All-Semiconductor Photonic Crystal Surface Emitting Lasers.


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Photonic crystal surface emitting lasers (PCSELs) [1] offer a high degree of control in semiconductor lasers. They have been shown to exhibit power scaling with area as lasing occurs at the band edge [2], high single-mode powers [3], large scale coherent emission [4], control of the beam shape, polarization with design of the photonic crystal geometry [5], and beam steering [3]. Previous PCSELs utilised the high refractive index contrast between semiconductor and voids created in the structure by wafer fusion [1-5] or by epitaxial re-growth [6].

Here we report on the design and development of all-semiconductor PCSELs, which exhibit several differences as compared to previous void/semiconductor designs (see Fig.1). In the PCSEL, a photonic crystal structure is embedded within a planar waveguide. The photonic crystal is designed to provide second-order Bragg diffraction, enabling coupling between orthogonal directions, the formation of a 2D standing wave within the plane of the laser, and surface emission. In terms of waveguide design, we show that the low refractive index of the void/semiconductor photonic crystal layer plays a significant factor in the design of the laser structure. Whilst the all-semiconductor photonic crystal containing devices exhibit a comparatively low index contrast, we find that the much stronger mode overlap in all-semiconductor structures offers the possibility to obtain high coupling coefficients. We discuss various waveguide design rules for a range of wavelengths/materials systems.

We go on to discuss the effect of materials choices on the photonic crystal band-structure and coupling coefficients of the photonic crystal. The design of a photonic crystal structure to realize a beam of the desired pattern and polarization is further complicated by the need to ensure that the standing wave has suitable symmetry for constructive interference in the far-field. The opportunity to tailor photonic crystal designs as contrast between “atom” and “background” is highlighted [8].

The epitaxial regrowth of complex high aspect ratio, structures is challenging. We discuss the development of MOVPE processes to achieve high material quality. We utilize technologies developed for GaAs based regrowth which rely upon InGaP/GaAs regrowth, where AlGaAs is never exposed [7]. Here, the control of As/P exchange through careful epitaxial design, and control of the regrowth is critical. The infill of high aspect ratio structures is also non-trivial, with the careful optimization of the growth processes being discussed.

Figure 1 shows a TEM image of the regrown device, and room temperature operating characteristics are discussed. Low divergence (< 2 degrees) single-mode emission is observed, and various characteristics of the device will be detailed.

**Figure 1.** Device schematic, TEM image of the regrown device, and typical room temperature characteristics.

**REFERENCES**