$, the transmissivity T of the coupler-loop mirror can be calculated as

$$T = (1 - 2\sin^2(\pi L'/2L_0))^2 = (\cos(\pi L'/L_0))^2 = (\sin(\pi \Delta L/L_0))^2$$

Total reflection R=1 occurs at $L = L_0/2$.

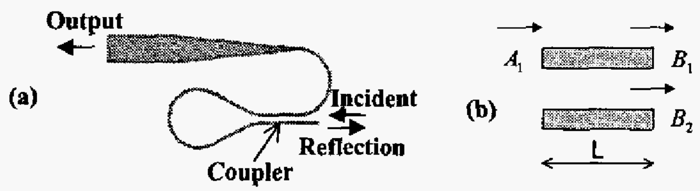

Fig. 2. (a) Schematics of the output end loop mirror, (b) coupler used in the loop mirror reflection calculation.

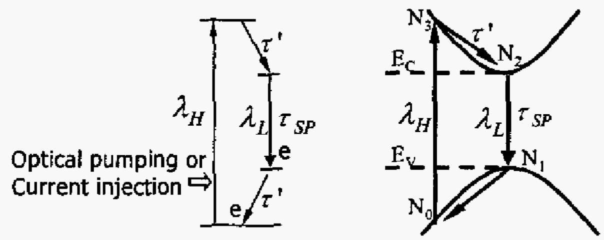

Fig. 3. Simplified model for gain medium used in FDTD simulation of loop mirror laser.

Next we use a simplified model for semiconductor gain in FDTD simulation by using a 4-level energy level model to simulate the laser operation [4,5,6]. The laser structure simulated has high reflectivity (>98%) loop mirror in one end and 90% reflection loop mirror in the other end. The center part of the laser is tapered up to 2um in this simulation to provide higher output power. The electrical field pattern of the laser is shown in Fig. 4.

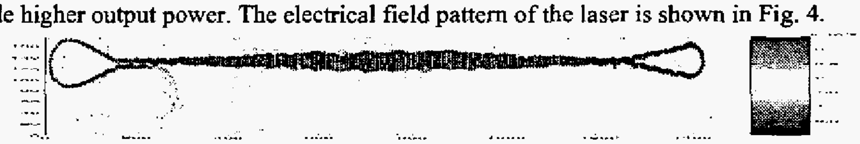

Fig. 4. FDTD simulated electrical pattern of looped mirror laser operation.

3. Fabrication and Results

In initial fabrication, we have the high reflectivity looped mirror on both ends of the laser. We used commercially epitaxial grown InGaAs-InP quantum well wafer with five 5.5nm unstrained InGaAsP quantum wells separated by 12nm thick barriers. In order to reduce the laser threshold, the micro loop section at both ends of the laser are bandgap blue shifted by >100nm to transparency via quantum well intermixing technique [7]. 1.2 μm SiO2 is deposited as ion implantation mask and windows are then opened for areas where bandgap will be shifted. After ion implantation, the SiO2 is removed and the wafer is annealed in Rapid Thermal Processor. The bandgap shifted photoluminance (PL) is shown in Fig. 5.

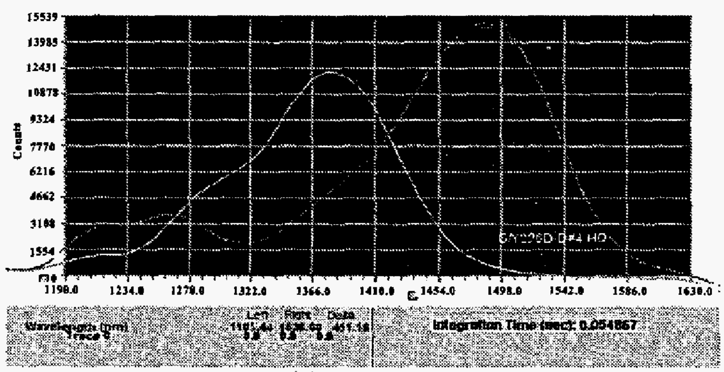

Fig. 5. PL result for the quantum well wafer before and after quantum well intermixing.

400nm SiO2 is then deposited as the mask for InP deep etching. The SiO2 mask is patterned by Ebeam lithography and is etched in RIE. The PMMA Ebeam resist is then removed and the wafer is etched in ICP chamber to form ridge waveguide structure. The SEM picture of the etched loop mirror before planarization is shown in Fig. 6. The structure is then passivated by SiO2 and planarized using BCB. After etching back the BCB, electrical contact windows are opened, and metal contacts are deposited.

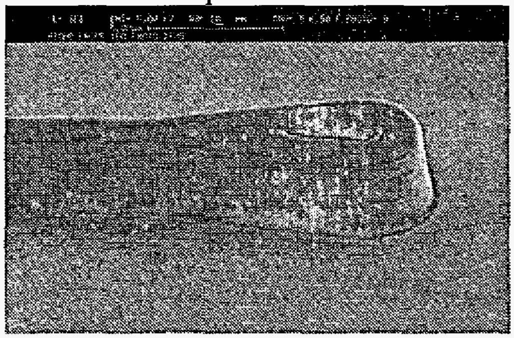

Fig. 6. SEM picture of the ICP etched looped mirror laser with SiO2 mask on top.

The output-injection current relation of the micro-loop laser with 20μm long and 2um wide center gain region is shown in Fig. 7. The threshold of the laser is ~0.4mA.

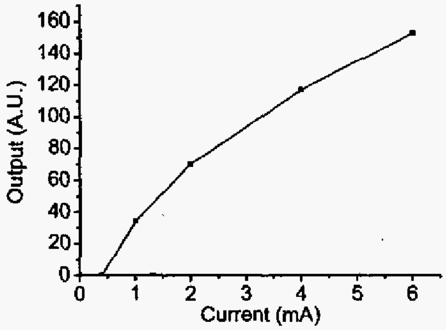

Fig. 7. Current-output relation of the micro loop laser.

4. Conclusion

We have described a linear laser with micro loops as end mirror to achieve single directional output. The micro loop mirror reflectivity is adjustable via varying the length of the coupler section. FDTD simulation is used to examine the mirror loss and simulate the laser operation. Initial fabrication and testing result of the micro loop mirror laser is presented. Low lasing threshold of ~0.4mA is achieved.

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