Optical tweezers based translational and rotational active microrheology of soft materials

Rheology is the science about flow and deformation of complex materials, and microrheolgy is about looking at this properties from perspective of a probe not much larger than voids in polymer network, or droplets forming emulsion. Flow and deformation of matter are described by its viscus and elastic properties, and if material exhibit both of them it is viscoelastic. The character of the material might change from more liquid like to more solid like with changes of temperature, pressure or characteristic timescale (rate) of strain. This mean that the same material might be softer or harder, or flow faster or slower depending on a temperature, pressure and strain rate. The viscoelasticity is describe by a tensor and it depends on direction in which the stress is applied and direction in which the strain is observed. The viscoelasticity might be anisotropic, it might be different depending on direction, like in liquid crystals. It might also have different components, such as bulk, Young or shearing, depending on strain and deformation relative orientation.

The project objective is to use optical tweezers and analysis of active translational and rotational motion of nano- and micro-probes to study interesting viscoelastic properties, non-equilibrium thermodynamics and phase transitions of polymers, liquid crystals and biomaterials.

The optical tweezers allow to optically trap nano- and micro-particles, move and rotate them, and simultaneously measure forces acting on them with very high precision. The biggest advantage of using optical tweezers is that they allow to measure very small volumes of interesting materials, which might be impossible to obtain in volumes necessary for macroscopic rheology, like many of biological materials. Due to very local measurements, optical tweezers also allow to look at heterogeneity of the measured materials.

Microscopic probes, used in optical tweezers, feels different forces than macroscopic objects. The gravity, which is one of a dominant force in macro-world is negligible in nano- and micro-worlds, and dominant forces which nano and micro-particles feel are stochastic force of Brownian diffusion, optical forces, when particle is in optical trap and viscoelastic friction caused by interaction with surrounding medium. Using theories, which describe all this forces, it is possible to retrieve some information about the surrounding medium from observation and analysis of the probe motion in optical trap. There are two general approaches for such measurements, first, passive where only Brownian diffusion of the probe is observed. Second, active, when the probe is actively moved through surrounding media and its response upon this motion is measured. The active method allows to measure nonlinear response of the material and observe its changes with the strain rate.

Additional possibility is to use translational and rotational motion of the probe to look at the properties of surrounding media. Most of the researchers look only at the translational motion, which is might be observed for any probe using camera or fast position sensitive detectors. In order to observe rotational motion the probe have to be anisotropic in shape or optical properties. Good example of anisotropic probes are gold nanords, which are elongated gold nanoparticles, showing plasmonic resonances and very strongly interacting with light. This strong, resonance driven, light-matter interaction allow to rotate them at very high frequencies and use them as an active rotational probes.

Translational motion of the nano- or micro-probe through the medium is a complicated motion. The probe is both pressing and stretching the network in different directions, and the friction, which it feels, is composition of bulk and shearing frictions. Therefore, even though translational motion is easier to measure, it is hard to analyze and compare with macroscopic properties of material. The rotational motion, on the other hand, might be harder to measure experimentally, but it is relatively easy and strait forward to analyze and describe theoretically, as it only probe shearing viscoelasticity. Combination of both, active translational and rotational motions might allow to measure full tonsorial viscoelastic moduli.

Some of the nanoprobes, which will be used in the project, allow to measure its internal temperature. Combining independent local temperature sensor with active microrheological probe gives unique possibility to study non-equilibrium thermodynamics and phase transitions in soft materials induced by temperature or strain rate changes in extremely small volumes.

Results obtained within the project will pave a way towards temperature and frequency dependent rheology of the cytoplasm and cytoskeleton in living cells. What is of a great interest for biology and medicine, where mapping of local properties of cytoplasm is crucial for understanding of the cell aging and development of diseases such as Alzheimer’s disease.