PROCESSING OF LIGHT WITH MICRO-TO-NANO-SCALE MIRRORS AND LENSES FOR THE EMERGING OPTOELECTRONIC APPLICATIONS

State of the art. Micro-scale optoelectronics is evolving into nano-scale one. New integrated photonic circuits are urgently needed, capable of dense-volume light guidance and processing. Quite obviously, they must extensively use free-space propagation of light signals carrying the information. Here, semiconductor microlasers play a key role as the sources of light with ultra-low power consumption and high degree of integrability. E.g., lasing in the 1-10 micron diameter disk cavities has been reported at room temperatures, both with photo-pump and carrier injection [S. McCall *et al*., *Appl. Phys. Lett.*, 60, 289, 1992; T. Baba *et al.*, *IEEE Photonic Technol. Lett.*, 9, 878, 1997; B. Gayral *et al., Appl. Phys. Lett.*, 75, 1908, 1999]. Improved laser designs are needed with a control of threshold and stability against jumping to nearest modes that can be achieved by proper design of the cavity and the pump characteristics. Moreover, usually it is necessary to provide highly directional radiation of laser that can be achieved by using microlenses and micromirrors. These micron-size passive devices are also used for focusing the light beams – e.g., when feeding an optical fiber or illuminating a photoreceiver. Preliminary CAD of these devices is a well known way to reduce the cost and the time of their design. However, today modeling of the light processing with microlenses and micromirrors is based on quite rough analysis tools, which are either analytical Geometrical Optics (GO) solutions or finite-difference time-domain (FDTD) numerical codes or small-contrast and paraxial approximations like the beam-propagation method (BPM). Either of them fails to provide high accuracy of the optical field modeling, especially if the distances to the optical mirrors and lenses and their dimensions are comparable to the wavelength. E.g., staircasing of scatterer boundaries and back-reflections from the virtual boundaries of computational windows are well-known sources of errors in the FDTD that make nearly impossible to unambiguously interpret the results of electromagnetic simulations [G. Hower *et al.*, *IEEE Trans Antennas Propagat.*, 41, 982, 1993]. If the designers could work with more accurate and economic optical simulation tools, they would develop photonic circuits with higher degree of integration.

Problem statement:

The subject of work is accurate mathematical and numerical modeling of micro-scale to nano-scale optical metallic mirrors and dielectric lenses used for the processing of light in the novel photonic integrated circuits. Micromirrors are supposed to be shaped as thin imperfect curved screens – flat, parabolic, elliptic, and arbitrary-shape. Microlenses are to be considered as uniform or layered transparent scatterers having specific shape, e.g., elliptic with specially designed eccentricity, truncated elliptic, etc. Numerical study will be concentrated on the effects of finite size and realistic material parameters in the optical range on the electromagnetic performance of microantennas.

The project objective is basic research into the analysis and design of *micro-size optical metallic mirrors and dielectric lenses* for the light beam collimating and focusing. This will be achieved by the mathematical and numerical study of the corresponding wave scattering problems as the *boundary-value problems for the set of Maxwell's equations* with exact or generalized boundary, edge, and radiation conditions. Underlining concept is the use of *boundary integral equations*, which do not imply small-contrast or high-frequency approximations and lead to convergent, stable, and efficient numerical algorithms. Directivity of radiation, efficiency of focusing, wavelength dependences, and the field patterns in the near and far zones will result from this analysis, and the ways to improve these characteristics will be elaborated and analyzed.

The methods of CAD of micromirrors and microlenses will be based on rigorous uniquely solvable integral-equation (IE) formulations. This implies reducing original boundary-value problems to equivalent IEs whose class of solution is determined by the corresponding edge and radiation conditions. In each case the IE will be obtained from the corresponding boundary conditions at the boundary of the light scattering object. For microlenses and thick mirrors this is electromagnetic transmission condition. If a micromirror has a shape of thin metallic or layered-dielectric sheet, with the thickness of several units or tens of nanometers, then the generalized resistive-type boundary conditions will be used, to reduce the complexity by seeking only the fields outside of the sheet. As the full-wave IEs have singular kernels, they should be either converted to the Fredholm second-kind IE by using the *Method of Analytical Regularization* (MAR) and then discretized, or directly solved numerically with the *Method of Discrete Singularities* (MDS). Both methods have been developed in Kharkov since the 1970's. Each of them has its specific merits and the both have guaranteed convergence and controlled accuracy – unlike FDTD, BPM, GO, and other approximations. On solving IEs, one obtains the surface or polarization currents, near and far optical-field patterns, and can easily compute cumulative microscale antenna characteristics such as directivity, sidelobe level, and focusing efficiency.