QUASI-3D ELECTROMAGNETIC MODELING OF MICROCAVITY LASERS AND LASER ARRAYS WITH LOVERED THRESHOLDS AND IMPROVED DIRECTIONALITY

Motivation:
Semiconductor lasers with quantum wells, boxes or dots that exploit the “whispering-gallery” modes around the edge of a thin disk have been studied since the early 1990’s, as ultra-low-threshold light sources. Still surprisingly, it appears that an accurate mathematical and numerical study of the thin circular-disk lasing modes has been absent. We have proposed a new approach to their analysis that consists in introducing a material gain in the optical cavity, and in studying a lasing eigenvalue problem (LEP) of new type, for an active open resonator. One may call the LEP a "cold-model-with gain problem". The gain over the cavity can be uniform (e.g., if optical pumping is arranged with a wide beam) or the gain non-uniformity (typical for injection lasers) should be taken into account. We study LEP problems with full Maxwellian formulation, transparent-boundary conditions, and radiation condition at infinity. New feature is that, instead of the search for the complex-valued natural frequencies (as for a passive open resonator), we seek the eigenvalues as the pairs of two real parameters frequency and threshold material gain. These parameters are well-known and adequate quantities in self-excitation of electron devices and in optical lasing. Note that lasing thresholds have not been quantified with previous theories, and their study was substituted with analysis of mode Q-factors, which do not characterize lasing directly.

Objectives:
1. Develop mathematical formulation of the lasing problems able to provide the threshold gain values in addition to the spectra.
2. Develop and test gradient-type iterative algorithms for the search of the lasing frequencies and thresholds.
3. Investigate the lasing spectra and threshold gains of free-standing microdisk lasers with uniform and non-uniform gain.
4. Investigate the spectra and thresholds of linear arrays of proximity-coupled microdisk lasers seeking the ways for reduction of threshold and improvement of directionality.
5. Investigate the spectra and thresholds of circular arrays of proximity-coupled microdisk lasers; study of the role of symmetry.
6. Investigate arbitrarily shaped microlasers and find optimal geometries for rarefaction of mode spectra, lowering of thresholds, and better directionality.

(a) (b) (c)

Schematic images of microdisk lasers to be studied: (a) disk with a ring-shape active region, (b) disk having “spiral”-shape cavity, (c) cyclic photonic molecule of disks. Note that, besides of the shown here air-clad on-pedestal versions, these structures can be also manufactured as disk-on-substrate ones.