

Optical sensors find many applications in various areas. They can be used for example in motion sensors or in gas detection. In most cases, the detector consists of a light source and a detector that observes changes of emitted light (light intensity or wavelength) and based on that performs detection. Small dimensions of the detector are particularly important in some applications. Meanwhile, two-element sensors (light source and detector) usually require additional optical elements and proper calibration, which greatly complicates their construction. In my project, I propose a new design of the optical sensor, which consists of only one element: a semiconductor laser, which is a source of light and a detector at the same time.

In the proposed project I want to show that it is possible to design semiconductor lasers that are sensitive to changes in the environment, can be used as liquid and gas detectors. The presence of liquid or gas in the vicinity of the laser causes a change in the quality factor of the laser's resonance cavity, and consequently a change in the threshold parameters of the laser and its current-voltage characteristics. Then, by measuring current and voltage, it is possible to conclude about the presence of liquid or gas in the surrounding of the laser. For this we can use VCSELs with top HCG mirror, but it would also be possible to use other semiconductor laser constructions.

VCSELs (Vertical-cavity surface-emitting lasers) are semiconductor lasers in which radiation is emitted in a direction perpendicular to the plane of the active region. In comparison with other semiconductor laser designs, VCSELs are characterized by very good parameters of the emitted beam and lower production costs.

HCG (high refractive index contrast grating) mirrors are diffraction gratings that are made of a material with a high contrast of refractive index (much higher than the refractive index of surrounding media). The geometric parameters (especially the grating period) of the HCG mirrors are smaller than the wavelength (in vacuum) for which the mirror is designed. Properly designed HCGs can provide a very high (close to 100%) reflectivity. You can also design them in such a way that they are sensitive to changes taking place in the surroundings of the mirror (for example changes in the refractive index or changes in the absorption coefficient of the surrounding medium).

The preliminary calculations made by me show that the VCSEL with a monolithic HCG mirror can be used as a one-piece methane detector. The calculations were performed using a computer model that was created in the Photonics Group of the Lodz University of Technology. This model allows us to study the thermal, electrical, gain and optical phenomena that occur in the laser. The optical model is a three-dimensional vector model that allows analyzing the properties of HCG mirrors and the entire VCSEL's structure.

In my project I would like to analyze various designs of HCG mirrors in terms of sensitivity to changes taking place in the environment. I will also analyze the properties of various active regions that can be used in VCSELs. I will consider various constructions of active regions based on quantum dots and quantum wells. I will design the active region and mirror HCG, which will allow to create the most-sensitive sensor possible. The semiconductor laser structures I design will be able to be used as gas or liquid detectors. They can also be used to test the properties of liquids, e.g. to perform blood tests. Currently, many blood tests are based on the measurement of its optical properties - for example, the study of glucose levels, hemoglobin content or blood oxidation. The devices proposed by me could find many applications in this and other areas.