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Optimization of optical resonators for Biological Imaging

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Contemporary biological and medical imaging uses multi-layer optical systems (photonic crystals) to gain smaller X-ray focal spots and to enhance spatial resolution. Further development of imaging techniques requires improvement of resonant properties of multi-layer structures.

In the simplest 1-D case, resonances of an optical multi-layer structure can be defined as eigenvalues ω of the problem $c^2 E''(x) = \omega^2 \varepsilon(x) E(x)$ with the radiation boundary conditions imposed on the electric field $E(x)$ at $\pm\infty$. The dielectric permittivity function $\varepsilon(x)$ represents the electromagnetic structure of the devise. The following resonance optimization problem has recently attracted considerable interest among specialists in Optical Engineering and Numerical Analysis: find a function ε that create a resonance ω with a very small decay rate $|\mathrm{Im}\,\omega|$. The aim of the talk is to present a new analytic approach to this problem. The method is based on a specially developed two-parameter perturbation technique and on convex analysis of leading terms of perturbed resonances.

In the case when the side constraints $\varepsilon_1 \leq \varepsilon(x) \leq \varepsilon_2$ are imposed on ε, the main result states that optimal structures consist of alternating layers of two materials with extreme allowed dielectric permittivities ε_1 and ε_2, and that coordinates of the interface planes between the layers can be calculated via a nonlinear eigenvalue problem of the form $c^2 E'' = \omega^2 f(E) E$. An explicit expression for the function f allows us to exclude the unknown optimal function ε from the process of calculation of optimal resonances. This reduces the resonance optimization problem to the zeroes-finding problem for a function of three real variables.