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Single-Mode Performance Analysis for VCSELs

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INTRODUCTION

In this work, the simulation of the single-mode stability in vertical-cavity surface-emitting lasers (VCSELs) is presented using a microscopic electro-opto-thermal model [1]. Experimental data for oxide-confined VCSELs emitting at 850 nm with different contact metal designs are also available. It is shown that detailed models for the optical losses in the cavity consisting of out-coupling and absorption are required in order to explain the experiments. The role of cavity losses in the nonlinear electro-opto-thermal simulation framework will be discussed in a quantitative manner.

The fundamentals of the electro-opto-thermal simulation models are described in [1], [2] and only a summary and update with respect to new models is given. The optical modes of a VCSEL are modeled by solving Maxwell's vectorial wave equation using a finite element method and absorbing boundary conditions. Cavity losses consist of optical out-coupling, scattering, metallic absorption, and free-carrier absorption. The electro-thermal description comprises a Poisson equation, a drift-diffusion model for carrier transport and a continuity equation for the heat flux. Gain is modelled by the microscopic polarization based on Heisenberg's equation of motion in the second Born approximation [3]. The quantum well bandstructure is calculated by an 8-band k·p method. In general, the simulator can be used to calculate the stationary, transient, small-signal, large-signal and noise characteristics of VCSEL devices in a 2-D and 3-D [4] setup.

RESULTS

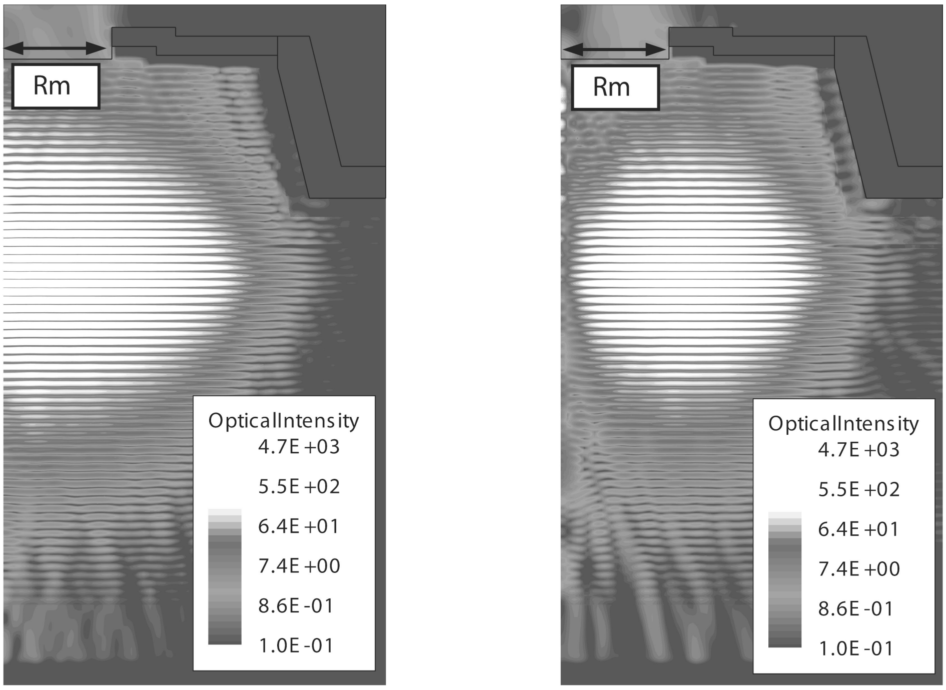
Besides reliability properties, the maximum single-mode power is one of the most important performance criteria in industrial VCSEL design. A straight forward approach is the use of a narrow ($<3\mu\mathrm{m}$) oxide aperture diameter in order to feed the carriers to the center of the HE_{11} mode, however this results in a higher differential resistance and tends to degrade the reliability. Other approaches introduce mode selective losses, either by surface reliefs or by narrowing the aperture of the contact metallization.

Here, the impact of the contact metallization aperture on the single-mode behavior of an 850 nm AlGaAs/GaAs VCSEL is analyzed. The basics of a similar structure are discussed in [2]. Figs. 1(a) and 1(b) show the first two optical modes of a design with a top metal radius Rm$<$3.5 $\mu\mathrm{m}$. The losses are obtained by the dissipation rates of the optical field vectors. Simulation shows that the losses increase with decreasing metal radius. Concurrently, the net out-coupling losses also decrease, which results in a reduced slope efficiency. On the other hand, the threshold for the onset of the higher order mode is decreased with larger metal radius. Therefore, a trade-off between partition of the contact metallization and the current confinement to the active region has to be found for high single-mode power. Fig. 2 shows the power-current characteristics from simulation and measurement, which are in excellent agreement. A detailed interpretation will be given in the presentation.

In conclusion, this contribution aims to simulate 850 nm oxide-confined VCSELs with the aid of microscopic simulation. In particular, the single-mode behaviour is determined by a complicated interplay of electrical (current confinement), thermal (self-heating) and optical (losses) processes.

REFERENCES

[1] Synopsys Inc., Mountain View, USA, *Synopsys Sentaurus Device User Manual*, 1995-2005.
[2] M. Streiff *et al. IEEE JSTQE*, Vol. 9, pp. 879-891, 2003.
[3] B. Witzigmann *et al.*, *Journal of Comp. Elect.*, Vol. 4, pp. 7-10, 2005.
[4] B. Witzigmann *et al.*, *Proc. of NUSOD*, pp. 23-24, 2005.



(a) HE_{11} mode (b) HE_{21} mode

Fig. 1. Normalized optical intensity for a VCSEL with metal aperture radius Rm<3.5 μm. Due to absorption in the metal, the total losses for the HE_{21} mode are significantly higher than for the fundamental HE_{11} mode. This results in an improved single-mode behaviour.

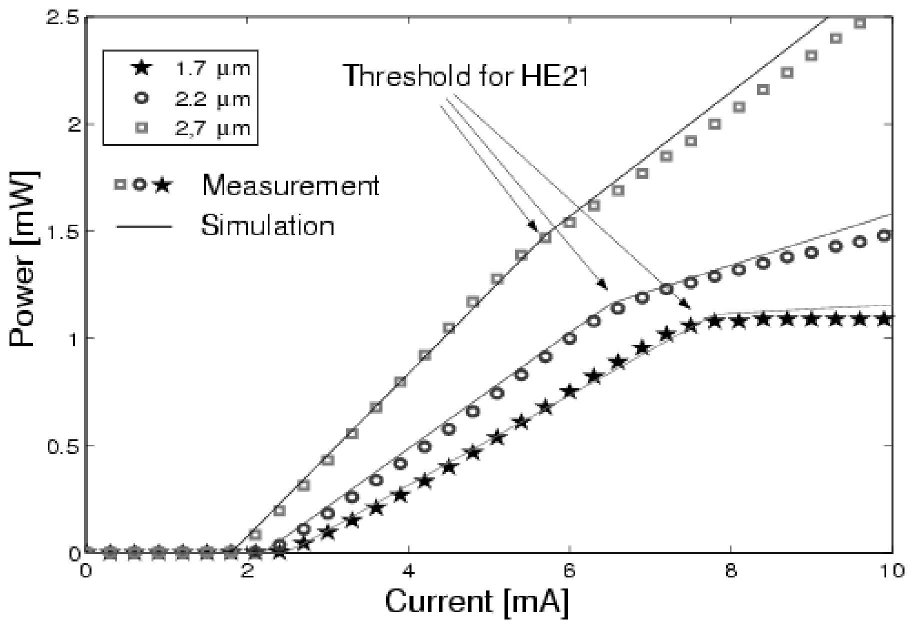


Fig. 2. Simulated (solid lines) and measured power-current characteristics of VCSEL designs with different metal aperture radii at T = 303 K. With decreasing metal aperture, the threshold currents for the fundamental and higher order modes increase due the higher absorption in the metal. Concurrently, the slope efficiency decreases since the power generated in the device is absorbed in the metal, too.