**INTRODUCTION**

VCSELs (Vertical Cavity Surface Emitting Lasers) have become an established product as key light source in computer mice, fiber-optic data links, and laser printers. Their superior performance in terms of size, power consumption, spectral purity, and temperature stability give them advantageous characteristics for these applications. An important future emerging field of application for VCSELs is optical interconnect technology in computers (board to board or rack to rack). It is currently under development by major computer companies worldwide, and a large market is expected. A major bottleneck in this application is the limited bandwidth of the VCSEL under direct modulation. The data rate required in this technology is beyond 10 Gbit/s, ideally 40 Gbit/s. Current VCSELs are limited to bandwidths below 12.5 Gbit/s in research and industry. The workaround for existing optical interconnect prototypes is to use multi-channel, parallel links. They require costly, bulky and energy inefficient VCSEL arrays, and should be ideally replaced by single, high-speed sources.

**RESEARCH OBJECTIVES**

The eventual goal of this project is to develop original solutions for ultra-high bandwidth, GaAs-based VCSELs that can be manufactured using current technology. The design is developed using predictive simulation, which contains the underlying physics in a rigorous fashion. From measurements for existing commercial 10 Gbit/s VCSELs, a thorough electro-opto-thermal calibration is performed, i.e. determination of the process related parameters such as defect densities, optical losses from scattering, and free carrier absorption. In a second step, the simulation is set up so that temperature dependent static and dynamic specifications match the experimental data.

The methodology for the project is physics-based predictive simulation: knowing the material compositions, thicknesses, doping levels, and physical shape of the device, a 2-dimensional finite-element model is created. For the electronic problem, microscopic carrier transport equations are solved, which include quantum transport for the nano-scale regions, and carrier-phonon interaction that causes self-heating. The light-matter interaction (resulting in gain and spontaneous emission) is modelled solving a quantum kinetic equation with many particle effects included in the Hamiltonian.
Measurement (dots) and simulation (lines) of the resonance frequency versus bias currents and temperature. At high bias currents, the resonance frequency saturates due to thermal and parasitic effects.

After careful calibration, different scenarios are investigated, which include multiple active regions, external optical modulation, reduced parasitic capacitance designs. If a successful and manufacturable strategy is derived, the ultimate operation bandwidth of a directly modulated VCSEL shall be determined, and a high-bandwidth design that can be readily implemented by the industrial partner shall be developed.

**APPLICATION PERSPECTIVES**

The main motivation of this project is to realize ultra high-speed VCSELs for optical interconnects. If successful, a major breakthrough in the field of optical interconnects will have been achieved. The ‘winner’-design can then also be applied to other applications, such as extension of the wavelength range to optical communications wavelengths.

Contact:
Prof. Bernd Witzigmann (ETH Zurich)
http://www.iis.ee.ethz.ch

For more information on this and other projects in the NCCR Quantum Photonics please visit our web site: [http://nccr-qp.epfl.ch](http://nccr-qp.epfl.ch)

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