

Plasmonic SERS Nanoplatfoms for Probing Molecular Signatures of Cancer

Dr. Jyothi B. Nair¹, Dr. Dana Cialla-May^{1,2}, Prof. Dr. Jürgen Popp^{1,2}

1. Leibniz Institute of Photonic Technology, Jena, Germany

2. Institute of Physical Chemistry and Abbe Centre of Photonics, Friedrich Schiller University Jena, Jena, Germany

Abstract

Raman spectroscopy and its plasmon-enhanced variant, surface-enhanced Raman spectroscopy (SERS), have emerged as powerful analytical modalities for disease diagnostics owing to their high chemical specificity, ultra-sensitivity, and non-destructive, label-free nature. The integration of plasmonic nanostructures enables SERS to overcome the intrinsically weak Raman scattering cross-section by generating intense localized electromagnetic fields, thereby allowing the detection of unique molecular fingerprints at the single-cell and, in favourable cases, single-molecule level. These attributes render SERS particularly attractive for interrogating complex biological systems and disease-associated molecular heterogeneity. Recent advances have demonstrated the applicability of SERS in the detection and molecular profiling of extracellular vesicles, including exosomes, underscoring its potential for early-stage cancer diagnostics. In this work, we report the rational design and application of spherical and hollow gold nanoparticle-based SERS nanoplatfoms for combined diagnostic and therapeutic (theranostic) applications. Spherical gold nanoparticles were employed as intracellular SERS probes to investigate the molecular effects of paclitaxel (PTX), a non-fluorescent chemotherapeutic agent, with a specific focus on drug-induced perturbations of microtubule organization and cellular cytoskeletal integrity. In parallel, hollow gold nanoparticles were integrated into an engineered drug-delivery system, enabling SERS imaging and spectral fingerprinting to monitor drug release dynamics and therapeutic responses at the molecular level.

These investigations were performed in both two-dimensional (2D) cell culture systems and three-dimensional (3D) tumor spheroid models to more accurately recapitulate the tumor microenvironment and cellular heterogeneity. At present, our research is primarily directed toward exploiting the diagnostic capabilities of SERS for the early and precise detection of molecular alterations associated with cancer initiation and progression. The analytical outcomes demonstrate that SERS-based nanoplatfoms provide a robust and sensitive means to monitor therapeutic efficacy, decode

intracellular drug mechanisms, and track cancer-associated molecular events.