Title: Highly Integrated Biosensors Based on Fiber Optics

Abstract:

Benefited from the advantages of flexibility, miniaturization, immunity to electromagnetic interference and compatibility with today's well-developed optical communication system, fiber-optic sensors show huge potentials with the increasing demand of comprehensive perception in every aspect of life. Especially in the practices of biosensing, optical fibers are prevailing platforms for highly-sensitive, real-time, label-free and in vivo detection due to their high degree of integration, dielectric nature, non-toxicity and chemical inertness. In this thesis, we investigate several approaches focusing on the proper design of fiber structure and the efficient integrations with functional materials to enhance the effectiveness of light-matter interaction and the reliability of biosensing output.

Firstly, we develop a highly sensitive magnetic field sensor based on magnetic-fluid-coated long period fiber grating (LPG). The emergence of optomagnetic biosensors in recent years brings the needs of all-optical, integrated and flexible magnetic field sensors. Benefited from the acute response of LPG to ambient medium and the remarkable magneto-optic properties of magnetic fluid, our proposed magnetic field sensor provides a superior sensitivity of 0.154 dB/Gauss and a low measurement threshold of 7.4 Gauss. Secondly, we investigate the possibility of improving the performance of conventional fiber-optic surface plasmon resonance (SPR) biosensors by employing two-dimensional (2D) materials. The one-atom-thick 2D material can be seamlessly integrated with noble metal nanofilm to form a 2D material/metal hybrid plasmonic structure. Introducing a graphene layer not only strengthens the excited surface plasmons, but also acts as an excellent replacement of surface functionalization thanks to the fact that graphene stably immobilizes biomolecules via π-stacking interaction. We construct a biosensor that integrates the hybrid plasmonic architecture with a side-polished optical fiber and apply it in the detection of single-stranded DNA (ssDNA). Both linear response to a wide range of ssDNA concentration from 1 pM to 10 μM and a limit of detection as low as 1 pM are achieved. Thirdly, we explore the potentials of adopting transition metal oxides as an alternative class of plasmonic 2D materials in fiber-optic biosensing. Since surface plasmons of most 2D materials locate intrinsically at terahertz or mid-infrared range that are not accessible for frequently used and cost-effective optical system, 2D materials are predominantly used as a booster of conventional SPR sensing in visible and near-infrared (NIR) range. Here we demonstrate the strong surface plasmons of highly-doped 2D molybdenum trioxide (MoO_3) nanoflakes in NIR range. Integrated with a microfiber, the positively charged MoO_3 nanoflakes show good affinity to negatively charged biomolecules and our proposed biosensor provide a detection limit of bovine serum albumin as low as 1 pg/mL. Lastly, we propose a highly-birefringent microstructured optical fiber (MOF) based SPR biosensor. Since birefringence of fiber-optic platforms can hardly be avoided in practical applications and surface plasmons are only excited by TM-polarized light, external perturbation would induce polarization crosstalk thereby destabilize the sensor output. Here we theoretically investigate the relation between birefringence and measurement offset and find that large birefringence effectively suppress the impact of polarization crosstalk. We design and analyze a polarization-maintaining MOF with birefringence larger than 4×10^{-4} while providing a sensitivity as high as 3100 nm/RIU.

In the studies we conducted so far, it is shown that the vast possibilities of optical fiber design and the breakthroughs of functional materials facilitate promising potentials in achieving highly sensitive and highly integrated biosensors. Further improvements in the specificity, sensitivity and integration of fiber-optic biosensors will be carried out in the near future.