A Novel Fiber-Integrated SPR Platform Combining Two-Photon-Printed Micro-Optics, Novel Fluidics and Advanced Data Analytics

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Abstract. Surface plasmon resonance (SPR) has become a well-established technique to rapidly investigate biomolecular interactions in a multiplexed manner by achieving very low detection limits and minimal sample preparation. Nevertheless, further improvements in optical stability, coupling efficiency, and signal processing are required to fully exploit SPR in compact, fiber-based and field-deployable sensing platforms. In this work, we present a novel SPR sensing approach that combines advanced micro-optical integration with novel fluidics and data-driven signal analytics. Two-photon polymerization (2PP) is employed to fabricate freeform micro-optical interfaces directly on optical fiber facets, enabling precise and reproducible fiber coupling into integrated collimator geometries. This monolithic alignment strategy significantly improves optical throughput, reduces coupling losses, and enhances mechanical robustness compared to conventional bulk-optical assemblies. The approach is particularly well suited for miniaturized and multiplexed SPR sensor architectures. In parallel, we introduce an advanced laser cut SPR chip that enables novel data analytics methods for SPR signal evaluation, combining advanced preprocessing, adaptive baseline correction, and multivariate analysis to improve detection sensitivity and signal-to-noise ratio. The proposed analytics framework enables more robust extraction of resonance shifts under low signal conditions and in the presence of optical and environmental perturbations. 2PP-micro-optics and data analytics enable sensitive, scalable SPR.

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1 2PP micro-optical interface

The micro-optical coupling structure was optimized to couple adjacent fiber inputs to pre-defined spots at the target chip. Each coupling lens was customized to match the specific input wavelength and target output position at the SPR chip. 2PP structures were designed to be placed on a glass substrate where micro-optical structures can be precisely aligned and which allows to keep the height of the printed optical surface thin. At the assembly stage, this substrate needs to be aligned and attached to the fiber array, and then the whole package needs to align towards the SPR chip.

2 Advanced SPR chip

The SPR sensor chip is designed to integrate optical interrogation with controlled microfluidic sample delivery. The plasmonic sensing surface is combined with a microfluidic layer fabricated in polydimethylsiloxane (PDMS), enabling precise handling of liquid samples and reagents over the active sensing area. Microfluidic channels are defined by laser cutting, allowing rapid prototyping and flexible channel geometries without the need for complex mold fabrication. This approach supports accurate alignment of flow channels with the plasmonic structures while maintaining optical access to the sensing surface.

3 Advanced data analytics

Advanced data analytics are incorporated to improve sensitivity and robustness of the SPR readout beyond conventional resonance tracking. The analytics pipeline combines adaptive baseline correction, noise-aware preprocessing, and multivariate data analysis to enhance signal-to-noise ratio and suppress optical and surrounding disturbances. These methods enable reliable extraction of resonance shifts under low signal conditions and support more accurate quantification of biomolecular interactions in compact and fiber-integrated SPR platforms.

References

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