Dynamics of self-propelled colloids and their application as active matter
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7: Summary
7.1 Summary

In this thesis, the behavior of active particles spanning from single particle dynamics to collective behavior of many particles is explored. Active colloids are out-of-equilibrium systems that have been studied extensively over the past 15 years. This thesis addresses several phenomena that arise in the field of active colloids.

The first chapter gives a brief introduction to mechanisms of propulsion of active colloids and related fabrication techniques.

In the second chapter, a simple technique to increase the speed of catalytic motors is discussed. Janus-particles, half coated with a catalyst are the most widely studied system of self-propelled colloids. To fabricate these particles, physical vapor deposition techniques, such as sputtering, are used, and a catalyst (typically Platinum) is evaporated onto the colloids inside a vacuum chamber. Here, it is examined if one can use nano-structuring to increase the speed of the Janus particles. A simple technique of introducing a thin oxide underlayer underneath the catalyst is demonstrated. The oxide layer creates nanoscale roughness on the surface of the colloids. By depositing metal platinum catalyst on top of the oxide, the active rough catalytic surface has a higher surface area than if it had been deposited on the smooth surface of the particle. Hence, a higher turnover rate due to an effectively larger surface area is expected. This results in a higher speed of the catalytic motors and a four-fold enhancement of their speed is observed.

In the third chapter of this thesis, the motion of active self-propelled colloids on a complex surface topography is studied. The model surface consists of a close-packed monolayer of spherical particles. This model system shows similarities to the periodic potential found in atomic diffusion. The self-propelled colloids could be considered as “model adatoms” to understand basic physics of atomic diffusion process. The slow micron scale dynamics of the colloids permit observation by simple optical microscopy and simplifies measuring otherwise challenging surface diffusion process. On two-dimensional crystalline surfaces, at low fuel concentrations, sub-diffusive behavior is observed. However, as the fuel concentration was increased, the active colloids could easily hop from one lattice site to the next and freely diffuse, although with a lower diffusion coefficient compared to a planar
substrate. The dynamics of activated diffusion of colloids on surfaces was studied and compared to a theoretical model.

In the fourth chapter, an application of active colloids in the field of nanoscale sensing is described. Here, for biocompatibility and ease of integration into the experimental setup, a self-thermophoretic rather than a chemically-active colloid is used. By coupling a fluorescent nano-diamond on the tip of the colloid, a swimming hybrid structure was fabricated. The fluorescence stems from a nitrogen vacancy center in the nano-diamond and is exceedingly sensitive to temperature and local electro-magnetic fields. The colloid-coupled NV center was excited with a laser at 532 nm and the fluorescence was observed between 637-750nm. The colloid was also equipped with a small metallic patch, such that the same 532 nm laser could locally heat the colloid and hence the fluid near the colloid. This self-thermophoretic process propelled the microstructure and made a micro-swimmer that could be manipulated with light. The shape of colloid was designed by glancing angled vapor deposition technique, so that it could perform rotary or translatory motion. Electron spin resonance measurements on the NV center attached to a rotary swimmer were used to detect the magnitude and direction of an externally applied magnetic field. Thus, a microscale self-thermophoretic “compass” capable of sensing local magnetic field with NV center was realized. Future applications of such swimmer-sensor can include sensing of local physical properties in biological fluids.

In the final results chapter, an active opto-rheological suspension is demonstrated. Here, the collective behavior of a dense active suspension of self-propelling (chemically-active) colloids was studied. The single unit of the suspension is a shape-asymmetric anatase titania colloid that is powered by the photochemical decomposition of an aqueous fuel to self-propel and interact with neighboring particles. Since, the catalytic reaction is light controlled; the properties of the suspension could be tuned with light. By increasing the activity (or the light intensity), the suspension makes a microstructural transition from a fluctuating state to an arrested state. The microstructural change translates into change in viscosity of the suspension. Magnetic micro-rheology was used to measure the change of viscosity of the chemically-active suspension and an 8-fold increase in the local viscosity was observed. Next, the suspension was transferred to a commercial rheometer to
investigate the bulk properties of this active medium. A reversible 10-fold increase of the suspension’s viscosity was demonstrated. Further, the viscosity could be changed multiple times by switching the light on and off. It is thought that this presents a first demonstration of the collective behavior of synthetic active colloids giving rise to a change of a bulk material property. This study opens up possibilities for the large scale application of active colloids and for the development of novel materials that are based on non-equilibrium physics.

In the concluding sixth chapter, the contributions of the thesis were evaluated briefly and possible future directions are discussed. Future studies can lead to both fundamental insight regarding the behavior of active particles, and to applications of active matter.