Modal gain in single-layer InAs/InP(100) quantum dot amplifiers in the 1.6 to 1.8 μm wavelength range

Modal gain in single-layer InAs/InP(100) quantum dot amplifiers in the 1.6 to 1.8 µm wavelength range

Y. Jiao, P.J. van Veldhoven, M.K. Smit, E.A.J.M. Bente

COBRA, Eindhoven University of Technology, The Netherlands

E-mail: y.jiao@tue.nl

The wavelength range from 1.6 to 1.8 µm is important to the application of optical coherent tomography (OCT) for its deeper penetration through the tissue due to a reduction of scattering [1]. In order to benefit of the fast sweeping speed and low cost potential of a swept-source OCT (SS-OCT), a tunable laser using semiconductor optical amplifiers (SOAs) as its gain material is desired. We have demonstrated a tunable laser using a 5-layer InAs/InP(100) quantum dot SOAs (QD-SOAs) in the 1.6 to 1.8 µm wavelength range [2]. The gain provided by the QD-SOA is low, which made the laser operate just above threshold. In this contribution, we present new single-layer InAs/InP(100) QD-SOAs, which provide more gain than the previous 5-layer QD amplifiers.

The single-layer QD-SOA structure has been demonstrated as a ridge waveguide laser operating around 1.7 µm [3]. But the modal gain of this type of QD-SOA has not been studied yet. We have fabricated 26 single-layer QD-SOA sections with various lengths, 10 of which show good quality and are used in the gain calculation. The cross-section of the SOA is shown in Fig. 1(a). The structure is grown by low-pressure metal organic vapor phase epitaxy (MOVPE) on n-type InP(100) substrate. The InAs QDs are grown on top of a thin (1.6 nm) InAs quantum well (QW) layer. The total active region is embedded in the center of a 500 nm thick Q1.25 waveguiding layer. The gain spectra are derived by analyzing the amplified spontaneous emission (ASE) spectra from different lengths of amplifiers using the method described in [4]. The measurement is done under several injection current densities and at several temperatures.

The measured modal gain spectra are shown in Fig. 1(b). It can be seen from the figure that as the current density increases, the gain increases dramatically. The peak gain at 3 kA/cm^2 at 20 degrees is more than 8 cm^{-1}, which is already higher than for a 5-layer QD layer (6 cm^{-1} at 3 kA/cm^2 at 15 degrees [4]). The peak gain can be as high as 18 cm^{-1} at 5 kA/cm^2 at 0 degree. As the current density increases, a blue shift (more than 100 nm) of the gain peak is observed. This is mainly due to the larger contribution from the excited state at higher current density. The gain can also be improved by lowering the device temperature. For example, the improvement of the gain is about 2 cm^{-1} per 10 degrees temperature drop at 5 kA/cm^2. A slight blue shift is also observed as the temperature drops. It can be explained by the suppression of carrier recombination in the wetting layer at lower temperatures. Thus more carriers will be captured by the excited state.

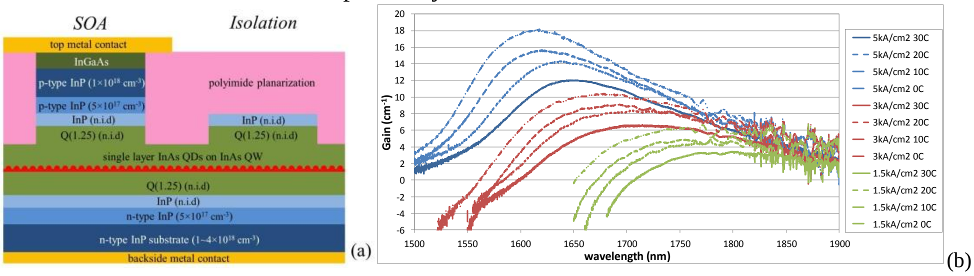

Fig. 1 (a) The cross-section of the single-layer QD-SOA. (b) Measured modal gain spectra of single-layer QD-SOAs under three current densities and four temperatures.

In conclusion, single-layer InAs/InP(100) QD-SOAs are fabricated and characterized. The calculated gain spectra show much higher gain than 5-layer QDs. A blue shift of the peak gain is observed both at different current densities and temperatures. This single-layer QD-SOA is a good candidate to be used in the new generation tunable laser in the 1.6 to 1.8 µm.

This work was supported by the Brainbridge Project, China Scholarship Council (CSC) and the NRC Photonics Program.

References

[1] V. M. Kodach, J. Kalkman, D. J. Faber, and T. G. van Leeuwen, "Quantitative comparison of the OCT imaging depth at 1300 nm and 1600 nm" Biomedical Optics Express **1**, 176 (2010).

[2] B. W. Tilma, Y. Jiao, J. Kotani, B. Smalbrugge, H. P. M. M. Ambrosius, P. J. Thijs, X. J. M. Leijtens, R. Notzel, M. K. Smit, and E. A. J. M. Bente, "Integrated Tunable Quantum-Dot Laser for Optical Coherence Tomography in the 1.7 µm Wavelength Region," IEEE Journal of Quantum Electronics , **48**, 87-98 (2012).

[3] J. Kotani, P. J. van Veldhoven, T. de Vries, B. Smalbrugge, E. A. J. M. Bente, M. K. Smit, and R. Notzel, "First demonstration of single-layer InAs/InP (100) quantum-dot laser: continuous wave, room temperature, ground state," Electronics Letters, **45**, 1317 (2009).

[4] B. W. Tilma, M. S. Tahvili, J. Kotani, R. Notzel, M. K. Smit, and E. A. J. M. Bente, "Measurement and analysis of optical gain spectra in 1.6 to 1.8 µm InAs/InP (100) quantum-dot amplifiers," Optical and Quantum Electronics, **41**, 735 (2009).