Abstract

The widespread contamination of water by pathogenic microorganisms, heavy metals, and agricultural pesticides poses a significant threat to environmental sustainability and public health. Moreover, the rapid emergence of antimicrobial resistance (AMR) among clinically important pathogens has created an urgent need for rapid, sensitive, and label-free analytical technologies. Conventional detection methods are often labour-intensive, require extensive sample preparation, and are unsuitable for real-time or point-of-care analysis. This thesis addresses these challenges through the development of advanced plasmonic sensing platforms based on Surface-Enhanced Raman Spectroscopy (SERS) and Surface Plasmon Enhanced Autofluorescence Spectroscopy (SPEAS) for ultrasensitive detection of environmental contaminants and urinary tract infection (UTI) pathogens.

The proposed sensing platforms integrate chemically synthesized plasmonic nanoparticles, direct laser lithography-based periodic nanostructures, and a hollow-core silver-coated fiber (HCSF) to enhance light–matter interaction and improve detection sensitivity. Spherical Ag and Au nanoparticles were synthesized using microwave-assisted reduction, while Ag nano dendrites were fabricated through chemical reduction. Periodic checkerboard and pentagon-shaped Au nanoparticle arrays were realized using maskless lithography followed by electrochemical deposition, providing precise control over nanoparticle geometry and periodicity for reproducible plasmonic hotspot generation. Three-dimensional finite-difference time-domain (3D-FDTD) simulations further confirmed strong electromagnetic field localization within the nanogaps, validating the substrate design.

The developed plasmonic platforms demonstrated exceptional analytical performance, achieving an enhancement factor of **7.1×10^{10}** and an ultrasensitive detection limit of **10^{-17} M**, with excellent reproducibility (RSD < 8%) and long-term stability of up to **180 days**. The periodic Au nanoparticle substrates enabled rapid detection of five clinically relevant UTI pathogens—*Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Staphylococcus aureus,* and *Enterococcus faecalis*—with a detection limit of **10^2 CFU/mL**. In addition, strain-level discrimination of antibiotic-resistant *E. coli* variants demonstrated the platform's potential for rapid AMR screening.Beyond biomedical diagnostics, the developed sensing platforms were successfully extended to environmental monitoring. The integrated HCSF-SERS/SPEAS platform enabled sensitive detection of five heavy metal ions and three agricultural pesticides in water, while the checkerboard Au nanoparticle array achieved multiplexed detection of heavy metals with a detection limit of **1 pM** on a reusable substrate. The confined optical interaction within the HCSF significantly improved analyte interaction, making the platform suitable for portable and real-time sensing applications.

To evaluate practical applicability, the proposed SERS platform was validated using **100 real patient urine samples** collected from AIIMS, New Delhi, demonstrating successful identification of UTI pathogens, with *E. coli* accounting for approximately **80%** of the positive samples. Overall, this thesis presents a cost-effective, scalable, reproducible, and highly sensitive plasmonic sensing platform that integrates SERS, SPEAS, fiber-optic sensing, advanced nanofabrication, numerical simulations, and clinical validation. The ability to detect pathogens, heavy metals, and pesticides on a unified platform highlights its strong potential for environmental monitoring, point-of-care diagnostics, and early detection of antimicrobial resistance.