Unveiling Refractive Index Variations During Bioassays Through Plasmonic Tilted Fiber Bragg Gratings

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Biosensors are essential tools in fields such as drug discovery, disease diagnosis, biomedicine, food safety, environmental monitoring, and security. At the core of their functionality lies the detection and monitoring of biological compounds—proteins, nucleic acids, or microorganisms—a task made particularly challenging by the complexity of biological interactions and the high sensitivity required. Traditional detection methods frequently face challenges in identifying low biomolecule concentrations, especially in non-controlled laboratory environments. Biosensors address these limitations by converting molecular binding events into measurable physical signals, often through shifts in the refractive index (RI) at the sensor surface.

Surface plasmon resonance (SPR) is a widely adopted technique in biosensing, leveraging plasmonic effects to enhance RI sensitivity. By coupling light with electron oscillations at a metal-dielectric interface, SPR enables the precise detection of small RI changes. This principle forms the foundation of systems such as the Biacore® device, which excels in laboratory biomolecular analysis. However, this traditional prism-based SPR setup, though effective, is often bulky, costly, and difficult to adapt for portable, field-based applications.

To overcome these limitations, recent advancements have integrated SPR-based systems with optical fibers, significantly reducing the sensing area while maintaining high performance. Among these innovations, plasmonic tilted fiber Bragg gratings (TFBGs) have emerged as particularly promising. These sensors utilize inclined grating planes and thin metallic coatings to excite plasmonic modes, enabling highly sensitive refractometry.

By adapting the planar setup into a cylindrical geometry, TFBGs achieve enhanced portability, scalability and cost-efficiency.

Despite their advantages, analyzing the complex spectral data produced by TFBGs remains a challenge. These data, characterized by numerous cladding mode resonances modulated by SPR attenuation, requires sophisticated analysis techniques. Conventional approaches, such as single-peak tracking near the SPR attenuation, are widely used but often lack the precision and robustness necessary for diverse biodetection and refractometry applications. To address these shortcomings, this thesis introduces and evaluates optimized analytical techniques. These methods aim to transition from conventional, complex signal analysis to streamlined, effective approaches tailored to plasmonic TFBG sensors, enhancing their accessibility, precision and suitability for field-deployable applications.