Efficient numerical analysis of dielectric cavities

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Scope and Motivation

Dielectric cavities with high quality factors, such as microdiscs and photonic crystals, are of particular interest since they lower the lasing threshold. This is of great benefit when dealing with difficult gain media, such as quantum dots or quantum cascades, where a high Q factor can help overcome high pumping and cooling requirements. We present an efficient simulation tool that targets the rapid design of such cavities.

Methods

The cavity problem is defined by Maxwell equations along with absorbing boundary conditions. In our calculations, the latter are perfectly matched layers (PML)[1]. An automatic algorithm based on the Laplace equation generates the PML coefficients and ensures a tight and conforming absorption layer. The Maxwell equations are reduced to a single vector-valued wave equation for the magnetic field (assuming $\mu(\vec{r}) = \mu_0$), $\vec{\nabla} \times (\frac{1}{n^2}\vec{\nabla} \times \vec{H}) = (\omega/c_0)^2 \vec{H}$. We transform the equation making use of $\vec{\nabla} \cdot \vec{H} = 0$:

$$\left[\partial_i \frac{1}{n^2} \partial_j - \partial_j \frac{1}{n^2} \partial_i\right] H_i \vec{e}_j - \vec{\nabla} \cdot \frac{1}{n^2} \vec{\nabla} \vec{H} = \left(\frac{\omega}{c_0}\right)^2 \vec{H}$$

This allows us to discretise the equation using the anisotropic finite volume method (FVM) developed in [2] by applying the Gauss theorem. This ensures flux conservation in the discretised system.

The discretisation is performed on a three-dimensional tetrahedral Delaunay mesh where we use an octree-based refinement. The grid density is chosen to account for the shorter wavelength in regions of higher refractive index. The discretised system yields a non-Hermitian algebraic eigenvalue problem, of which *semi-interior* eigenpairs are sought. They are computed using the Jacobi-Davidson (JD) method combined with a preconditioned GMRES algorithm. The JD method lets us select the spectral region where to look for eigenpairs a-priori thus minimising time and memory consumption.

All neccessary computational components were efficiently implemented in C++ and are part of the Vienna Schrödinger-Poisson simulation framework[3].

Results

As test device we chose an elliptic microdisc cavity measuring 52µm and 38µm along its principal axes and 10µm in thickness. The device and propagation region including PML were constructed and meshed using CAD tools (Fig. 1). The resulting eigenvalue problem had a rank of $\approx 5 \cdot 10^5$. The simulation was performed on an off-the-shelf workstation computer within one hour without parallelisation. Fig. 2 shows four of the computed modes along with the corresponding radiation profiles.

In this work we demonstrated a single engineering tool that allows efficient analysis of dielectric cavities of arbitrary shape and configuration.

Acknowledgment

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References

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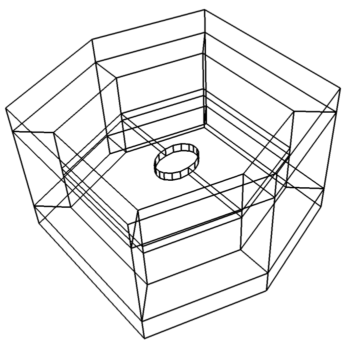

Figure 1: CAD tool view of the cavity problem

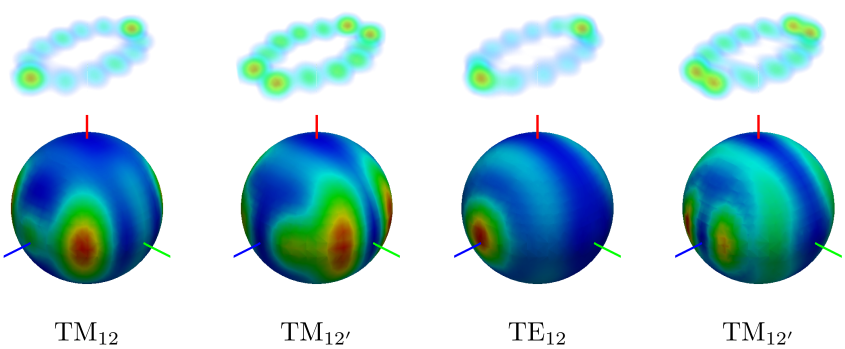

Figure 2: Energy densities and radiation patterns of TM and TE modes of angular order 12