DESCRIPTION FOR THE GENERAL PUBLIC

Currently it would be difficult to imagine nation economy of any developed country without semiconductor lasers, mostly diode lasers. As a matter of fact, they are essential in all areas of science and modern technology. Moreover we are commonly taking advantage of them in many spheres of our everyday life.

Two main configurations of diode lasers exhibit completely different properties. Edge-emitting lasers emit beams of relatively high power but of not satisfactory properties, from which very divergent radiation beams and an operation on many longitudinal modes are the most painful ones. Vertical-cavity surface-emitting lasers (VCSELs) emit low divergent beams usually of a single-fundamental-mode radiation and of a narrow spectral characteristic. Emission range of commercially available VCSELs is however limited only to a narrow sector around 1 μm. Besides quite an essential shortcoming is connected with their thick multilayer Bragg mirrors, because of which miniature laser structure is surrounded from both sides by much thicker DBR (distributed Bragg reflector) mirrors. Moreover those mirrors absorb laser radiation as well as make difficult current spreading and heat abstraction from a laser volume. Very recently, however, a very essential improvement has been created in this field by an application of relatively thin (about half-wavelength) high-contrast-grating (HCG) mirrors with a step index of refraction in a direction perpendicular to a radiation beam.

In standard diode lasers, radiative recombination of electrons from the conduction band and holes from the valence band is applied. Then energy of emitted radiation is directly connected with a width of the semiconductor energy gap and its wavelength is limited by accessibility of suitable semiconductors. However recently a new class of semiconductor lasers, quantum cascade lasers, has been proposed. In these lasers, emission of radiation is a result of electron jumps between levels of a properly designed quantum wells. Hence a wavelength of emitted radiation is in these lasers independent of used materials but is defined by their designs, mostly by sizes of an above mentioned quantum wells.

Currently the world-wide optical telecommunication is mostly based on waveguide fibers. However its future will be definitely connected with an optical free-space communication limited mostly by light absorption in the Earth atmosphere. Therefore for this communication, the most suitable is the radiation corresponding to the wide 8–14 μm window in an air absorption. In the case of semiconductor lasers, however, such a radiation may be emitted only by quantum-cascade lasers. These lasers as edge-emitting devices emit divergent radiation of relatively wide spectrum, which limits their possible applications.

The main goal of the present project consists in designing a completely new configuration of a semiconductor laser, which is expected to demonstrate advantages of both designs — VCSELs and quantum cascade lasers. A quantum cascade laser emitting from its surface is generally considered to be impossible. We propose, however, a completely new solution of this problem, which has not been considered until now. **Its main designing novelty consists in putting the structure of the quantum cascade laser into the HCG mirrors of VCSEL. Such a laser is expected to emit from its surface a single-fundamental-mode laser beam of a minimal divergence, as VCSEL, and, as a quantum-cascade laser, it would enable emission of radiation of a wavelength entirely defined by its design.** Moreover, an application of the HCG mirrors would bring about a considerably reduction of a laser thickness, followed by a substantial saving of applied materials. Besides the proposed structure would enable manufacturing two-dimensional laser arrays emitting radiation from the middle infrared range, which currently is unattainable.

At present the main anticipated application of the proposed laser would concern the free-space optical communications, spectroscopy and a distant gas detection (for example ozone) in atmosphere. It would be, however, difficult to anticipate today all other possible applications of such a new laser of completely new properties.

The research planned in this proposal is based on the theoretical analysis combined with advanced numerical simulations of VCSELs. It will be realized with the aid of the advanced and fully self-consistent simulation methods developed in Photonics Group at the Institute of Physics, Lodz University of Technology.