Handheld Chem/Biosensor Combining Metasurfaces and Engineered Sensor Proteins to Enhance Surface Plasmon Resonance (SPR)

CNF Project Number: 2430-16

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Primary CNF Tools Used: DWL2000 photomask writer, JEOL 9500 electron beam lithography, ASML DUV stepper, SC4500 evaporator, Oxford 81 etcher, Zeiss SEM, DISCO dicing saw

Abstract:

Since 2003, Phoebus Optoelectronics has enabled custom R&D solutions in the fields of metamaterials, plasmonics, antennas, and sensors. We work closely with our customers throughout device development, from product realization to small volume manufacturing. Our R&D portfolio spans the spectral ranges of visible light, infrared, terahertz, and microwave radiation, for applications in high resolution infrared imaging systems, wavelength and polarization filtering, tunable optical components, beam forming and steering, solar cells and renewable energy devices, and chemical and biological toxin sensors. Our agile team makes extensive use of the resources at the CNF for our nano/micro fabrication and testing, to provide cost efficiency and rapid turnaround. In the present report, we discuss recent efforts to develop a chem/bio toxin detection system, which provides the state-of-the-art sensitivity of a typical benchtop system with the superior SWaP performance of a handheld system. Our surface plasmon resonance (SPR)-based sensor is expected to be capable of detecting ng/mL concentrations of selected toxins in under five minutes.

Summary of Research:

SPR is a highly sensitive, label-free optical detection technique, whose underlying physics is illustrated in reflection mode in Figure 1. A laser passes through a prism, at an incident angle θ, on a gold film which is in contact with an analyte solution on its opposite side. The illumination produces an evanescent wave (surface plasmon), which significantly reduces the reflectance at a resonant angle. The resonant angle is strongly dependent on the local refractive index, within a few tens of nanometers of the gold surface, and thus is extremely sensitive to enzyme-substrate or antibody-antigen binding events near the surface. The resonance is independent of the geometric configuration of the optical elements (see [8] for mathematical derivation.), such that these results also apply to devices which operate in transmission mode.

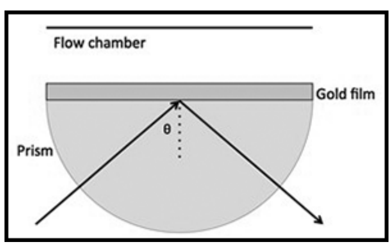
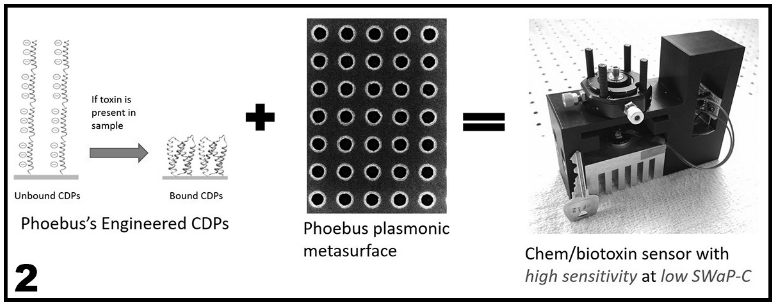
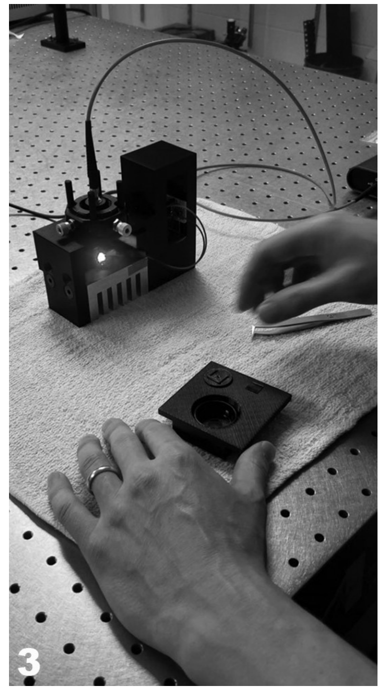


Figure 1: Surface plasmon resonance spectroscopy schematic. Reproduced from reference [8].

As illustrated in Figure 2, Phoebus has combined two recently developed technologies to enable an SPR sensor system, which provides enhanced sensitivity at lower SWaP, relative to technologies currently on the market. First, Phoebus detects toxins using computationally designed proteins (CDP's), engineered to undergo an exceptionally large conformational change upon binding their specific target. This conformation change increases the density of the protein layer, thereby locally increasing the effective refractive index, which in turn enhances the SPR signal by a factor of 100-1000x competing systems. Second, Phoebus uses the resources of the CNF to fabricate plasmonic chips patterned with a metamaterial surface to enable extraordinary optical transmission (EOT), a phenomenon unique to metastructures in which light is transmitted through apertures much smaller than the incident wavelength, at anomalously large intensities relative to the predictions of conventional aperture theory.

EOT was first observed by T.W. Ebbesen in 1998 [1]. Since its founding in 2003, Phoebus has successfully harnessed EOT by incorporating metasurfaces into devices used





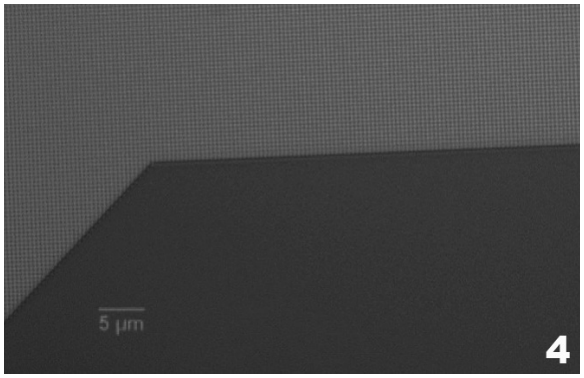


Figure 2, top left: *Phoebus-engineered sensor system combines; (a) Designed CDPs which undergo extreme conformational changes upon binding target (b) Gold metasurface, patterned to maximize transmission at SPR resonant wavelength into (c) a high sensitivity, low SWaP-C chem/biotoxin sensor system.* ***Figure 3, top right:*** *Complete Phoebus handheld biosensor system.* ***Figure 4, above:*** *Optical microscope image of a metasurface used in disposable biosensor chip.*

to perform light filtering [2-3], photon sorting [4-5], polarimetric detection [6], high speed optical detection [7], and most recently, in our SPR plasmonic sensor chips [8].

These two innovations are combined by attaching the engineered CDP's to the patterned gold metasurface using standard thiol-based attachment chemistry, to make a disposable sensor chip. As shown in Figure 3, this chip is inserted into the complete 3D printed module. All of the optical elements are already assembled in-line as indicated, for a transmission-based detection system. Except for Phoebus's disposable sensor chip, all of the optical components are inexpensively commercially available, which helps to make our overall system a highly cost-effective toxin sensing solution.

Our second-generation metasurface chips, shown in an optical microscope image in Figure 4, consist of an array of gold pillars, which serve both to bind the designed IDPs and to undergo SPR. To make the chip, we patterned the wires using the JEOL 9500 e-beam lithography system, evaporated Cr/Au, and performed a liftoff. This process is capable of consistently producing lines down to ~ 200 nm wide, with smooth enough sidewalls for an operable optical device.

References:

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