Output Characteristics of an InP/InGaAsP Triangle Microcavity Laser *

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Mode competitions between modes with different output coupling efficiencies can result in optical bistability under certain asymmetric nonlinear gain. For a GaInAsP/InP equilateral triangle microlaser with the side length of 10μm, the drop of the output power with the increase of the injection current is observed corresponding to transverse mode transitions. Furthermore, the measured laser spectra up to 270K show that lasing modes coexist with the wavelength interval of 39 nm at 240 K. The emission at 5.2 THz can be expected by the mode frequency beating with the 39 nm interval.

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Directional-emission semiconductor microlasers are potential light sources for optoelectronic integration applications. Recently, GaInAsP/InP equilateral triangle resonator (ETR) microlasers with an output waveguide connected to one of the vertices were fabricated by planar semiconductor technologies, and continuous-wave electrically injected ETR lasers were realized at room temperature. Optical bistability was observed for a GaInAsP/InP ETR laser with the side length of 30 μm, and strong mode competition was identified from the laser output spectra in the upper and lower states of the hysteresis loop. Furthermore, the numerical results of two-mode rate equations indicated that asymmetrical cross gain saturation can result in the bistability own to the mode transition with different output coupling efficiencies.

In this Letter, we report the output characteristics of a GaInAsP/InP ETR laser with the side length of 10 μm. The drop of output power versus injection current is observed accompanying with the transverse mode transition at 90 K. The results clearly indicate that different transverse modes can have different output coupling efficiencies in the ETR laser. In addition, lasing modes with the wavelength interval of 39 nm are observed at 240 K, corresponding to a beating frequency of 5.2 THz.

The GaInAsP/InP ETR lasers were fabricated from a common edge-emitting laser wafer with the active region consisted of five quantum wells by standard photolithography and inductively-coupled-plasma (ICP) etching technique process. First, an 800-nm SiO$_2$ layer was deposited by plasma-enhanced chemical vapor deposition on the as-grown GaInAsP/InP laser wafer as a hard mask for dry etching. Next, the ETR patterns were transferred onto the SiO$_2$ layer using standard photolithography and ICP etching techniques. Then, the patterned SiO$_2$ was used as hard masks to define the ETR geometry for subsequent ICP process to etch GaInAsP/InP. Finally, a 300-nm SiO$_2$ insulating layer was deposited and the contact window was opened on top of each ETR pattern using chemical wet etching process. Ti-Au was used as the p-type contacts, and Au-Ge-Ni metallization was used as n-type contact metal after lapping down the laser wafer to a thickness of about 100 μm. Microscopy image of an ETR with a 2-μm-wide output waveguide is plotted in Fig. 1, which is covered by insulating SiO$_2$ layer with a current injection window chemically etched on the SiO$_2$ layer on the top of the ETR. Some SiO$_2$ layers on the vertices of the ETR and on the both sides of the output waveguide are also etched accidentally. The ETR laser was cleaved over the output waveguide in the position as shown in Fig. 1 for output test.

![Image of an ETR after opening the current injection window](image-url)

Fig. 1. Image of an ETR after opening the current injection window on the insulating SiO$_2$ layer by wet chemically etching technique on the top of the ETR. A triangle ring of SiO$_2$ layer with width about 2 μm surrounds the injection window on the top of the ETR. Some of the SiO$_2$ layers in the vertices region are etched accidentally.

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The ETR microlasers are mounted in a cryostat to characterize the output characteristics at different temperatures. Figure 2 shows the output spectrum of an ETR laser with the side length of 10 µm at room temperature. The vertical dashed and dotted lines are mode wavelengths of the fundamental and the first order transverse modes with the longitudinal mode numbers from 64 to 72, and effective mode index of 3.2.

Fig. 2. Output spectrum of a GaInAsP/InP ETR laser with the side length of 10 µm at room temperature. The vertical dashed and dotted lines are mode wavelengths of the fundamental and the first order transverse modes with the longitudinal mode numbers from 64 to 72, and effective mode index of 3.2.

The ETR microlasers are mounted in a cryostat to characterize the output characteristics at different temperatures. Figure 2 shows the output spectrum of an ETR laser with the side length of 10 µm at room temperature. The vertical dashed and dotted lines are mode wavelengths of the fundamental and the first order transverse modes, calculated from the mode wavelength formula in Ref. [5] with the longitudinal mode number from 63 to 73 and the effective mode index of 3.2. The modes are marked as \((m, l)\) in the figure, where \(m\) and \(l\) are the transverse and longitudinal mode numbers, respectively. The deformed peaks consist of several transverse modes. Output powers versus the injection currents are measured and plotted in Fig. 3 at the temperature of 80, 90, and 100 K, which shows the threshold current about 1.5 mA. Above the threshold current, the output power at 80 K is much larger than that at 100 K, respectively.

Fig. 3. Output power versus injection current for the ETR laser at 80, 90, and 100 K. The open and solid circles are results obtained by increasing and decreasing the current at 90 K, respectively.

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The output power at 90 K is near that at 80 K as the injection current is less than 6 mA, and then drops to that of 100 K as the injection current is larger than 10.3 mA. The laser spectra of the ETR laser at 90 K under the injection current of 9, 10, and 15 mA are plotted in Fig. 4, which shows mode jumping at 10 mA corresponding to the drop of the output power in Fig. 3. The lasing mode wavelength is 1416.6 nm at the injected current of 9 mA, and other two modes around 1432 nm appear as the injection current is 10 mA. At higher injection current, the lasing mode at 1416.6 nm disappears and the lasing modes are around the wavelength of 1432 nm. The wavelength interval of 16 nm in the mode jump is equivalent to the transverse mode interval between the even and odd transverse modes as shown in Fig. 2. [4] The mode jump can result in the drop of the output power in Fig. 3 if different transverse modes have different output coupling efficiencies. [3] At 80 and 100 K, the lasing modes keep around 1417 and 1432 nm, respectively. Thus power drop cannot be observed at the temperatures.

The lasing spectra of the ETR laser are plotted in Fig. 5 at the temperatures of (a) 110, 140, 170, 200 K and (b) 240, 260, and 270 K, with the injection current between 15 and 30 mA. The curves at different temperatures are vertically shifted 20 dB for clarity. Detailed measurement shows that the mode wavelength shifts with the temperature at 0.09 nm/K. Four modes at the wavelengths of 1454.08, 1461.76, 1500.46, and 1504.18 nm coexist at 240 K, with a large wavelength interval 39 nm related to the longitudinal mode wavelength interval. We can realize 5.2 THz emission based on mode beating between the two modes with the wavelength interval of 39 nm. The detail mode spectra are difficult to exactly assign mode indices for each peak. In addition to the whispering-gallery-like modes, Fabry–Pérot type modes can also have high Q factors in the ETR laterally confined by p-electrode Au layer. [5] Furthermore, deformed ETR with rough sidewalls can result in the variation of mode wavelengths, especially the wavelength split for degenerate modes. [6]
In conclusion, output characteristics including output power versus injection current and laser spectra at different temperatures are reported for a GaInAsP/InP equilateral triangle microlaser with the side length of 10 µm. The output power drop is observed due to the transverse mode transition, which indicates the different output efficiencies for different transverse modes. The microlaser with lasing modes at the wavelength interval of 39 nm is a potential device for generating THz emission by mode beating.

References