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Near field analysis of broad-area high-power laser diode using nonlinear bidirectional beam propagation method

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Summary: A modelling tool based on a nonlinear finite-difference bidirectional Beam Propagation Method (BPM) was developed to study the optical filamentation of the near field in high-power broad-area laser diodes. The near-field pattern, resulting from the multimode laser waveguide in the slow-axis direction, can show strong peaks whose optical density could exceed the Catastrophic Optical Mirror Damage (COMD) threshold. A control of the optical filamentation at the design stage is thus of utmost relevance to fabricate highly reliable high-power semiconductor lasers.

1 Introduction

Semiconductor lasers emitting in the 9xx nm range whose optical output power significantly exceed 10W are commonly used for many applications including fiber-laser pumping and direct-diode material processing. In order to manage high optical powers, these devices necessarily have a broad-area multimodal active waveguide in the lateral direction (*slow-axis*) causing optical filamentation of the lateral far- and near-field by self-focusing mechanism and mode instability [1], see Fig. 1(a). The waveguide is single mode in the vertical direction (*fast-axis*), where the optical confinement is due to the epitaxial heterostructure embedding the quantum well active layer. The main issue associated with the slow-axis near-field filamentation pattern is the possible presence of peaks whose optical density can reach several tens of MW/cm^2 causing high facet-temperature spots followed by COMD [2].

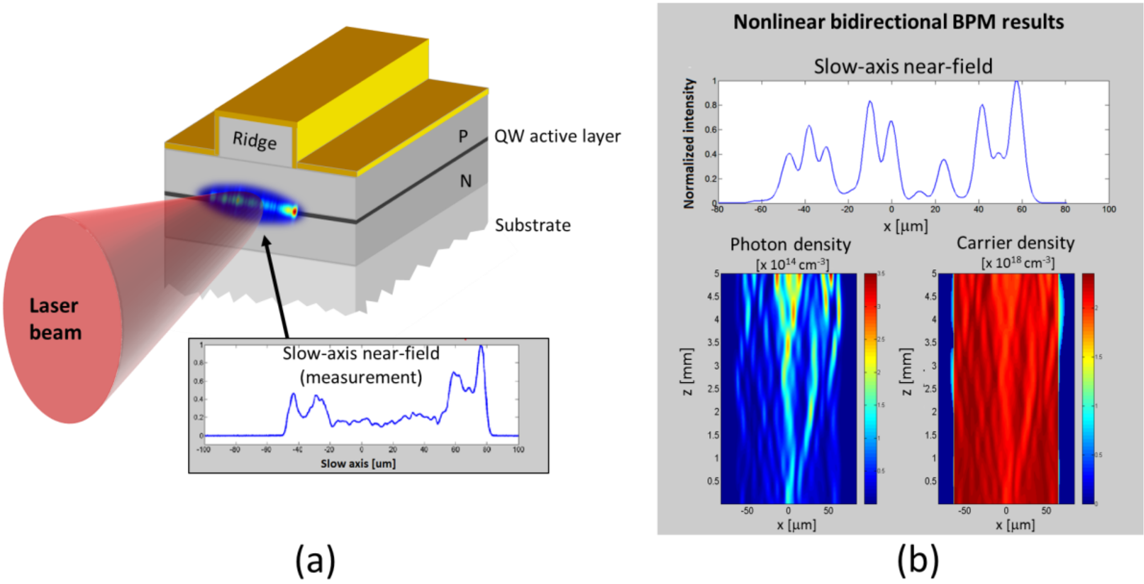


Figure 1: (a) slow-axis near field of a high-power broad-area semiconductor laser, (b) modelling results

In order to address the issue at the device design stage we have developed a numerical tool based on the nonlinear finite-difference bidirectional BPM. The tool was used to identify laser structure changes affecting the near-field pattern with the goal of reducing the strongest peaks, thus increasing the laser-facet reliability.

2. High power laser structure

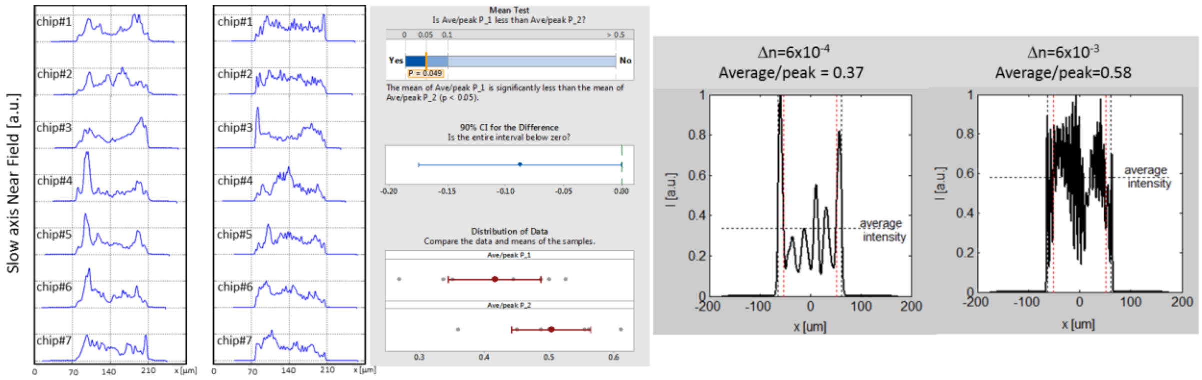
Our laser epitaxial structure consists of a single 8nm InGaAs/AlGaAs QW embedded between asymmetric GRIN-SCH AlGaAs layers. It was grown by MOCVD on a n-doped (100) 2-degree-off GaAs substrate. The QW and the cladding layer's thickness, doping, and composition were designed to achieve a reduced vertical and lateral far-field width (FWHM@1/e^2 < 58º ⊥, 12º ‖), an high differential efficiency (> 1 W/A) and a low series resistance (< 20mΩ). Low optical losses (< 0.8cm^{-1}) allowed a 5mm cavity length and lateral optical confinement was provided by a broad area ridge waveguide structure 130µm wide. A low reflective (~2%) and a high reflective (> 95%) mirror coatings were applied to laser facets, after protection with a proprietary passivation technology. Fabricated chips were mounted in 90W multi-emitters for CW fiber-laser pumping.

3. Modelling tool and results

The numerical tool, developed with a Matlab and Fortran code, is based on the Crank-Nicholson scheme solution for the finite-difference bidirectional BPM including the transfer-matrix method to account for reflectivity at the numerical-grid points [3, 4]. A model of the quantum-well's non-linear complex refractive index [5] and the photon-carrier rate equation are self-consistently included in the calculation scheme. The propagation equations for the BPM are:

$$\frac{\partial \psi^+}{\partial z} = i\hat{\beta}\left(\sqrt{1+\frac{1}{\hat{\beta}^2}\left(k_0^2\hat{n}^2-\hat{\beta}^2+\frac{\partial^2}{\partial x^2}\right)}-1\right)\psi^+$$

and its time-reversed for the counter-propagating field ψ^-, where the squared-root operator is evaluated using the Padè approximants [3]. The tool allows the calculation of the optical property variations, the carrier density and the nonlinear electromagnetic field propagation along the resonant cavity at varying injected currents, see fig. 1(b). Nonlinear effects like the Spatial Hole Burning (SHB) and the induced transparency in waveguide surrounding regions are numerically reproduced. The tool has been used to calculate the near field pattern, showing a qualitative agreement with the experimental findings. In particular, we observed the highest-intensity peak location toward waveguide edges, where COMD statistical frequency shows a maximum. We studied, both experimentally and numerically, the flattening of the near-field profile by increasing the waveguide optical confinement by means of the ratio between the average intensity and the maximum peak, see fig.2. In order to evaluate the mode distribution (Parseval's coefficients) contributing to the emitted field, a modal decomposition of the calculated field was performed.



(a) Near field measurements:
(left) Process PE102 ($\Delta n=4\times10^{-4}$),
(right) Process PE104 ($\Delta n=2\times10^{-3}$)

(b) Two-sample t-test between average/peak for processes PE102 and PE104

(c) Nonlinear bidirectional BPM results: near field and relevant average/peak values for a low confining and a high confining waveguide

Figure 2: Slow-axis near-field measurements of laser chips belonging to wafer processes with different optical confinement (a), statistical comparison of average/peak values (b) and numerical calculations (c)

5. Conclusions

The nonlinear finite-difference BPM is a powerful tool to study and control the optical filamentation of the high-power broad-area semiconductor-laser slow-axis near-field. The effect of the optical confinement was investigated. Future analysis will be focused on other structure parameters and waveguide-side geometry in order to control the mode distribution. Future developments of the tool could consider the photoelastic and the thermorefractive effects in order to reproduce realistic behaviour of mounted laser devices under CW operation.

5. References

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