InAs/InP(100) quantum dot laser with high wavelength stability

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InAs/InP(100) quantum dot lasers with lasing wavelength insensitive to operation temperature are demonstrated. Very high wavelength stability of 0.088 nm/K in the temperature range 80–310 K is obtained, which is 6.2 times lower than that of the reference quantum well laser.

Introduction: The lasing wavelength of a semiconductor laser inevitably changes with varying the operation temperature, which is, however, not desirable for applications requiring specific and stable light wavelength. Thus, laser diodes with wavelength insensitive to temperature are fascinating and can drastically ease the critical requirements on precise temperature control. The quantum dot (QD) laser is a good candidate [1–4]. Temperature coefficients of 0.09 [1], 0.11 [2], 0.14 [3] and 0.166 [4] nm/K have been reported for InAs/GaAs QD lasers by different groups, which are several times lower than the quantum well counterpart. But only few studies of wavelength stability have been reported for InAs/InP QD lasers [5]. In this Letter, we demonstrate InAs/InP(100) QD lasers with wavelength stability of 0.088 nm/K between 80 and 310 K measured under continuous-wave (CW) mode, which is 6.2 times lower than the reference InGaAs/InP QW laser working in the same wavelength region. Maximum output power per facet is measured as 10 mW under CW mode at 20°C, with the lasing peak centred at 1.67 μm.

Experiment: The laser structure consisting of five-stacked InAs QD layers embedded in InGaAsP waveguide ($\lambda_g = 1.18$ μm) was grown on nominally (100) exact oriented *n*-type InP substrate by gas source molecular beam epitaxy. Each QD layer was formed by deposition of 3.5 monolayers InAs at 485°C with InAs growth rate of 0.1 ML/s. Five QD layers separated by 40 nm-thick InGaAsP space layers are embedded in the 200 nm InGaAsP waveguide. The bottom and top cladding layers are a 600 nm *n*-InP buffer and 1.5 μm *p*-InP followed by a 200 nm *p*-InGaAs contact layer. Ridge waveguide QD lasers were fabricated with stripe width of 6 μm and length of 1.5 mm. The chips with a cleaved facet without coating were bonded on a heatsink and all the device tests were carried out in CW mode. The output power measurements were performed by a Melles Griot optical power meter equipped with an integrating sphere Ge detector. The lasing spectra were collected by a Fourier transform infrared spectrometer using an InSb detector, while the devices were loaded in a cryostat with temperature varying from 80 to 310 K.

Results: The light output power characteristic of the QD laser under CW operation at the heatsink temperature of 20°C is shown in Fig. 1. The QD laser is lasing at 1.67 μm as shown in the inset of Fig. 1, with threshold current density of 3.7 kA/cm^2. Maximum output power per facet is measured as about 10 mW, with the power slope efficiency of 43 mW/A just above the threshold.

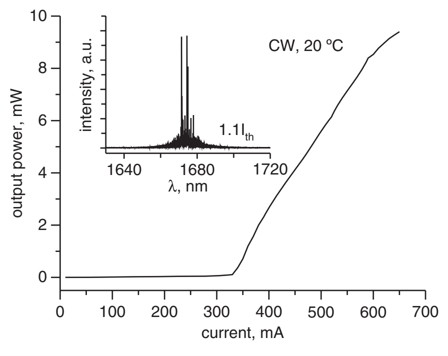

Fig. 1 *Output power against injection current of QD laser measured at 20°C in CW mode*

Inset: Lasing spectrum at operation current of 1.1I$_{th}$

Since the bandgap shrinks with increase in temperature, a higher temperature will inevitably result in a red-shift of the lasing wavelength.

Fig. 2 shows the lasing spectra of the QD laser at different temperatures with injection current of 1.2I$_{th}$ in CW mode. The red-shift of the lasing peak is less than 20 nm in the temperature range 80–310 K. The temperature stability of the lasing wavelength of the QD laser and a reference QW laser were measured at operation temperatures from 80 to 310 K in steps of 10 K, as shown in Fig. 3. For the QD laser, the lasing wavelength measured at 1.2I$_{th}$ shifts from 1659.4 to 1677.8 nm when the operation temperature is raised from 80 to 310 K, resulting in a remarkable low temperature coefficient of 0.088 nm/K. In contrast, the wavelength of the reference QW laser shifts from 1449.4 to 1572.8 nm at an average rate of 0.548 nm/K. The temperature coefficient of the lasing wavelength of the InAs/InP QD laser is 6.2 times lower than that of the QW counterpart, indicating that the QD lasers have much better wavelength stability. Broad gain profile [6, 7] and state-filling effect [4] in the QD lasers are likely playing an important role in reduction of the temperature sensitivity of the lasing wavelength. The broad gain profile of QD lasers drastically prevents mode-hopping in the lasing spectrum. Mode-hopping to long wavelength with raised temperature frequently occurs in the QW laser and is the main reason for the QW laser's low wavelength stability. Moreover, the state-filling effect in the QD state ensemble composed of states from individual QDs with different sizes may result in mode-hopping to short wavelength, which partially compensates for the red-shift of the cavity modes during raising the operation temperature.

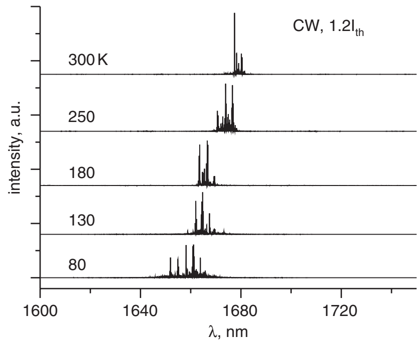

Fig. 2 *Temperature variation of lasing spectrum over range 80–300 K*

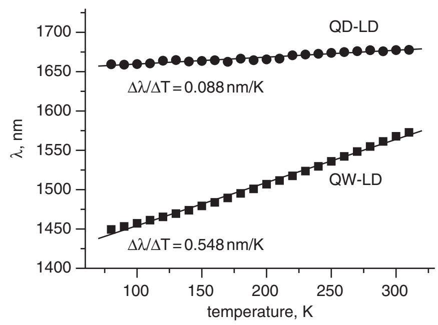

Fig. 3 *Temperature dependence of lasing wavelength for InAs/InP QD laser and reference QW laser*

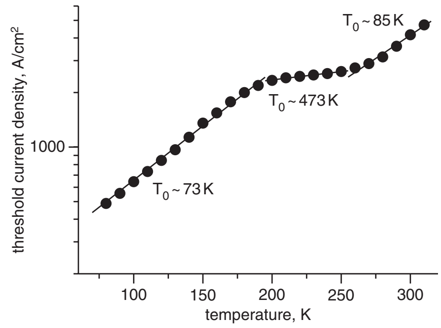

Fig. 4 *Temperature dependence of threshold current density for InAs/InP QD laser*

The temperature dependence of the threshold current density is shown in Fig. 4. Three sections are found in the curve of I$_{th}$ against temperature, corresponding to characteristic temperatures of 73 K(80–190 K), 473 K(200–250 K), and 85 K(260–310 K).

Conclusion: InAs/InP(100) quantum dot lasers with high wavelength stability of 0.088 nm/K have been demonstrated in the temperature range 80–310 K. The temperature coefficient of the lasing wavelength for QD lasers is 6.2 times lower than that of the reference QW counterparts.

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