Abstract

In this work, the correspondence between ray (based on geometric optics) and wave (based on solutions of Maxwell's equations) descriptions in a particular type of optical microcavities, deformed microdisk cavities, is studied both in cases where it can be successfully applied and in cases where it fails. For many applications of microcavities, such as laser resonators, optical modes which have directed far field emission and long life-times are desirable. Unfortunately, it is in general difficult to achieve both these goals simultanously.

A special deformed microdisk shape that support long-lived modes with directional emission is presented in this work. It is a microdisk with an elliptical cross-section and a wavelength-scale "notch" at the boundary. The fact that long-lived modes with directional emission exist here can be understood with a ray model: rays which travel along the boundary for a long time (corresponding to so-called "whispering gallery" modes) eventually are scattered by the notch and reflected to the opposite cavity boundary, which acts like a lens and collimates the rays in the far field. The predictions of this ray model agree well with the far field of the optical modes. Elliptical microdisk cavities with a notch have been fabricated experimentally by our collaborators in Prof. Dr. Federico Capasso's group at Hardvard, who used them as resonators for quantum cascade lasers; the ray and wave simulations of the far field are compared to the measured far fields, and good agreement is found as well.

Ray models can be expected to fail if the wavelength of cavity modes approaches the cavity length scale; examples for this failure of ray-wave correspondence are given in this work. One solution for this problem, which allows one to retain the simplicity of a ray model, is to extend the ray description by introducing corrections to it which are based on the wave description; these corrections are the Goos-Hänchen shift (GHS) and the Fresnel filtering effect. The calculation of such corrections and their inclusion in the ray description of deformed microdisk cavities is a main point of this work; the results of this extended ray dynamics are compared to wave calculations and applied to experimentally measurable quantities such as far field patterns.

As the results of the extended ray model scale with the ratio of the wavelength corresponding to cavity modes, it can not only be investigated in optical microcavities, but in microwave cavities as well. This is convenient, because while the electric field inside a microcavity can not be measured accurately with current techniques, this can easily be done in microwave cavities. Such measurements of the GHS in microwave cavities, which have been performed during a visit to Prof. Dr. Hans-Jürgen Stöckmann's group at the University of Marburg, are presented in this work. Beams with different incoming angles are generated by superposition of the plane waves produced by microwave antennas; the resulting beams are then reflected at the cavity boundary and the GHS can be measured. The results agree well with numerical calculations.