Design, Characterization and Development of Various Plasmonic Optical Sensors for Biomedical Applications

A thesis submitted

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by

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ABSTRACT

In the recent past, rapid development and globalization have brought healthcare issues to the fore. Nowadays, healthcare has become the most essential and challenging matter worldwide. Because of that, demands for fast and low-cost detecting methods and devices in biomedical industries have been growing rapidly. Plasmonics has attracted a lot of attention in the arena of medical diagnostic due to the unique optical properties of plasmon resonant nanostructures (NSs). Enough attention has been given to the development, preparation, and durability of plasmon materials. A variety of materials, structures, and functionalities are closely related to the basic structure of plasmonics, which allows for the development of biosensors that can be used in real-life situations. The proposed localized surface plasmon resonance (LSPR) phenomenon-based optical fiber sensors (OFSs), thoroughly investigated in the present thesis, have great potential and can contribute immensely to biosensing field in coming days, both on research and application fronts. Owing to the diversity and nature of the work requiring complementary skills and expertise, many scientists and researchers from the multidisciplinary fields/ areas are increasingly getting involved in this area of LSPR based OFSs. These sensors have the special ability to detect molecules associated with events in real-time. Advances in nanotechnology and nanoscience have allowed the development of plasmonic NSs, thin films, and highly sensitive methods for the determination of optical properties. Advances in nanotechnology and nanoscience have made it possible to develop plasmon NSs, thin films, and development of a highly sensitive optical characterization technique. Different aspects of LSPR based OFSs like, detection schemes, realization, configuration, component, and application of sensors have been reported here. Moreover, advantages and challenges related to several practical aspects, synthesis of nanomaterials (NMs), detection mechanisms, and innovative methodologies to enhance the sensitivity, selectivity, and limit of detection (*LoD)* is thoroughly studied and highlighted. The latest challenges in engineering and role of different NMs (metallic, magnetic, carbon-based NMs, latex nanoparticles (NPs), etc.) to enhance the performance of optical sensors are discussed as well. Such information should provide useful insight needed for further development of future plasmonic biosensors.

The present thesis deals with the design, characterization, and development of various LSPR phenomenon-based OFSs for various biomedical applications. These include different configurations of the sensors and activation methodologies aimed at detection and measurements of some of the very important analytes present in human body fluids. These arrays of newly developed sensors are briefly mentioned below:

1. *Dopamine Sensor:* Dopamine (DA) biosensor using silver NPs (AgNPs) nanocoated tapered optical fiber probe has been successfully designed and developed. The important sensing parameter such as linear range, *LoD*, sensitivity, and correlation coefficient (CC) that could be achieved are 10 nM - 1 µM, 0.058 µM, 9.7 nm/ µM, and 0.992, respectively. Typical challenges and concerns of these types of LSPR sensors have been considered thoroughly in this work.

2. *Ascorbic Acid Sensor:* Periodically tapered optical fiber structure with gold NPs (AuNPs), and graphene oxide (GO) nanocoated ascorbic acid (AA) sensor probe has been developed. Comparative performance for four, five, and eight sections periodically tapered structures-based AA sensor have also been investigated. The results such as *LoD*, sensitivity, and CC for proposed AA sensor (Probe-2) are recorded as 51.94 µM, 8.3 nm/mM, and 0.9724, respectively.

3. *L-Cysteine Sensor:* Development of LSPR phenomenon-based L-Cysteine (L-Cys) biosensors have been demonstrated successfully. Structural advancements such as tapering and hetero-core design are employed in the development of proposed L-Cys sensor. Nanomaterials such as AgNPs and GO are used to improve the sensitivity. The combined features of two different structural modifications (i.e., tapered and hetero-core), results in significantly increased linearity range, CC, sensitivity, and *LoD* and their values are recorded as 10 nM- 1 mM, 99.04%, 7.0 nm/mM, and 63.25 µM, respectively.

4. *Cholesterol Sensor:* LSPR phenomenon-based Cholesterol (Cho) sensor has been investigated and realized. An improvised and a new combination of multimode fiber (MMF), photosensitive fiber (PSF), and single-mode fiber (SMF) based core mismatch MMF-PSF-MMF (MPM) and SMF-PSF-SMF (SPS) structure has been proposed for the first time. Moreover, NMs such as AuNPs, and zinc-oxide NPs (ZnO-NPs) are deposited over the proposed bare fiber structure for improving the performance. The measured sensing parameters of proposed Cho sensor (Probe-1) like *LoD,* CC, and sensitivity are found to be 0.6161 mM, 0.9754, and 0.6898 nm/mM, respectively.

5. *Uric acid Sensor:* SMF-MMF-SMF-MMF-SMF (SMSMS) structure-based hetero-core design for the effective detection of uric acid (UA) has also been carried out. The requirement of sensing devices with a wide measurement range is fulfilled with these hetero-core structures. The performance of one of such sensor developed for the measurement of UA available with serum, with respect to *LoD*, sensitivity, and correlation correlator are observed as 69.26 μM, 6.15 nm/mM, and 0.9439, respectively, whereas those parameters for detection of UA available with urine, are observed as 0.35 mM, 1.23 nm/mM, and 0.9695, respectively.