Term “laser” is usually associated with a bulky and heavy equipment. The aim of the project is to design and demonstrate a tunable, ultra-low threshold micro-laser, so that the structure producing coherent light, but of a micrometer size. The first component implemented to achieve this goal, is a so called subwalength grating, that is a grating made of dielectric or metal with a period much smaller than the wavelength of the light. Despite its tiny spatial dimensions such element is able to act as a highly efficient mirror. Unlike in the case of a typical mirror, the principle of its operation is a destructive interference between the light propagating through regions of a grating of a different optical thickness. Subwalength gratings offer an attractive alternative to multi-layered Distributed Bragg Reflectors commonly implemented in optical microcavities so far.

Another component of the proposed micro-laser is an ultrathin semiconductor emitter. The best candidates are thin layers of perovskites or monolayers of van der Waals type materials such as transition metal dichalcogenides, intensively developed and studied over the recent years. One of the main advantages is high efficiency of emission, surviving up to the room temperature.

Integration of the dielectric subwalength grating with an ultra-thin layer of such efficient semiconductor emitter will results in formation a hybrid structure acting as a micro-laser of ultra-low threshold. In order to obtain such a structure a few micrometer thick dielectric/semiconductor layer will be microstructured to produce a subwalength grating. Next, a layer of a 2D perovskite type or a monolayer of van der Waals type semiconductor will be deposited on the grating surface. Methods of wet chemistry, molecular beam epitaxy, where atoms are deposited layer by layer or exfoliation from a bulk sample will be used for production of such thin semiconductor layers.

The proposed hybrid-structures will be designed by numerical calculations in a collaboration with Institute of Physics at Łódź University of Technology. The preliminary calculations indicate that a strong confinement of the light in a small volume of the proposed structure is associated with in a large amplitude of oscillating electric field in the region of a thin semiconductor layer deposited on the grating. The resulting enhancement of the light-matter interaction should lead to formation of quasiparticles called exciton-polaritons, that is hybrid quasiparticles being half-light and half-matter. Due to their bosonic nature, exciton-polaritons undergo a Bose-Einstein condensation induced by a stimulated scattering of polaritons to the massively occupied fundamental state. When such condensate decays radiatively, a coherent light emission takes place. Such emission, in analogy with a typical lasing is described as a polariton lasing. The onset of polariton lasing, being a consequence of stimulated scattering of the polaritons requires much smaller excitation power than the onset of typical lasing, where population inversion is necessary. Thus, the proposed micro-laser will exhibit not only the ultra-small spatial volume, but also, thanks to its ultra-low threshold operation, it will consume a small amount of power.

The issue of spectral tunability of the produced micro-lasers will be approached by stretching of the structures using piezo-elements in the direction perpendicular to the grating. The general issue of spectral tunability of subwalength gratings has not been solved so far.

It is worth to underline that properties of hybrid structures proposed in the project make them an excellent platform for realization of a variety of diffractive microdevices. They include light modulators, phase retarders, colour filters or sensors, which operation will depend on such properties of a beam as its incidence direction or polarisation. Recent advances in micro-structuration and 2D semiconductor technology ensuring ultimate degree of control of the fabrication process is promising for a mass production of such devices.