Investigation of optofluidic phenomena in liquids and soft matter employing optothermal Marangoni effect

The goal of the project is in depth study of optothermal Marangoni effect in millimeter to micrometer scale in liquids, liquids crystals and polymers with azobenzene derivatives. Marangoni phenomenon is related to near surface liquid flows from areas of low to areas of high surface tensions. The condition of occurrence of Marangoni effect is gradient of surface tension. Generally, these gradients can be realized by two ways, either via change of surfactant concentration at liquid surface (solutal Marangoni effect) or via generation of temperature gradient (thermocapillary Marangoni effect). We will use focused laser light beams absorbed in the bulk of studied liquid or by absorption of dyes or nanoparticles intentionally introduced to it. The strong temperature gradient achieved by this way under certain conditions generates stable in time whirls of liquid similar to phenomenon of tornado observed in an atmosphere. These whirls are capable of mass translocation, surface objects displacement, bending of liquid surface, gas bubbles formation, droplets manipulation and even condensation of dissolved substance in the liquid.

Our preliminary studies have shown that smart use of whirls can result in optical trapping of bubbles and their manipulation by the changing position of laser beam. Project will be devoted to development of physical grounds and conditions for trapping of gas bubbles, droplets and nano-objects by use of laser sources capable of inducing Marangoni flows. Investigations will not be limited to ordinary liquids, because we are planning to study also liquid crystals possessing anisotropic viscosity that could be controlled by electric field strength. We will investigate colloidal systems in which nanoparticles might whirling together with liquid streams and azo-polymers in which strong light absorption leads to near surface fluidization. We plan investigate Marangoni flows in the close proximity of the interface between two immiscible liquids,

The scientific disciplines, within which our studies are located, are optofluidics and microfluidics. Progress in nanotechnology, nanobiophotonics, nanophotonics and nanomedicine is closely related to our basic studies, however, we are not limiting our interests to nanoscopic scale.

The main reason to undertake this subject was the willingness to understand mechanisms of whirls formation in liquids under conditions of strong temperature gradients, then controlling them and using to, e.g. translocation of small objects, their rotation, controlled deposition of nanoparticles on a substrate, controlled by laser light crystal growth, steering of gas bubbles in microfluidic systems and even chemical reactions in nano liter volumes. Similar studies are performed by several research groups. However, added value is the use of our experience in the field of optical holography. We will use holography to preparation of structured laser light, i.e. light diffracted on a device called Spatial Light Modulator (SLM). Employing SLM one can display pre-calculated digital holograms and changing them with time one is able to steer movement of several beams at a time. Moreover, displaying specific holograms in the form of „forked" diffraction gratings, the beams with the dark field in the focal point carrying Orbital Angular Momentum can be synthesized. This OAM couples with matter and can determine direction of whirling or nano-object rotation. In that respect our approach is similar to that of "optical tweezers", however we are using heat production due to light absorption instead of pure gradient force.

Understanding of such complex physical mechanisms at the edge of laser optics, photonics, hydrodynamics, heat transport or thermodynamics requires solving coupled differential equations describing phenomena in which helpful will be programming and simulation platform of physical systems COMSOL Multiphysics.

Joining structured light with heat production in liquids that employs optothermal Marangoni effect should bring experimental and theoretical results useful for all people working in the fields of opto- and microfluidics, photonics and other related disciplines of science. Light-induced Marangoni flows can be treated as a tool of remote control of small objects movements in liquid, like nanocrystals, nanoparticles or formation of micro assemblies of crystallites of a given geometry.