Simulation and Design of InGaAlAs O Band PCSELs

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Abstract *We present a high power, high efficiency, single mode InGaAlAs PCSEL, designed using 3D coupled wave theory approach. An output power of more than 400mW with a wall plug efficiency of 15% at 25℃ was measured.*

Introduction

Photonic Crystal Surface Emitting Lasers (PCSELs) are emerging as a promising and disruptive new technology, attracting significant attention due to their potential applications in laser processing, free space optical communication (FSO), structured light, and light detection and ranging (LIDAR). There is also potential for the PCSEL to displace incumbent laser technologies such as distributed feedback lasers (DFBs) and vertical cavity surface emitting lasers (VCSELs) in communications applications.

In this work, we report on the simulation and design of an InGaAlAs PCSEL at 1.3μm. Our study aims to simulate and design a high efficiency, single mode Indium Phosphide based PCSEL to improve on those recently reported at 1.3μm and at 1.55μm [1-5]. Our results suggest that, as with previously reported PCSELs, the devices presented here offer distinct advantages over incumbent technologies. PCSELs are scalable in power and area while maintaining single transverse mode emission, low beam divergence and have a symmetric near field and far-field, which improves coupling efficiency. Furthermore, the use of an InGaAlAs active region results in improvements to over temperature and dynamic performance, due to a higher conduction band offset and higher differential gain than InGaAsP.

This paper discusses the design of the PCSEL including the photonic crystal (PC) design based on Coupled Wave Theory (CWT).

Simulation and Design

CWT is a very fast - 0.1s, successful semi-analytic model for simulating PCSELs. Detail of the theory is presented in [3]. Light generated in the active is evanescently coupled into the Photonic Crystal (PC). Standing waves are formed through diffraction in the PC: 180° direct and 90° indirect coupling at the symmetric Γ point. Coupling of the 4 Bloch waves within the PC occurs, leading to vertical emission. The four-wave coupling at the Γ point is described by a set of matrices, determined by the Fourier component of the PC, the 1D slab vertical mode and the Green's slab function within a 3D framework of CWT. The eigenvalue equation is solved and the solutions are the radiation constants and resonant frequencies of the 4 waves in either the infinite or finite domain, identifying the highest Q (lowest modal threshold gain) mode. Consequently, PCSELs can exhibit single mode, high brightness and low beam divergence lasing with output powers that can scale with area.

The PC pattern used is based on a double

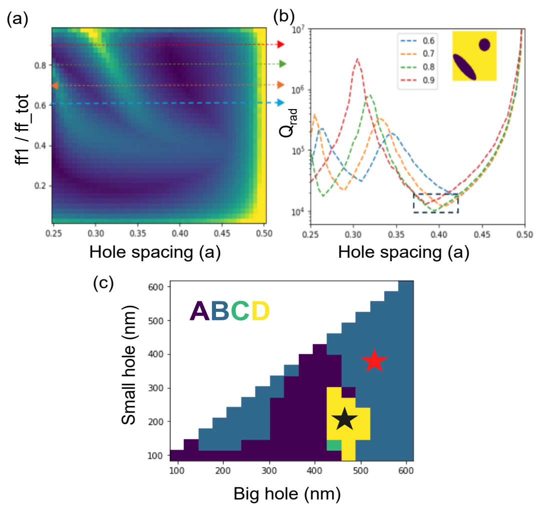

Fig. 1: Simulations: (a) Contour plot: Q_{rad} (color) as a function of FF ratio and hole-spacing (units = lattice constant a), (b) slice through contour plot4 the inset shows a PC design (c) 2D plot – dominant lasing mode for given hole depths in DL design.

lattice (DL) with elliptical and circular holes. CWT is used in the simulation and design of the device: key parameters are spacer layer thickness, fill factor (FF), lattice design, PCSEL area, hole spacing usually quoted relative to the unit cell width a, ellipticity, hole depth and the position of the back reflector. The coupling strength between the active and the PC is strongly influenced by the high refractive index of the PC and the InP spacer layer which constitutes the gap between the PC and active.

Figure 1(a) the design has a FF = 17% and a spacer thickness = 205nm, shows a simulated contour plot of FF ratio (FF-ellipse/FF-DL) and hole spacing in the DL design. A slice through the contour plot in (b) shows when the ellipse is greater than the circle (FF ratio > 0.5) the lowest Q_{rad} values occur for hole spacing of 0.4constant). Figure 1(c) shows a contour plot of dominant lasing mode for an Ellipse-Circle PC design (mode A=purple, B=blue, C=yellow, D=green), with respect to the small and big hole depths. For high lasing output power and low threshold gain, the small hole depth must exceed 350nm (red star) to avoid lasing across the bandgap to a degenerate mode (black star). The red star in the plot indicates the optimal region where lasing occurs on the B mode ensuring high efficiency, and high SMSR. This sensitivity to the hole depth is pertinent to the DL design and the impact of the position of the reflector that the PC-modes are affected by. The choice of InGaAlAs based active material is driven by its superior properties, including higher conduction band offset and high differential gain, leading to an improvement in over temperature performance and higher intrinsic bandwidth [6].

Measurements

A PCSEL with a circular 330 μm diameter P-side contact window and a 500 μm PC was tested at 25°C. Figure 2 (a) shows no significant roll-over up to 2.5A at voltage < 1.2V. Measured maximum power = 413mW, slope efficiency (SE) = 0.22W/A, and PCE = 15%. Figure 2(b) shows pulsed LI results at 25°C with a pulse width of 3μsand 4% duty cycle, achieving greater than 1W. The measurements in figure 3 show the lasing spectrum and band-edge modes at 25°C with an SMSR >50dB at 1.2A.

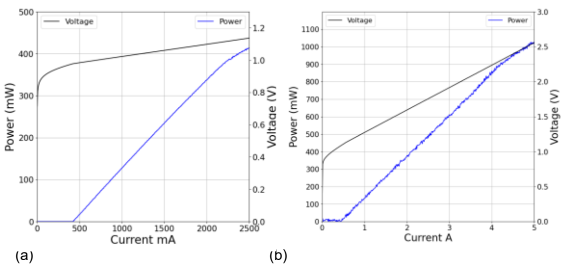

Fig. 2: (a) CW LIV at 25°C. Power at 2.5A is 413mW at V < 1.2V, (b) Pulsed LIV at 25°C. Power > 1W at 5A.

Conclusions

We have presented the first InGaAlAs-based PCSELs operating at 1.3μm, demonstrating promising performance. We have demonstrated the use of CWT in simulating and finding the optimum designs based on trade-offs between key parameters.

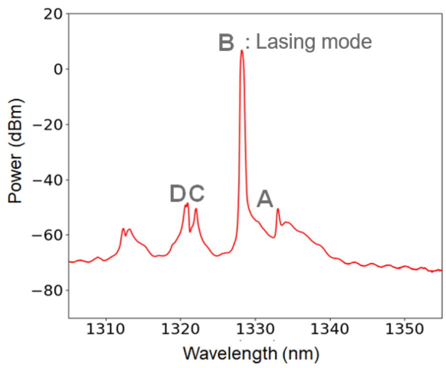

Fig. 3: CW Spectra at 25°C.

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