

Abstract

Sensitive, label-free biomolecular binding detections using a one-dimensional photonic crystal sensor

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Novel optical methods for performing label-free detection have attracted growing attention driven by increasing demands for better understanding of specific interactions between biomolecules, which provide a chemical foundation for all cellular processes. Although a number of label-free techniques for directly monitoring biomolecular binding exist, they are limited in their ability to measure the binding kinetics of very small molecules, to detect low concentrations of molecules, or to detect low affinity interactions. In this thesis, I develop a one-dimensional photonic crystal biosensor for highly-sensitive, label-free, real-time biomolecular binding analysis.

This sensor uses a one-dimensional photonic crystal (PC) structure in a total-internal-reflection (TIR) geometry (PC-TIR), which forms a high-finesse Fabry-Pérot resonator with an open cavity. Detailed analysis on how to effectively design and fabricate suitable sensor structures is discussed. Experimentally, the sensor achieved a narrow resonance width (~ 1 nm) and large sensitivity (~ 1840 nm per refractive index unit (RIU)).

By adopting normalized intensity modulation, this sensor demonstrates ultralow detection limits (i.e. high performances) in a series of experiments: 10^{-8} RIU for bulk solvent refractive index, 2×10^{-5} nm for molecular layer thickness, and 6 fg/mm² for surface mass density. Moreover, its capability for label-free biomolecular detection is characterized with a standard streptavidin-biotin binding system. The specific binding of

biotinylated molecules ranging over three orders of magnitude in molecular weight including very small molecules (< 250 Da), DNA oligonucleotides, proteins, and antibodies ($> 150,000$ Da) to streptavidin covalently adsorbed sensing surface, are detected in real time with high signal to noise ratios. Furthermore, it shows high efficiency for quantitative analysis on DNA studies, including strand length measurement, low concentration binding, and hybridization.

Compared to the state-of-the-art surface-plasmon-resonance (SPR)-based biosensors whose performance is mainly restricted by broad resonance widths, the high-Q resonant cavities such as whispering gallery modes (WGMs) based biosensors which suffer from low sensitivity, thermal instability and nontrivial coupling, the PC-TIR sensor employing a simple geometry and a moderate Q, has achieved orders of magnitude higher sensitivity than other label-free optical biosensors reported to date, and thus is promising to be a new sensing platform for biomedical research and medical diagnoses.

