Development of Scalable and Cost-effective SERS Substrates for Bio-photonics Application

Sathi Das (2019PHZ8690)

Ph.D. Supervisor: Prof Dalip Singh Mehta

Department of Physics, IIT Delhi

Abstract

In recent years, the world has faced various public health and environmental sustainability challenges. Globally, there is a surge of infectious diseases due to increased international travel, urbanization, and the ability of pathogens to evolve and adapt antibacterial resistance genes. According to WHO, more than 1.2 million people died from severe bacterial infections in the respiratory, gastrointestinal, and central nervous systems. A healthy individual can acquire pathogens from other humans, the environment (contaminated food, water, and air), pets, and farm animals (zoonotic transmission). The pernicious spread of bacteria with antibiotic resistance poses a serious risk to the public's health. Traditional detection techniques, including polymerase chain reaction (PCR), flow cytometry, and enzyme-linked immunosorbent assay (ELISA), are time-consuming and laborious and require specific laboratory infrastructure and trained personnel. Thus, the culture-based detection technique precludes its use for rapid, ultralow detection of pathogens. Furthermore, regular exposure to antibiotics often drives the evolution of resistance via horizontal or vertical transfer of resistant genes, thereby enabling bacteria to escape antibiotic assaults. Consequently, the treatment of multidrug-resistant pathogens is becoming a challenge for clinicians. Thus, it is of utmost importance to determine the phenotypic characteristics of bacterial strains for rapid clinical diagnosis and initiation of a proper treatment regime in time. Thus, there is an ardent need to develop a fast, accurate detection method to diagnose bacterial infections. Apart from the diseases, air and water pollution have reached alarming heights due to industrialization and the increased pace of urbanization. These pollutants harm ecosystems, the climate, and human health. Chemicals are produced by various sources, including industrial emissions, agricultural, and urban areas. For a sustainable future, environmental contamination must be closely monitored and reduced.

This thesis has been inspired by an intense dedication to addressing the aforementioned issues and utilizing innovative technologies to offer practical solutions. The main goal of this study is to develop the methodology of molecular detection and evaluation, with the overriding objectives of enhancing public health and preserving the environment as its foundational values. The specific goals and justification for this undertaking are clarified by the purposes listed below:

One of the primary goals of this research is to realize the enormous potential of Raman spectroscopy as a versatile analytical method. Raman spectroscopy has several advantages, including its non-destructive nature and real-time study of molecular vibrational energy levels. Unlike many traditional procedures, it eliminates the need for time-consuming and laborious sample preparation, making it an essential tool for fast and accurate analysis. However, the inherently low Raman signal intensity limits its utilisation to detect analytes at the trace level.

Thus, the technique requires an enhancement mechanism to identify molecular signatures for ultra-low detection.

Surface-enhanced Raman Spectroscopy (SERS) is an emerging detection method that addresses the inherent difficulty of low Raman scattering signal strength. This research intends to develop a robust platform for identifying compounds at ultra-low concentrations by relying on the unique features of SERS. The requirement for quick detection in the contexts of infectious pathogens, antibiotic resistance, and environmental monitoring has prompted the development of SERS. The SERS effect is based on the interaction of light with nanostructures. Hence, the investigation of enhancement activity and plasmonic tunability is explored. This study comprehensively investigates various SERS fabrication techniques, including top-down and bottom-up methods, using physical and chemical synthesis approaches. The objective is to determine the advantages and disadvantages of each technique and its applicability to diverse applications.

The evaluation of SERS performance in detecting complex biomolecules in suspension is critical to this research. The research includes various analytes, from biomarkers and infections to environmental pollutants. The versatility and applicability of SERS in detecting biological and chemical compounds are revealed through systematic examination, providing insights into its potential as a revolutionary tool.