Listeria Sensor Chip via Surface Plasmon Resonance (SPR)

CNF Project Number: 2498-16

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Primary CNF Tools Used: DWL2000 photomask writer, ASML DUV stepper, AJA sputterer, Au electroplating, AJA ion mill, 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 biosensor system, which provides the state-of-the-art sensitivity of a typical benchtop system with the superior SWaP performance of a handheld system. Although our proof-of-concept prototype system is designed to detect *Listeria monocytogenes*, our system may be easily adapted to target any viral or gram-negative bacterial pathogen of interest, simply by designing new detection proteins specific to the new targets. We expect our system to find broad applications in public health and safety, medicine, and agriculture.

Summary of Research:

Metamaterial structures exhibit the unique phenomenon of extraordinary optical transmission (EOT), first observed by T.W. Ebbesen in 1998 [1]. In EOT, light is transmitted through apertures much smaller than the incident wavelength, at anomalously large intensities relative to the predictions of conventional aperture theory. Since its founding in 2003, Phoebus has successfully harnessed EOT by incorporating metasurfaces into devices used to perform light filtering [2-3], photon sorting [4-5], polarimetric detection [6], high speed optical detection [7], and most recently, including the present effort, in our SPR plasmonic sensor chips [8].

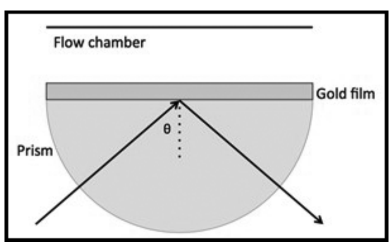

Figure 1: Surface plasmon resonance spectroscopy schematic. Reproduced from reference [8].

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.

Phoebus's technology, for the first time, enables an inexpensive (<$1,000), hand-held system for the optical detection of *Listeria* via surface plasmon resonance (SPR), with a sensitivity currently only available in expensive (>$100,000) benchtop SPR systems. We have achieved this by combining two key innovations: 1) Computationally designed proteins (CDPs), engineered to simultaneously bind their target pathogens with the specificity of wild-type enzymes, while undergoing an exceptionally large conformational change upon binding to maximize the SPR signal, and 2) Disposable plasmonic sensor chips, fabricated using the resources of the CNF, to pattern plasmonic chips with a metamaterial surface to enable as shown in Figure 2.

Our fabricated first-generation metasurface chips, shown in Figure 3, consist of an array of gold wires, which serve both to bind the designed CDPs and to undergo SPR. These two innovations are combined by attaching the engineered IDP's to the patterned gold metasurface using standard thiol-based attachment chemistry, to make a disposable sensor chip. This chip is inserted into a handheld 3D printed module, as shown in Figure 3. 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.

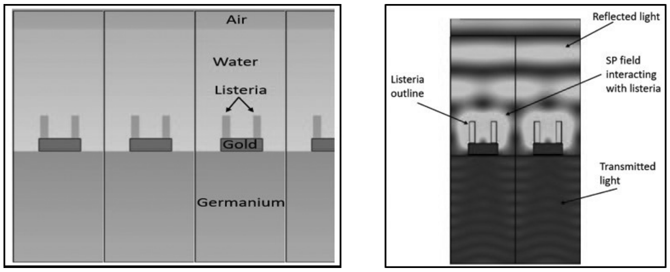

Figure 2: (Left) Unit cell of Listeria sensor. The full plasmonic chip consists of an array of these structures. (Right) Electric field profile at SP resonance, when bound to individual Listeria.

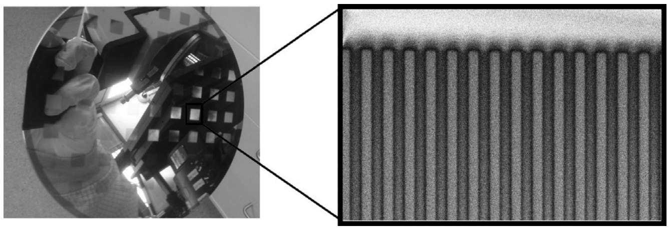

Figure 3: (Left) Wafer of plasmonic chips, fabricated on ASML DUV stepper. (Right) SEM image of a typical metasurface used in sensor chip.

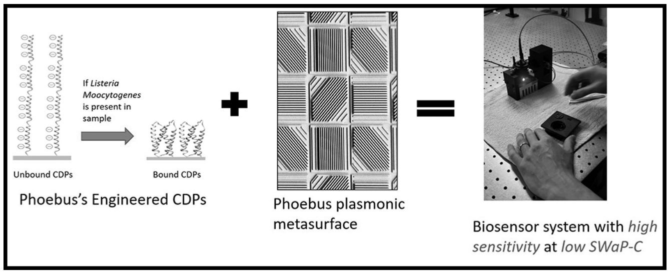

Figure 4: Phoebus-engineered sensor system combines (a) designed CDPs, which undergo extreme conformational changes upon binding target and (b) gold metasurface patterned to maximize transmission at SPR resonant wavelength into (c) a high sensitivity, low SWaP-C chem/biotoxin sensor system.

References:

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