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Ultralow Threshold Lasing in InGaAs/InGaAsP MQW Microdisk Laser*

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Abstract InGaAs/InGaAsP MQW microdisk lasers with the diameter of 2μm were fabricated by using ractive ion etching and wet chemical etching. An ultralow lasing with a threshold of only about a few microwatts was achieved when the microdisk laser was continuously pumped at liquid nitrogen temperature by Ar ion laser. The phenomena of multiple mode lasing, mode chirping and output saturation were investigated. A possible explanation is that the optical mode distribution and the competition between different modes are influenced by pump power.

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With the advance of semiconductor nanofabrication technique and the need for ultralarge scale integrated optical electronic devices, microcavity lasers have been more and more attractive. Semiconductor fabrication techniques have advanced to a stage where it is possible to make optical resonators with dimensions of the order of an optical wavelength. In this microcavity limit there is only one low loss mode that interacts with the optically active materials in the cavity. Microdisk lasers represent a class of structures capable of providing three dimensional photon confinement in the semiconductor environment. Photons can be confined in a disk by means of a whispering gallery mode (WGM), which is different from that of F-P cavity semiconductor laser. WGM optical field is constructed in a microdisk cavity due to the total internal reflectance at the circumference of the disk. There

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have been many reports on the lasing characteristics of microdisk lasers up to date[1~8]. Most of these microdisks were pulsely pumped by an optical source. In this paper, we reported the fabrication of InGaAs/GaAs MQW microdisk laser with a diameter of 2μm. An ultralow threshold lasing was achieved in this disk by continuously optically pumping.

InGaAs/InGaAsP MQW structure used in this work was grown on InP substrate by gas-source MBE technique. The detailed layer structure is shown in Fig. 1. All the epitaxial

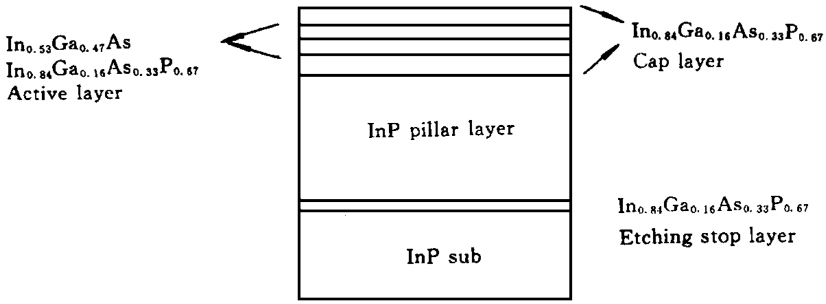

FIG. 1 Layer structure of InGaAs/InGaAsP/InP MQW microdisk laser

layers were undoped. An InGaAsP etch-stopping layer was used to prevent selective etching into the InP substrate during the mcirodisk fabrication processing. A 1μm-thick InP pillar layer was used to form a pillar to support microdisk in the air. MQW active layer consists of three 10nm-thick InGaAs quantum wells separated by 10nm InGaAsP barrier layers. The MQW active region was caped by two 70nm-thick end caps on both sides. Nanofabrication techniques including standard photolithography, reactive ion etching (RIE), and wet chemical etching were used to fabricate the microdisk lasers with the diameters of 2~20μm. Figure 2 shows a SEM image of a 2μm-diameter microdisk laser.

To study the lasing property and the spectrum characteristics of the microdisk laser, the microdisk layers were optically pumped at liquid nitrogen temperature by a continuous wave 514.5nm line of Ar ion laser. The pump beam was focused with a 40X microscope objective to a single disk laser. The diameter of the focused spot is about 10μm. Light scattered from the microdisk laser was collected through the same objective and detected by a liquid-nitrogen cooled Ge detector. The pump power absorbed by one disk is calculated by measuring the pump power focused on one disk and subtracting the reflection on the surface of disk.

FIG. 2 SEM image of a 2μm-diameter InGaAs/InGaAsP MQW microdisk laser

Figure 3 presented the lasing spectra of a 2μm-diameter microdisk laser at different pump power. With increasing the pump power, a narrow lasing peak appeared. With increasing the pump power further, some new peaks appeared and became dominant in the

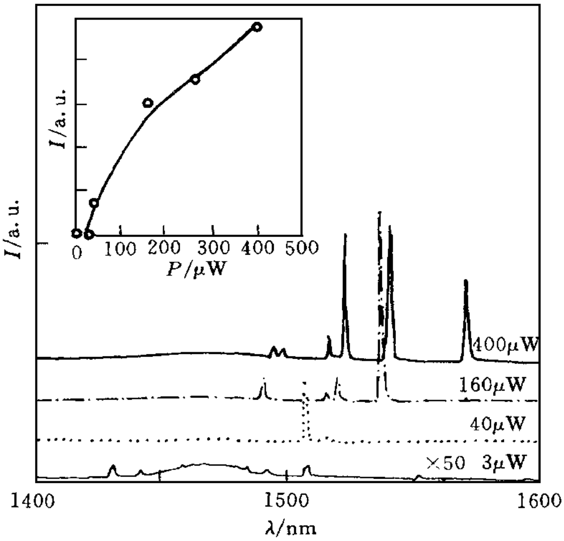

FIG. 3 Photoluminescence spectra and threshold characteristics of a 2μm-diameter InGaAs/InGaAsP MQW microdisk laser pumped at 77K

spectra. This phenomenon meant that there were multiple optical modes in the disk and the cavity Q factors and the competition capability of these modes were comparable. The chirping between different modes might be as follows: when pumping at high power, the temperature of the disk might get a little higher, resulting the changes and modification of the refractive index of the disk. This modification then resulted in the changes of the optical mode distribution and the competition between the different optical modes.

The inset of fig. 3 showed the output characteristics of the 2μm-diameter microdisk lasers. The intensity of the vertical axis indicates the integral sum of all lasing peaks in the spectrum. With increasing the pump power, the intensity of lasing line increased dramatically, indicating that lasing was reached. The threshold power was estimated to be only a few μW. It was also observed that the intensity of the lasing lines became saturated with increasing the pump power. We believe that the saturation is due to the changes of the temperature in the disk. When increasing the pump power, the temperature of the disk will get increased. The increase of the temperature will then reduce the gain in the activer region, resulting the decrease of the output intensity of the lasing line.

In conclusion InGaAs/InGaAsP MQW microdisk lasers with the diameter of 2μm were fabricated by using RIE and wet chemical etching. The lasing threshold was only about a few microwatts when pumped by Ar ion laser at liquid nitrogen temperature. Multiple mode lasing, modes chirping and output saturation were investigated when pumped at high optical pump density.

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