ThA1.2 (Invited)
9:00 am – 9:30 am

Rigorous optical VCSEL modelling based on vectorial eigenmode expansion

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To enable the further improvement of VCSEL properties, an accurate optical model is needed to study the effects of transverse optical confinement on threshold gain and modal stability. An important example in this respect is the choice of the thickness and the position of an oxide aperture in the design of high-performance VCSELs.

We will present different approaches for the optical modelling of these devices based on vectorial eigenmode expansion techniques. These approaches take the vectorial nature of Maxwell's equations into account and are therefore fully rigorous, even in the case of devices that are small compared to the wavelength or devices with high index contrasts, as is the case in oxide-apertured devices.

In eigenmode expansion techniques, the lasing mode in each layer is expressed as a linear combination of the eigenmodes of that particular layer:

$$\begin{cases} \mathbf{E}_i^{tot}(r,\varphi,z) = \sum_k \left\{ A_{i,k}^+ \mathbf{E}_{i,k}(r,\varphi)\exp(-j\beta_{i,k}z) + A_{i,k}^- \mathbf{E}_{i,k}(r,\varphi)\exp(j\beta_{i,k}z) \right\} \\ \mathbf{H}_i^{tot}(r,\varphi,z) = \sum_k \left\{ A_{i,k}^+ \mathbf{H}_{i,k}(r,\varphi)\exp(-j\beta_{i,k}z) - A_{i,k}^- \mathbf{H}_{i,k}(r,\varphi)\exp(j\beta_{i,k}z) \right\} \end{cases}$$

Generally speaking, the eigenmode approaches all proceed as follows:

- Find the eigenmodes and their propagation constants in every layer. This can be done either by locating the zeros of a dispersion relation or by means of a series expansion.
- Using mode matching, determine the reflection and transmission matrix of any incident field upon an interface between two layers.
- Using the reflection and transmission matrices of the different interfaces, construct the reflection matrices for the entire top and bottom half of the cavity.
- Find a combination of wavelength and material gain for which the product of these matrices has an eigenvalue of one. The corresponding eigenvector then describes a lasing mode of the cavity.

In order to model diffraction, we need to include radiation and evanescent modes in the eigenmode expansion. However, in open structures, these modes form a

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continuum that is difficult to treat numerically. In order to overcome this problem, there are a number of possible approaches:

A first approach is to place the structure under study inside a metal cylinder. This effectively discretises the mode spectrum. This technique works reasonably well, provided that the radius of the cylinder is large enough to prevent reflections from the metal wall to disturb the laser field. Unfortunately, the requirement of large cylinder radius leads to an increased number of modes needed to represent the field and therefore to large computation times.

A second approach consists in cladding the metal cylinder with a so-called perfectly matched layer (PML). This layer provides for reflectionless absorption of the incident field, regardless of wavelength, polarisation or incidence angle. In this way, we can more accurately model the properties of infinite space, while at the same time maintaining the advantage of a discrete set of radiation and evanescent modes.

Both approaches will be discussed and illustrated with a number of examples.

Acknowledgements

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References

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http://www.ele.kth.se/COST268/WG1/WG1.html#Modelling Exercise #1