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# The effects of carrier dependant nonlinear gain on quantum well VCSEL characteristics

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**Abstract** In this paper, we present a numerical opto-electro-thermal model for studying vertical cavity surface emitting lasers operation. The model is applied to an index-guided structure with an oxide aperture and multiple quantum-wells in active layer. The interdependent process of carrier transport, heat generation and optical field are solved self-consistently using finite difference time domain in cylindrical system. The gain of quantum wells (QWs) is calculated based on the solution of Schrödinger equation considering heavy hole-light hole band-mixing effect. The calculated maximum gain versus injected carriers is fitted by a 3th order polynomial function and used in opto-electro-thermal model. The inclusion of QW maximum gain calculation for constant wavelength in the model allows us to study threshold current value and higher order transverse modes as well as their dependencies on variation of gain and refractive index induced by carrier and heat more accurately than linear gain approximation. The results show a lower threshold current compared with linear gain approximation. For injection current above the threshold, we consider the spatial hole burning, thermal lensing and self focusing effects.

**Keywords** Finite difference time domain (FDTD) · Carrier dependant nonlinear gain (CDNG) model · Spatial hole burning (SHB) effect · Quantum well · Opto-electro-thermal · VCSEL

## 1 Introduction

Vertical-cavity surface-emitting lasers (VCSEL) with some features such as circular output beam with low divergence, high modulation speed, low threshold current, inherent single-longitudinal mode, and ease of fabrication in two-dimensional (2-D) array are attractive for

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