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Achieving O-band InAs Quantum Dot Laser Operation at 200 °C

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***Abstract*—We demonstrate O-band InAs quantum dot laser operation up to 202 °C. A Fabry Perot laser device with as-cleaved facets and a co-doped scheme within the active region enables ultra-high temperature laser operation without requiring high-reflective facet coatings.**

Keywords—Semiconductor Laser, InAs, Quantum Dots, Co-doping, p-modulation, High Temperature

I. Introduction

Recent developments in semiconductor lasers promise utility for various applications including monitoring environment, natural resources, and telecommunication [1, 2]. In harsh and uncooled environments, InAs/GaAs quantum dot (QD) based lasers are better candidates as compared to quantum-well based lasers for O-band operation, because of their superior temperature characteristics. This is due to the form of the available states and how this changes with increasing temperature. Previously laser operation at ultra-high temperatures, the highest for any type of laser, has been achieved by combining QD lasers with high-reflective (HR) coatings on the laser facets. Kageyama et. al. demonstrated InAs QD laser operation up to 220 °C by utilizing HR coatings on both facets of an InAs QD laser with eight layers of QDs in the active region [3]. Huang et al., utilized a SiO_2/Ta_2O_5 multilayer stack as the HR coating on the cleaved facet of InAs QD laser [4]. Such coatings are not suitable for lasers used as part of photonic integrated circuits and when used on both facets reduce the output power that can be achieved. HR coatings can also lead to enhanced thermal stress on laser devices [5].

The impact of different active region schemes such as undoped, n-doped, p-doped, and co-doped has been studied for achieving improvement in InAs/GaAs QD laser operation. Zunren et al., demonstrated InAs QD laser with p-type modulation doping operation up to 160 °C under pulsed biasing [6]. Deng et al., demonstrated co-doped InAs QD lasers with a lower threshold compared to that of p-doped, n-doped and undoped laser devices [7]. A co-doped active region scheme constitutes p-modulation doping adjacent to the n-doped InAs QD layers and thus such a laser device benefits from the p-type modulation and n-doped QD layers. In an optimised co-doped InAs laser device we demonstrate lasing operation up to 202 °C without relying on any HR coatings. A reference undoped InAs QD laser and co-doped InAs QD laser samples with InAs QD layers were epitaxially grown by using molecular beam epitaxy.

II. Results and Discussion

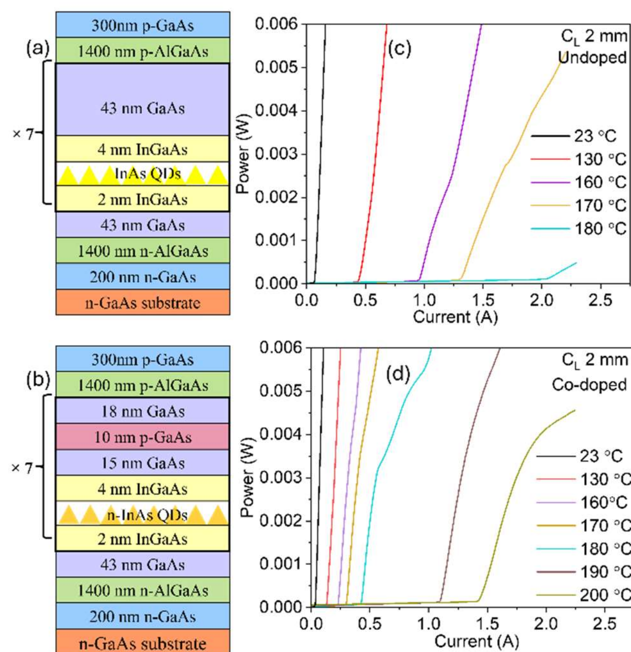

Fig. 1. Schematics of the (a) undoped, and (b) co-doped InAs quantum dot (QD) laser structure. Temperature dependent power-current plots of the (c) undoped, and (d) co-doped InAs QD laser devices with a cavity length 2 mm.

Figure 1(a-b) shows schematics of the undoped, and co-doped InAs QD laser structure grown on the n-GaAs substrate. InAs QD laser devices with 2 mm cavity length (C_L), 50 µm width, and with cleaved facets were implemented by using standard microfabrication process steps. The InAs QD laser devices were characterised at different temperatures under pulsed-bias conditions, with a pulse width of 1000 ns and a repetition rate of 5 kHz. Undoped InAs QD laser operated up to 180 °C (Figure 1(c)), whereas co-doped laser operated up to 200 °C and are shown in Figure 1(d). Figure 2(a) shows the

O-band (1260 nm to 1360 nm) wavelength spectra of a co-doped InAs quantum dot laser capable of operating from room temperature to 202 °C.

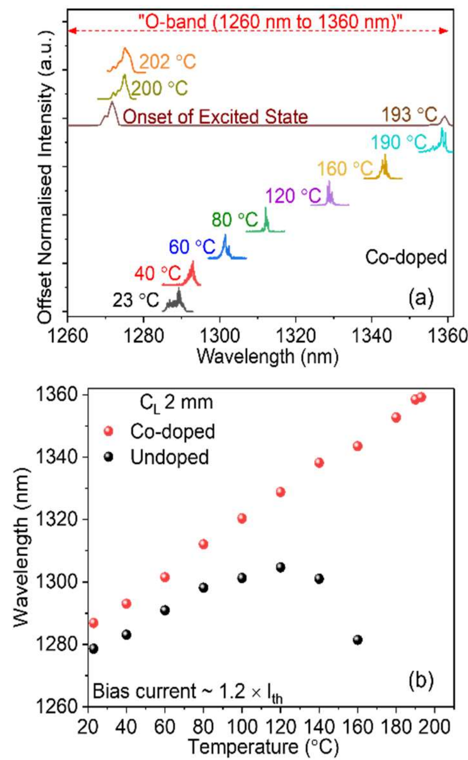

Fig. 2. (a) O-band wavelength spectra of a co-doped InAs quantum dot laser with cavity length 2 mm, operating from room temperatures to 202 °C. (b) Peak wavelengths of ground-state lasing from co-doped and undoped InAs quantum dot lasers with a cavity length (C_L) of 2 mm.

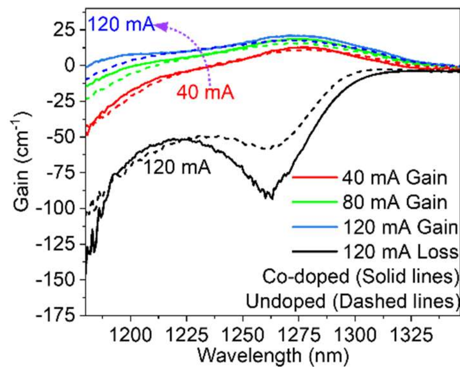

Fig. 3. Gain and loss plots of the co-doped (solid lines) and undoped (dashed lines) InAs quantum dot (QD) based multisegmented devices measured at different current bias levels.

The co-doped laser exhibits ground state (GS) lasing from ~1287 nm at room temperature to ~1359 nm at 193 °C. At higher temperatures excited state (ES) lasing dominates the spectra (Figure 2(a)). Bias currents of 1.2 × I_{th} based on PI measurements (Figure 1(d)) were used for acquiring wavelength spectra up to 200 °C. For ES spectra obtained at 202 °C, an estimated ~1.2 × I_{th} bias current value based on extrapolation of I_{th} vs temperature trend (not shown) was used. Figure 2(b) shows the variation of GS peak wavelength with temperature obtained for the co-doped and undoped InAs QD lasers. The co-doped laser shows a typical red shift with a linear variation of wavelength with increasing temperature up to 193 °C following the underlying band gap in agreement with the Varshni equation. The undoped laser, however, showed GS lasing up to 160 °C, with its GS lasing wavelength shows linear behaviour up to 120 °C. However, at temperatures above 120 °C, the peak wavelength deviates from a linear trend and exhibits blue-shift. This behaviour is a result of the wavelength-shift induced to maintain the gain at high temperature being larger than that due to the change in the underlying band-gap.

Figure 3 shows gain and loss plots of the co-doped (solid lines), and undoped (dashed lines) InAs QD based multisegmented devices measured at different current bias levels. Gain for the co-doped InAs QD laser is consistently higher as compared to that of undoped sample. This is consistent with the higher absorption seen in the co-doped sample, compared to the undoped material, which can be attributed to n-doping changing the dot potential and/or increasing the density of QDs [7]. Co-doped InAs QD lasers demonstrated ultra-high operating temperature up to 202 °C, benefiting from the combined advantages of p-modulation doping and direct n-type doping in the InAs QD active region.

Acknowledgments

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