InP Plasmonic DBR: Enabling Novel Vertical Cavity Laser Designs

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Mid-infrared optoelectronic devices are crucial for diverse applications, like gas sensing, thermal imaging or free space communication. These devices heavily rely on interband cascade and quantum cascade active regions within the 4 to 10 µm wavelength range. Surface emission and detection configurations, favored for low beam divergence and ease of integration, require highly reflective distributed Bragg reflectors (DBRs).

This work explores the operational physics of a novel type of semiconductor lasers known as quantum-cascade vertical-cavity surface-emitting diode lasers (QC-VCSELs) [1]. These lasers are anticipated to combine the advantages of both vertical-cavity surface-emitting diode lasers (VCSELs) and unipolar quantum-cascade lasers (QCLs). Similar to VCSELs, QC-VCSELs are expected to emit a low-divergence output beam with single-longitudinal mode radiation and without astigmatism. Additionally, these lasers offer the capability to assess the quality of their structures prior to any processing. Moreover, QC-VCSELs enable the design of laser structures for emitting radiation of desired wavelengths simply by adjusting parameters of their quantum wells, without requiring specific semiconductor materials with desired energy gaps for the laser's active region.

Proposed realization uses a monolithic high-refractive-index contrast grating as a top mirror, which works as a optical coupler and as the region in which the vertical component of the electrical field is induced, enabling stimulating emission from the QCs.

Traditionally, bottom mirror’s DBR face challenges in materials like AlGaAs and AlGaSb due to lattice mismatch and conductivity issues. In response, we propose a novel design using a monolithic InP structure with doping modulation, overcoming traditional limitations. While conventional materials are effective, the challenge is the total DBR thickness exceeding critical limits. Our design gets use of semiconductor properties in the mid-infrared range, utilizing variations in refractive index induced by plasmons through doping modulation. Unlike conventional DBRs, our approach is not constrained by lattice-match requirements.

In summary, our proposed design addresses existing challenges and offers new possibilities for mid-infrared optoelectronic devices. By taking advantage of semiconductor properties, it promises enhanced performance and reliability across various applications.

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[1] T. Czyszanowski, IEEE Photonics Technol. Lett. 30 (2018) 351–354.