Exactness of Scalar Approaches to Radiation Modes of the GaAs-Based 1.3-μm Telecommunication Oriented Diode Lasers

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The work presents a comparison between results of the optical simulation based on the scalar and vectorial models applied to semiconductor lasers. Validity limits of scalar model have been determined by comparing its scalar modes with more exact vectorial ones. The analysis is concluded with the determination of the regions where both models give satisfactorily close results.

1 Introduction

Optical model describing the behaviour of an optical field within a laser cavity is one of the most important parts of the diode-laser modelling. Up to now usually simplified scalar optical approaches have been used to this end requiring solving a single wave equation with appropriate boundary conditions. The main goal of this paper is to present the cases for which both approaches give practically identical results. Therefore the results achieved from the scalar methods will be compared with more exact vectorial ones. In the above comparison, the Effective Index Method (EIM) [1] is used as a typical scalar optical approach for Edge Emitting Lasers (EELs) and Effective Frequency Method for VCSELs [2], whereas the advanced Method of Lines (MoL) [3] – as a vectorial one which allows for simulation of both types of lasers. The methods are applied for simulation of an operation of a typical GaAs-based oxide-confined EEL and VCSEL structures emitting the optical wave of the wavelength close to 1.3 μm.

2 Results

Usually in the simulation of a laser operation, the final task is to calculate its output power as a function of an applied voltage. This makes it necessary to model selfconsistently a complex network of interrelations between electrical, thermal, gain and optical phenomena. All they interact with the optical model influencing both (real and imaginary) parts of the complex refractive indices of structure layers. But the focus of this paper is on purely optical determination of the optical modes with the help of both scalar and vectorial approaches what leads to determination of their validity limits. Let us consider the VCSEL structure reported in [4]. Fig. 1 presents intensity profiles of two arbitrary chosen lower order modes of the VCSEL. One can observe a better confinement of the fundamental vectorial mode within the active region than its scalar counterpart (Fig. 1a). It becomes even more pronounced for higher order modes especially in the radial direction. Distinct leakage of scalar modes brings out lowering of the real and imaginary parts of the mode effective refractive

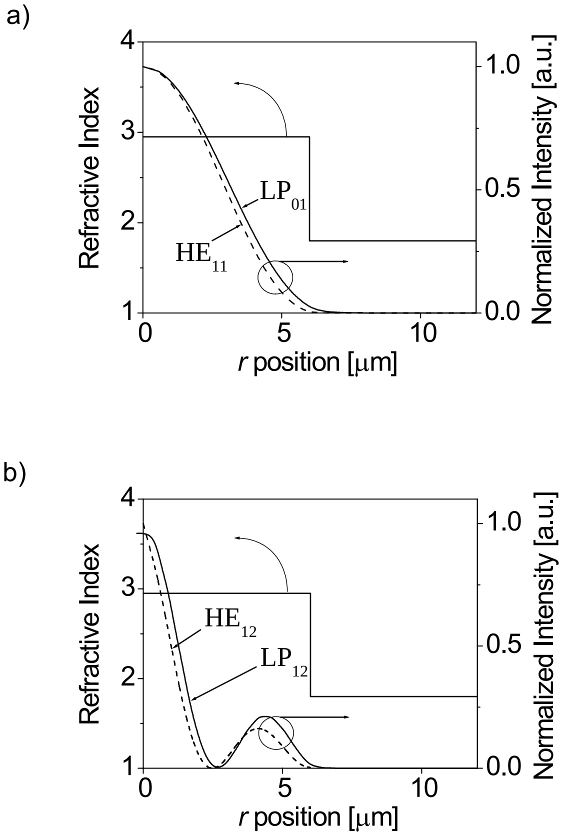

Fig. 1 Profiles of the intensity of VCSEL modes along r-axis calculated with the scalar (solid lines) and the vectorial (dashed lines) models. Figures correspond to modes a) HE_{11} and LP_{01}, b) HE_{12} and LP_{12}. Profiles of the refractive index along the r axis (within oxide layer) are additionally shown.

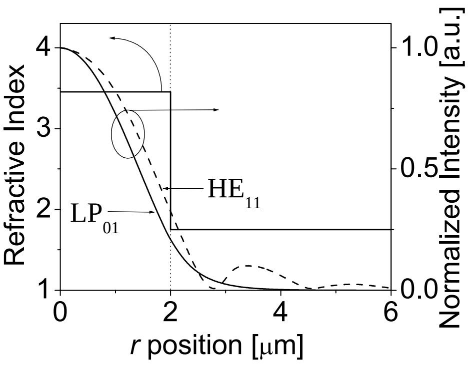

Fig. 2. Profiles of the fundamental mode intensity along r-axis calculated with the aid of the scalar (solid lines) and the vectorial (dashed lines) approaches for the VCSEL structure defined by the 4 μm aperture diameter. Profile of the refractive index along r-axis within oxide layer is additionally shown.

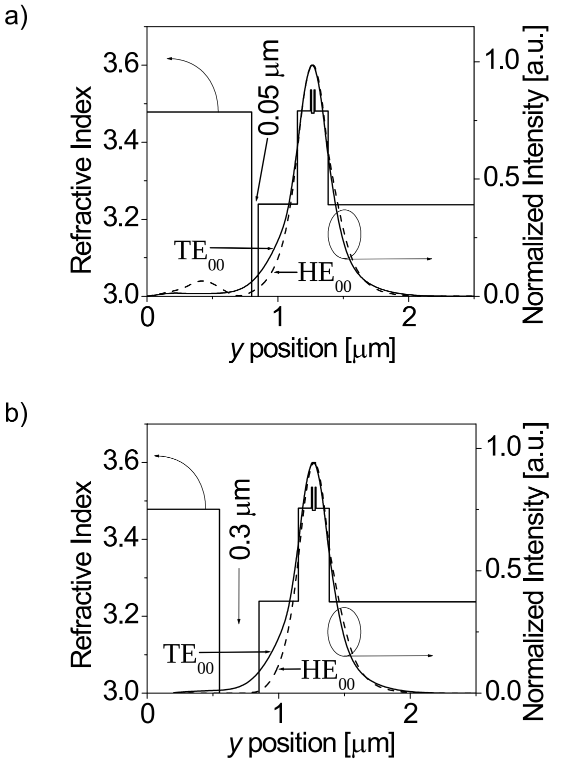

Fig. 3 Profiles of the fundamental mode intensity along y-axis calculated with the aid of the scalar (solid lines) and the vectorial (dashed lines) approaches for the EEL structure defined by the oxide layer of a) 0.05 μm and b) 0.3 μm thickness. Profile of the refractive index along the y-axis is additionally shown.

index or wavelength since field penetrates the lateral passive regions exhibiting lower index and high absorption. On the other hand, vectorial modes suffer from the diffraction losses, which are not included in the scalar approach. Fig. 2 presents the difference in the VCSEL mode profile in radial direction between scalar and vectorial model for a narrow aperture width. Narrowing of the oxide window causes the more pronounced penetration by the mode the lateral passive regions placed out of the central active region. That finally leads to the mode leakage. Both approaches predict such behaviour, however, vectorial model indicates the diffraction process as a main reason of the leakage. Fig. 3 presents process of weak guidance in case of the EEL [5]. Thick oxidation ensures stable waveguide process, whereas thin one allows for a leakage of the wave. This leakage is stronger in the *y* direction than in the *x* one. Too thin oxidation does not protect an optical field from the migration of the mode towards the high refractive *p*-contact layer. For a narrower oxidation layer, the vectorial model reveals an essential mode leakage and its oscillations within the *p*-contact layer whereas the scalar one penetrates this layer without any oscillations. The above means that too narrow oxidation layer may lead to a considerable increase in optical losses, which is followed by an increase in a lasing threshold.

3 Conclusions

Two approaches devoted to simulation of the electromagnetic field within cavities of EELs and VCSELs are presented. The less exact scalar approach owes its extremely short calculation time (10^2 – 10^3 times shorter than MoL) to the plane wave assumption what allows for a solution separation. The comparison of the mode profiles for both approaches reveals that profiles of the modes determined using both approaches are usually surprisingly close, excepting weaker guidance and higher-order modes operation. The above restrictions define validity limits of simple scalar optical approaches in modelling optical fields within cavities of diode lasers.

References

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