Comprehensive Simulation of Vertical Cavity Surface Emitting Lasers

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The performance of today's commercial Vertical Cavity Surface Emitting Lasers (VCSELs) results from designs that include the sensitive interplay of thermal, electrical and optical effects. Simulation with a predictive character needs to capture these aspects quantitatively, and the underlying equations have to be solved in multiple dimensions in space. In this contribution, the current status of LASER-DESSIS is presented including an improved many-body gain model, and a detailed comparison to measurements evaluates the predictive potential.

The optical modes of the VCSEL microcavity are modeled by solving Maxwell's vectorial wave equation using a finite element method. Perfectly matched layer absorbing boundary conditions ensure proper treatment of radiation and diffraction effects [1]. The interaction of the optical modes with the gain medium is based on a semi-classical description, with the classical optical field treated in the slowly varying amplitude approximation. For the quantum-mechanical gain computation with many-body effects, an 8-band k*p method provides the bandstructure of the active region. The gain calculation includes conduction band nonparabolicities, valence-band mixing effects, and Coulomb intersubband coupling. The polarization dephasing rates are calculated from a quantum-kinetic description using the second Born approximation in the Markovian limit [2], that leads to a microscopic derivation of level broadening.

Carrier transport is described using a standard drift-diffusion theory, with thermionic emission currents at the hetero-interfaces. In the quantum-wells of the active region, the ballistic carrier transport is modeled with a simplified scattering equation, which balances separated bound and unbound carrier distributions [3,4]. Self-heating is treated in the thermodynamic framework, which calculates the local temperature from energy balance, assuming equilibrium of carrier and lattice temperature. The equations are solved in a self-consistent fashion.

A comprehensive set of characterization data is available from a commercial, oxide confined single mode VCSEL lasing at around 850nm [5]. It includes optical power versus drive current and voltage, lasing wavelength versus drive current, and spectral gain measurements at different currents. The measurements have been taken at different ambient temperatures. The structural information is obtained from epitaxial growth and processing data. Figure 1 shows an illustration of the device geometry as used in the simulation. Figure 2 shows the comparison of modeled versus measured spectral optical gain. Due to measurement constraints, these gain curves are obtained from an edge-emitting configuration. Excellent agreement is achieved, and it is shown that an accurate description of optical gain is a key factor for predictive modeling of the temperature dependent electro-optic specifications of VCSELs.

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A full journal publication of this work will be published in the Journal of Computational Electronics.

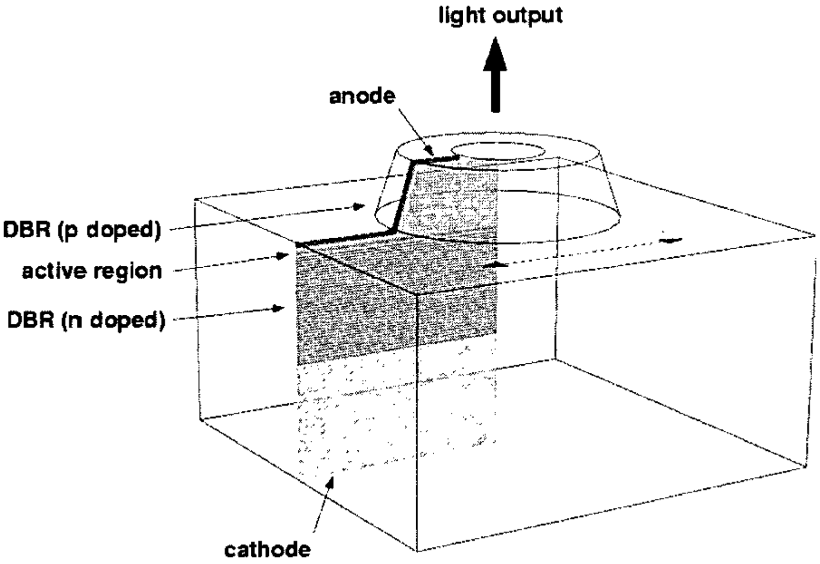

Figure 1: Schematic of the 2-dimensional device structure. Cylindrical symmetry is assumed, and the active region consists of multiple quantum-wells.

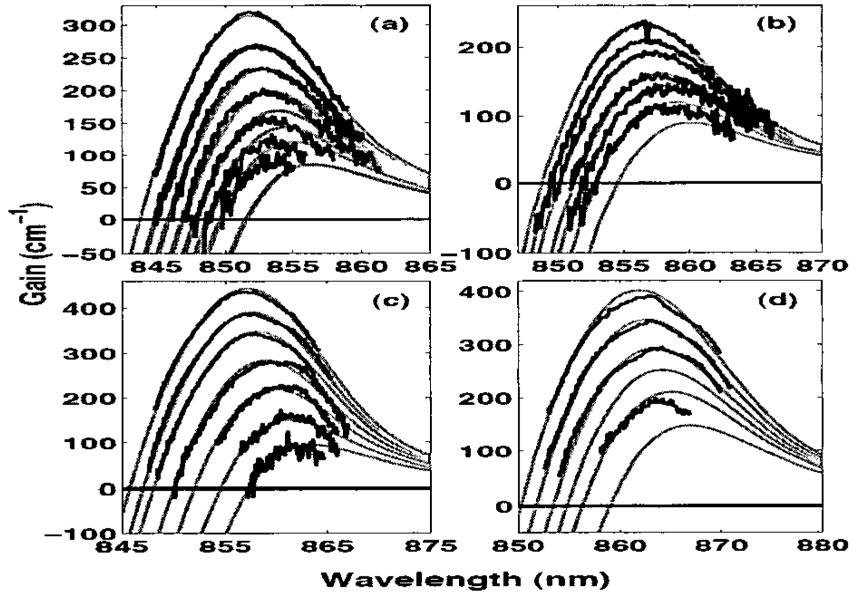

Figure 2: Comparison measured (black) and simulated (grey) modal optical gain using the quantum kinetic gain model. The ambient temperatures are 25°C (a), 40°C (b), 55°C (c), and 70°C (d), respectively.

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