Journal of Crystal Growth 227–228 (2001) 343–345

JOURNAL OF CRYSTAL GROWTH

www.elsevier.nl/locate/jcrysgro

InGaAs/InGaAsP microdisk lasers grown by GSMBE

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Abstract

Optical resonance modes have been observed in optically pumped microdisk cavities fabricated from 80 Å/50 Å InGaAs/InGaAsP multiple quantum wells structures grown by gas-source molecular beam epitaxy. We have achieved optically pumped InGaAs/InGaAsP multiquantum wells microdisk lasers at a pump power threshold of $P_{th} = 150\,\mu W$ at pump wavelength $\lambda = 514.5$ nm, which was measured for a 10 μm-diameter disk with lasing emission wavelength near $\lambda = 1.6$ μm.

PACS: 42.55.P, 81.15.H, 68.65.G

Keywords: A1. Low dimensional structures; A3. Molecular beam epitaxy; B2. Semiconducting indium compounds; B3. Laser diodes; B3. Micro-disk

1. Introduction

Microcavity lasers have been the topic of many recent publications. It is known that, in the case of a microcavity laser with a resonant cavity of dimensions comparable to the lasing wavelength, there may exist only a few optical modes that are coupled with excitation states of the working materials, and the spontaneous emission coefficient of the lasing mode is much larger than that of a conventional laser. Due to the larger spontaneous emission coefficient, the lasing behavior of a microcavity laser also differs considerably from that of the conventional laser [1]. Several structures of microcavity lasers have been introduced. Among them the microdisk resonator demonstrated by McCall and coworkers [2,3] is of particular interest [4]. As the optical mode structure of the microdisk resonator is relatively simple, so more precise analyses on the photon emitting process are possible. Comparing with the Fabry–Perot mode microcavities, the microdisk resonator is easier to be realized experimentally, since the complexity of multi-layer distributed Bragg reflector, which is necessary for obtaining high quality factor in Fabry–Perot micro-resonators, being avoided. The high quality factor is achieved by the so-called "whispering gallery (WG) mode" in the microdisk resonators. The optical wave in the WG mode can be thought as a narrow photon flux concentrated near the disk edge, propagating along and reflected continually at large incident angle by the disk edge. The optical field of a WG mode is characterized by the

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PII: S0022-0248(01)00718-7

factor of $\exp(iM\theta)$, where M is the order of the WG mode. For high order WG mode, only an extremely small part of the optical flux may pass through the disk edge, so the high-Q factor is achieved. In this letter, we report the results on the micro-fabrication of InGaAs/InGaAsP multiple quantum wells (MQW) microdisk lasers and the measurement of their emitting spectra.

2. Experimental procedure

The multiquantum well epitaxial layer structure shown in Table 1 was grown by gas-source molecular beam epitaxy (GSMBE), which was formed by three parts which were etch stop layer, post layer and gain layer, respectively. First, a 100–200 nm thick InGaAs etch stop layer was grown on InP substrate, then followed by a 500 nm thick InP post layer. The gain region of the structure consists of six 80 Å thick InGaAs quantum wells separated by 50 Å thick InGaAsP barriers. The quantum wells are sandwiched between two 210 Å thick InGaAsP layers. The total thickness of this well/barrier region was 1250 Å. The quaternary InGaAP and ternary InGaAs layers were lattice matched to InP and the quaternary had an energy band-gap corresponding to a wavelength of $\lambda_g = 1.1$ µm. All layers were grown nominally undoped. Microdisks, approximately 10 µm in diameter and regularly spaced every 20 µm, were formed by an ion beam etch and selective etch process. Standard photolithography and dry etching were used to pattern cylinders with 10 µm diameters (as shown in Fig. 1a). A 3HCl : H_2O solution was used to selectively etch away the InP around and below the quantum wells while leaving an InGaAsP well/barrier disk unetched. SEM images of the resulting disk structures are shown in Fig. 1b.

Table 1
Layer structure used in this study

Material	Thickness (Å)	Doping
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	210	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	50	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	50	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	50	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	50	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	50	*i*
$In_{0.53}Ga_{0.47}As$	80	*i*
$In_{0.84}Ga_{0.16}As_{0.33}P_{0.77}$	210	*i*
InP	5000	*i*
$In_{0.53}Ga_{0.47}As$	1000–2000	*i*
InP	Substrate	$n = 4 \times 10^{18}\,cm^{-3}$

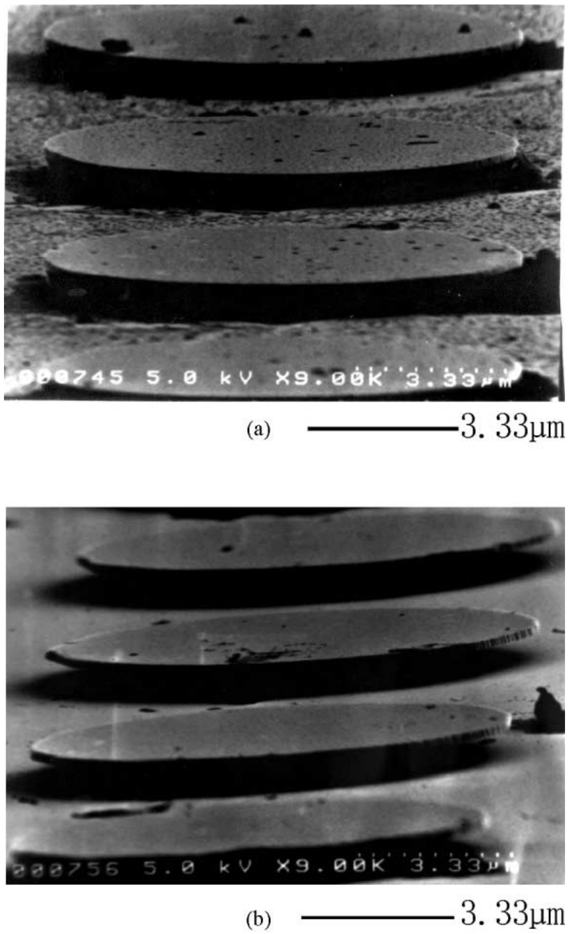

Fig. 1. (a) SEM image of a 10 µm-diameter and 0.5 µm high microcylinder array. (b): SEM image of a 10 µm-diameter and 20 µm-spacing microdisk array.

3. Measurement and results

The microdisks were cooled to the temperature near that of liquid nitrogen and excited with Ar^+ ion laser operating at a wavelength of 514.5 nm with pulse width 230 ps and duty cycle 50 : 1. Luminescence from the top face of the disk and a small fraction of the laser radiation were scattered into the collection optics. The spectra of the luminescence and laser radiation were analyzed using a 0.25 m spectrometer, a 600 g/mm grating and a cooled Ge detector array. The spectral resolution was 1 nm. Individual disk was pumped at 85 K with 514.5 nm laser pulses focused to a spot size much smaller than the disk diameter. We note that microdisk laser with large diameter has high threshold due to its lager pumped disk area. Due to the small pumped disk area and the strong coupling between optical mode and the gain medium, the threshold of a 10 μm microdisk laser is about 150 μW. The emission light intensity versus the pump power was plotted in Fig. 2. Fig. 3 is the emission spectra of the microdisk laser above threshold, which showed that only one mode dominated in the cavity and the peak wavelength was at near 1.6 μm.

4. Conclusion

Low dimensional structures can be used to modify the spontaneous emission properties of the active medium significantly. We achieved microdisk lasers in a strongly guided semiconductor waveguide grown by GSMBE. The lasing action in microcavity lasers with an optical wavelength-size in one or three dimensions takes advantage of the large enhancement of stimulated emission in these structures and the unwanted dipole emission was suppressed. Therefore, MBE is a good method to realize low-dimensional devices, which allows us to study spontaneous emission and lasing in low-dimensional structures.

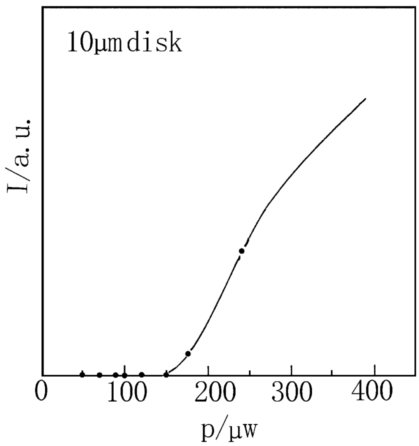

Fig. 2. The light intensity as a function of the pump power for a 10 μm microdisk laser.

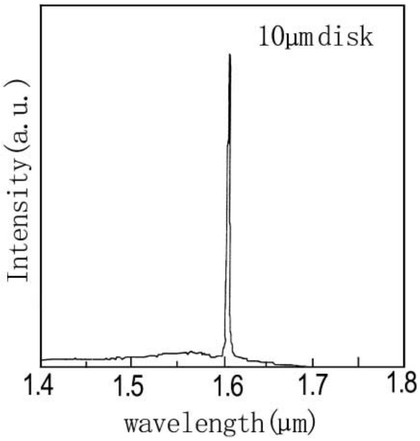

Fig. 3. The emission spectra of a 10 μm-diameter microdisk Laser.

Acknowledgements

The authors would like to thank Prof. L.J. Wang and Y. Liu for providing the photolithography. They are also grateful to Dr. Z.Y. Zhang for dry etching.

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