Space-folded metaphotonics for multiplexed biosensing on a single chip

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Biosensors are vital across a wealth of industries, from healthcare diagnostics, pharmaceuticals to food safety. Multiple complex techniques are currently needed in order to and monitor, and differentiate, specific analytes in real-time [1]. A label-free, compact and highly sensitive biosensing platform capable of detecting major application-specific analytes in real-time would be highly desirable. For example, a dynamic signaling biosensor functionalized to detect major human diseases would be invaluable as a point-of-care diagnostic tool in 21st century patient-focused healthcare.

Nanophotonic biosensors exploit nanoscale light-matter interactions to detect molecular interactions. Rapid progress has been made in recent years, from refractometric to surface-enhanced sensing [2]. Nevertheless, current real-time monitoring implementations are rudimentary—typically capable of single analyte detection and often still requiring bulky external electro-optical systems for readout capability. *Metasurfaces*—arrays of engineered sub-wavelength elements—have extended the scope of nanophotonic biosensing by enabling greater control of light-matter interactions with more degrees of freedom (polarization, phase etc.) [3]. These are still limited by bulky readout systems (i.e. spectrometers, bulky optical systems etc.) and typically single analyte detection etc.

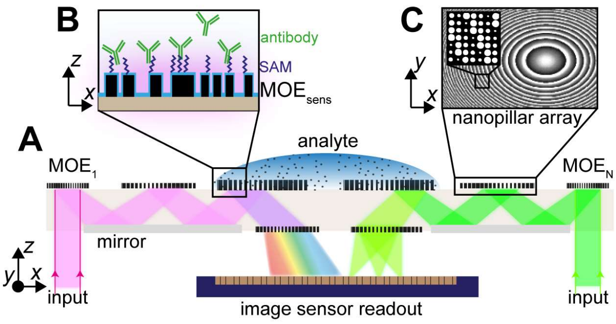

Fig 1. A. *Space-folded metaoptics built upon a CMOS image sensor for multiplexed biosensing.* ***B.*** *Self assembled monolayer (SAM) based functionalization of the metasurface optical element ($MOE_{1,2..N}$) surface for antibody sensing.* ***C.*** *Off-axis metalens encoded using a nanopillar array whereby pillar width phase modulation.*

In this project, we will develop a new class of biosensor based on space-folded all-dielectric metaphotonics (4) integrated atop a CMOS image sensor (CIS). Leveraging design concepts in planar integrated optics, metasurface design and spectral sensing, the proposed platform will consist of a multitude of metasurface optical elements (MOEs) lithographically patterned on a thin glass substrate which in-turn is built upon a CIS (**Fig.1A**). MOEs can be designed to engineer light-matter interactions in order to locally control the spectral, amplitude, polarization and phase of light—along with enhancing fluorescence and Raman signals. Top-down lithographic patterning means all MOEs can be fabricated in a single / double-step (two sides of substrate), reducing cost while permitting design complexity. Integrating all optics either side of a single glass substrate folds the optical path, greatly reducing size, and the CIS provides cost effective (<£25) electro-optic readout capability.

Our platform will enable cost-effective multiplexed sensing and imaging of different biochemical species. The envisaged design will consist of several classes of MOEs, including: separately functionalized biosensing regions for analyte interaction (**Fig.1B**); pre- and post-interaction light focusing and beam shaping regions (**Fig.1C**). Sensing MOEs will employ all-dielectric nanostructures that will include resonant wavelength shifting and fluorescence-enhancement approaches. Focusing and beam shaping MOEs will employ varying-width nanopillars for phase modulation. To validate the dynamic sensitivity and detection limits, we will use anti-mouse- secondary antibodies including as CD9 and IgG. Depending on progress, additional detection mechanisms may be implemented through novel MOE designs, such as chirality and depolarization sensing.

The Department of Physics at Exeter has extensive expertise across optical physics, photonic device development and metamaterials. The student will have access to world-class research facilities—including state-of-the-art nanofabrication cleanrooms, high performance electromagnetic simulation software, and laboratories for electro-optical characterization. Dr. C. Williams (PI) develops novel imaging and sensing technologies based on engineering nanoscale light-matter interactions (examples highlighted in **Fig 2**).

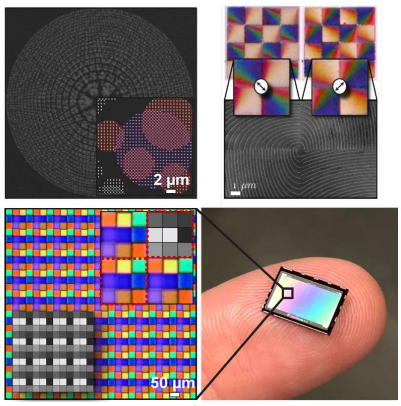

Fig 2. *Examples of nanophotonic devices developed by Dr. C. Williams.*

References

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[4] Faraji-Dana, M., Arbabi, E., Arbabi, A. et al. Nat Commun 9, 4196 (2018).