High performance index-coupled distributed feedback InAs/GaAs quantum dots-in-a-well lasers with laterally corrugated waveguides

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Abstract: We demonstrate an index-coupled distributed feedback InAs/GaAs quantum dots-in-a-well laser using a laterally corrugated ridge waveguide. Stable ground-state single-mode emission at 1224 nm with a side-mode-suppression-ratio more than 40 dB and low threshold is achieved.

OCIS codes: (250.5300) Photonic integrated circuits; (250.5590) Quantum-well, -wire and -dot devices; (250.5960) Semiconductor lasers.

1. Introduction

Distributed feedback (DFB) lasers with stable single-longitudinal-mode emission and narrow linewidth are key devices in high-bit-rate optical communication systems [1-2].Compared with the MQWs material system, self-organized InAs/GaAs quantum dots (QDs) are expected to exhibit better performances due to their atomic-like properties and delta-function like discrete density of states [3].As a result, InAs/GaAs QDs based DFB lasers have captured an increasing interest [4-5].Most of such devices are fabricated either with a conventional buried-grating DFB lasers fabrication technology or a loss coupled metal grating deposited laterally to the ridge waveguide. Although promising device performances are demonstrated, various drawbacks of the devices are brought in at the same time. For example, in the buried-grating DFB structure, regrowth steps are required to complete the epitaxy of the laser structure after grating fabrication, which is difficult for GaAs based materials due to oxidation of Al-containing cladding layer during the regrowth. Despite the fact that InGaP cladding layer can be used as the grating layer to avoid the Al oxidation in the step of regrowth, such regrowth process complicates the device fabrication, increases the cost of the device and affects the device performance and yield [5].While in the loss coupled metal grating structure, the injection threshold current increases and photon life time is reduced due to the extra optical loss in the metal grating, which limits its practical application. In this manuscript, a laterally index-coupled QDs DFB (LC-DFB) laser with three-order sidewall gratings is presented to simplify the fabrication process. To improve the carriers' injection efficiency, dots-in-a-well (DWELL) structure is used as the active material for the device. Longitudinal mode selection and lateral optical confinement are realized simultaneously by the laterally corrugated ridge waveguide.

2. Device design and fabrication

A schematic structure of the LC-DFB laser is shown in Fig. 1(a), where third-order deep gratings with duty cycle γ of about 0.5 are along the sidewalls of the ridge waveguides. The coupling coefficient of the device is one of the most important parameters, which determines the performances of DFB lasers such as threshold current, SMSR and

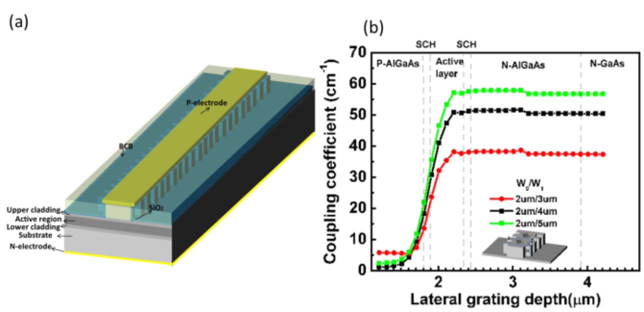

Fig.1(a) Schematic diagram of the quantum dot LC-DFB laser, (b)calculated coupling coefficients as a function of the lateral grating depths for different waveguide dimensions.

single-mode yield. The coupling coefficient κ versus the lateral grating depth for different waveguide dimensions are depicted in Fig.1 (b). W_0 is fixed at 2 μm and W_1 is chosen to be 4 μm for our devices and the cavity length is chosen to be 1.5 mm in order to avoid the excited state lasing which is much easier to appear with a short cavity length ($L < 1.2$ mm), less QD stacks and high injection current.The coupling coefficient-length product (κL) of our device is calculated to be 2.7. The QD laser wafers were grown on a Si-doped GaAs (100) substrate by one step molecular beam epitaxy process. InAs dots were embedded in an InGaAs quantum well which formed the DWELL structure. The material structure and the fabrication process of the device can be found in [6] ,what's different is that the ridge waveguide and lateral grating are defined simultaneously by electron beam lithography in the LC-DFB and Benzocyclobutene (BCB) was used to planarize the waveguide and gratings. For comparison and analysis, Fabry-Pérot LDs with a waveguide width of 2 μm was also fabricated simultaneously on the same wafer.

3. Experimental results and discussion

The light output power/injection current/voltage (L-I-V) characteristics of the fabricated DFB lasers with length of 1500 μm under continuous-wave (CW) operation are summarized in Fig. 2(a). A threshold current (I_{th}) as low as 23 mA ,corresponding to threshold current densities of 511 A/cm^2, and an output power of 20 mW/facet at 100 mA injection current were achieved. From the reciprocal of the measured differential efficiencies versus cavity length of Fabry–Pérot laser, we can get the internal optical loss of Fabry–Pérot laser, which is 3.20 cm^{-1}. By knowing the internal loss, mirror loss and the slope efficiency of the QD Fabry–Pérot laser, the internal optical loss and threshold modal gain of DFB QD lasers are extracted to be 4.67 cm^{-1} and 12.27 cm^{-1}, respectively. This means that the internal optical loss introduced by lateral DFB grating is 1.47 cm^{-1}, which is much lower than the loss coupled DFB lasers with lateral metal grating.Fig.2 (b) shows the optical spectra of the LC-DFB laser at an injection current of 45 mA (~2 I_{th}).The lasing wavelength centered at 1224 nm with a SMSR of more than 40 dB has been realized. When the injection current increases to 100 mA (~4.3 I_{th}), stable single mode can still be maintained. Both the single mode operation at high output powers and the good SMSR show that sufficient coupling can be achieved by the laterally patterned grating. Wavelength shift of 0.066 nm/K for LC-DFB lasers were observed in the range of 15 ℃–49 ℃ as shown in Fig.2 (c), and this value was much smaller than that of Fabry–Pérot lasers.

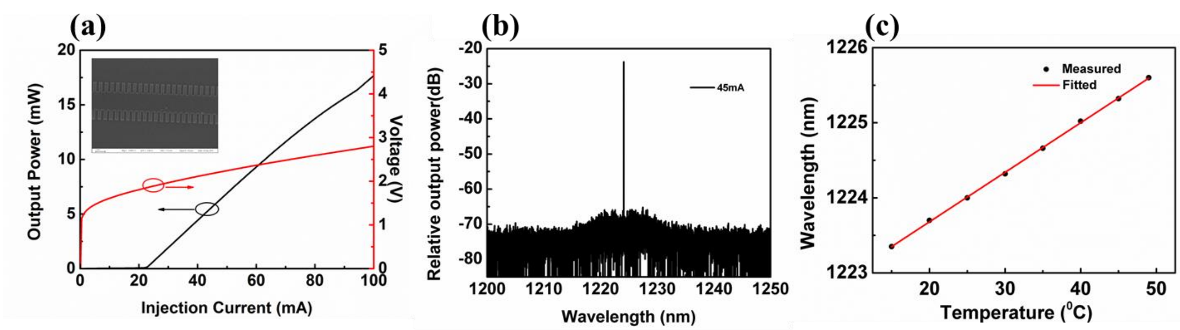

Fig.2 (a) Measured L-I-V curve of the fabricated quantum dot LC-DFB laser .The inset shows the top-view SEM image,(b) measured lasing spectra of the fabricated quantum dot LC-DFB laser and (c)temperature dependence of the emission wavelength at the same injection current.

4. Conclusions

An index-coupled distributed feedback InAs/GaAs DWELL laser using a laterally corrugated ridge waveguide is demonstrated. Longitudinal mode selection and lateral optical confinement are realized simultaneously by the laterally corrugated ridge waveguide with a third-order sidewall Bragg grating, which is formed by one-step inductively coupled plasma dry etching. This work is supported by A*STAR SERC Future Data Center Technologies, Thematic Strategic Research Programme under Grant No. 112 280 4038 and A*STAR -MINDEF Science and Technology Joint Funding Programme under Grant No.122 331 0076.

5. References

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