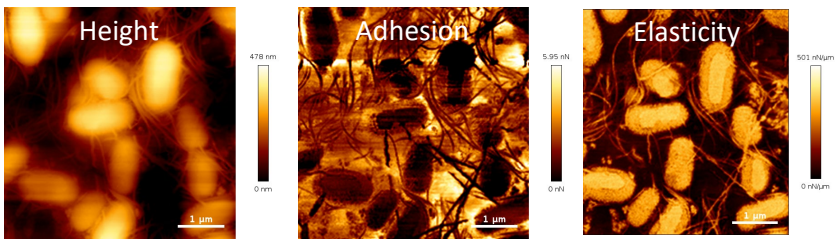
Bio-cell imaging and light induced stimulation by topological plasmonic superfocusing microscopy

In this project, which is part of the Cluster of Excellence "Balance of the Microverse" (https://microverse-cluster.de/en/), we aim at developing label- & background-free plasmonic superfocusing microscopy as a novel technique for membrane imaging and light induced stimulation of membrane receptors with a resolution down to the nanometer scale. The targeted ultra-high spatial resolution will allow resolving functional features at the cellular level, as e.g. single membrane receptors, receptor ensembles, or even lipid rafts, as well as their selective photo-chemical/thermal stimulation. By delivering simultaneously structural information on the surface topography and local functional information with unprecedented spatial resolution under in vitro conditions, we will provide a novel tool to the Microverse Cluster to disclose structure-functionality & cause-effect relationships of fundamental microbial processes that eventually govern the balance, disbalance, and resilience in microbial consortia. Beyond imaging and by interdisciplinary collaboration between scientists from physics, biology, and material science, we will expand the technique to photo-induced dynamic stimulations in microbial arenas. This will allow studying the role of chemical mediators (generating steep local gradients in the chemical environment, e.g. metabolites or metal ions, around producing/consuming microorganisms) or manipulating phototropic organisms by local light fields. Hence, the visionary goal of this project is to develop a tool for the direct spatio-temporal analysis and visualization of metabolic states of cells and metabolic fluxes on a very fundamental level. While such scanning near-field optical microcopy was already investigated for several years, only very recent advances in the physics of topological plasmonic superfocusing will enable the required in situ detection of molecules. Therefore, the proposed project will contribute directly to developing novel imaging technologies for real-time in situ molecule and single-cell detection in a non-invasive manner" and hence resolve a critical lack of functional analyses for addressing the basic biology of microbial balance.

The investigated microscopy technique is based on raster scanning a sharp metal coated optical fiber tip with sub-nm precision on a sample surface, allowing for simultaneous acquisition of topographic information and optical properties (spectroscopic), chemical properties (Raman) as well as stimulation (photo induced release of chemicals and ligands, photo-thermal), all with a spatial resolution of several nm. While previous optical tip-scanning approaches had been suffering from fundamental physical limitations in resolution, signal level, and background, the proposed technique, based on the novel topological plasmonic superfocusing principle, is free from such limitations. The physical feasibility of the approach was already demonstrated but needs to be adapted to cellular/microbiological problems relevant for the biological studies in the Microverse Cluster, including also the combination with chemical functionalization of the employed metallic tips as well as modern labeling and nanocontainer delivery technologies in collaboration with the chemistry groups of Prof. Ullrich Schubert and Prof. Kalina Peneva as well as the group of Prof. Miriam Agler-Rosenbaum from the Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute.



Left: Ultra-high-resolution imaging of bacillus subtilis by tip scanning technique.

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