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Widely Tunable InAs/InP Quantum-Dot External-Cavity Laser with Bent-Waveguide Structure

F. Gao, S. Luo, H.M. Ji, T. Yang*

Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors,
Chinese Academy of Sciences, P.O. Box 912, Beijing 100083, China
Phone: +86-10-82304529 E-mail: tyang@sme.ac.cn

Abstract

We report a widely tunable InAs/InP quantum-dot external-cavity laser grown by metal-organic vapor phase epitaxy. The gain device is processed with a bent-waveguide structure and antireflection/high-reflection facet coating, which are effective for suppressing the inner-cavity lasing and broadening the tuning bandwidth. A widely tunable range of 140 nm across the wavelength from 1442 nm to 1582 nm is achieved. The maximum output power from the EC laser reaches 20 mW at the injection current of 2500-mA.

1. Introduction

Broadband tunable laser sources play an essential role in a wide range of applications including precision measurement, biomedical treatment and environment monitoring. Furthermore, lasers emitting in the 1.55 μm wavelength band are of great interest for fiber telecommunication applications such as dense wavelength-division multiplexing (WDM) system [1]. Compared with traditional quantum well lasers, EC lasers based on quantum dot (QD) gain media are well suitable for low injection current and broadband tuning operation owing to their unique features. Firstly, the characteristic of large inhomogeneous broadening occurring in self-assembled QDs is beneficial to broaden the gain spectra of a QD device [2]. Secondly, the relatively low ground-state saturation gain makes the QD excited states easier to be filled at a fairly low current density [3]. For GaAs-based InAs QD-EC lasers, good performances have been achieved [4, 5]. However, the difficulty of the InAs/GaAs QD material to reach the wavelength of 1.55 μm and beyond results in much attention on the InP-based QD material system. So far, only a few results have been reported on tunable InAs/InP QD-EC lasers [6, 7].

In this paper, we demonstrate a widely tunable external-cavity laser emitting in the 1.55 μm wavelength band, based on InAs/InP QDs grown by metal-organic vapor phase epitaxy (MOVPE). Bent-waveguide structure and antireflection (AR)/high-reflection (HR) facet coating for the device are adopted to suppress the inner-cavity lasing so that the EC QD laser can work under higher injection level, thus its tuning range in the short wavelength side can be greatly extended. A broad tuning bandwidth of 140 nm across the wavelength from 1442 nm to 1582 nm is demonstrated and a maximum output power of 20 mW is obtained at an injection current of 2500 mA.

2. Experimental detail

The InAs/InP QD laser samples used in this study were grown by commercially AIXTRON 3×2 FT MOVPE system on exactly (100) oriented n-type InP substrates. The active region of the QD samples consists of seven stacked InAs-QD layers using InGaAsP (1.1Q) as barriers. The QD layers were formed by deposition of 3.3 monolayers of InAs and the total density of the stacked QD layers is approximately 3×10^{11} cm^{-2}. The active layers were embedded in a 150 nm thick 1.1Q waveguide core, providing both carrier and optical confinement. More details of material growth can be found elsewhere [8]. For device fabrication, 6 μm wide bent-waveguides were fabricated using standard optical lithography and wet etching, and the main waveguide structure parameters are shown in Fig. 1(a). A HR dielectric stack (R ≈ 80%) is deposited on straight-waveguide facet, while the bent-waveguide facet is coated with AR (R≈ 1%) stack.

The QD laser was then investigated by grating-coupled EC arrangement in the Littrow configuration as shown in Fig. 1(b). The radiation emitted from the front facet was collimated with an AR-coated aspheric lens, the grating provided optical feedback in the first diffraction order with a groove density of 600 lines/mm and blazed wavelength of 1.6 μm. Wavelength tuning was achieved by changing the incidence angle of the grating. The emission from the straight waveguide facet of the QD gain device was collected via an optical fiber bundle into the grating monochromator to perform emission spectrum measurements.

3. Results and discussion

The tuning spectra of the bent-waveguide InAs/InP QD-EC laser are evaluated at the pulsed injection of 1500 mA (1 kHz repetition rate and 3% duty cycle) at 18°C, as shown in Fig. 2. A widely tuning range of 140 nm is achieved, with the wavelengths ranging from 1442 to 1582 nm. As shown in the figure, the inner-cavity lasing is effectively suppressed in the most region of the EC tuning wavelengths, which profit from the bent-waveguide structure and the facet AR coating. In the extremely long wavelength side, the inner-cavity lasing appears, which can be explained by the decreased material gain caused by the low density of states at the corresponding EC lasing energy. Thus, the EC lasing is not strong enough to suppress the inner-cavity lasing at such large injection current.

Fig. 3 shows the threshold current density and output power of the bent-waveguide InAs/InP QD-EC laser as a function of tuning wavelength. The minimum threshold current is observed around 1560 nm where the as-cleaved gain device exhibits a peak in the ground state gain spectra. Another lower threshold current is located around 1475 nm, which corresponds to the peak region of the excited state gain. The corresponding two peaks in the output power curve are also from the contribution of the two states. Besides, the threshold current slightly increases and output power slightly decrease in the wavelength range between the ground and first excited states due to the decreased optical gain in this region. The maximum output power of 20mW is obtained at the injection current of 2500 mA. Because the measurements of the output power are performed on the straight waveguide facet with HR coating, the actual output power from the laser would be greater. Under a 2500mA injection, the tuning expands towards the short wavelength region because of the high energy filling at the increased injection current.

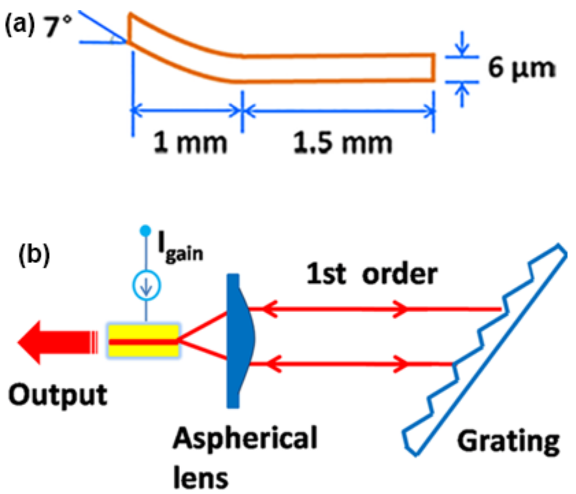

Fig. 1 Schematic of QD bent-waveguide structure (a) and external-cavity laser in Littrow configuration (b).

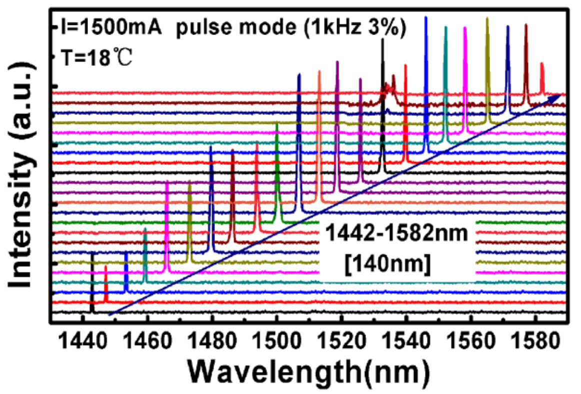

Fig. 2 Tuning spectra of 2.5-mm-long bent-waveguide InAs/InP QD-EC laser at pulsed injection current of 1500 mA.

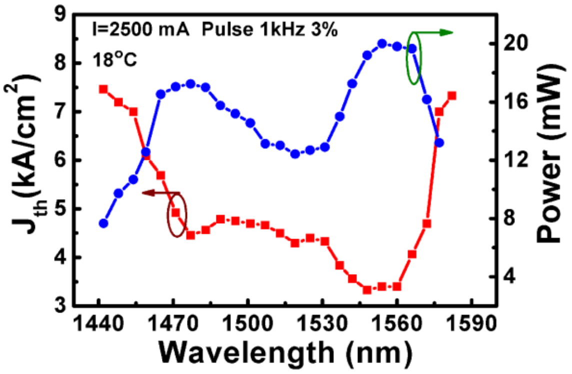

Fig. 3 Threshold current density and output power as a function of the tuning wavelength for the QD-EC laser.

4. Conclusions

In conclusion, we have demonstrated a widely tunable InAs/InP quantum dot laser with external-cavity arrangement in Littrow configuration, grown by MOVPE. It is found that using the bent-waveguide structure and AR/HR facet coatings can effectively suppress the inner-cavity lasing and broaden the tuning range. A tuning range of 140 nm (1442 nm-1582 nm) and a maximum output power of 20 mW are achieved.

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