Novel Approach to Constructing an Ultra Low Cost Flowcell Biosensor

THESIS

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Novel Approach to Constructing an Ultra Low Cost Flowcell Biosensor

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ABSTRACT

Here's my abstract, gee how interesting.

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I. INTRODUCTION

Flowcell sensors have many applications; disease detection, measuring refractive index and reactivity to name a few. These sensors have been operating on the basis of electromagnetic surface phenomena for decades. Most flowcells on the market work by exploiting surface plasma oscillations (SPOs). These oscillations are highly sensitive to changes in the optical properties of the adjacent medium and it follows from Maxwell's equations when the dielectric functions of each medium satisfies [**?**]

$$\frac{\epsilon_{spo}}{\epsilon_{adjacent}} < -1$$

Metals like aluminum, copper, gold, and silver have negative dielectric functions at wavelengths in the red/infrared, so films of these metals are used as to generate SPOs in most flowcell sensors via a process known as Surface Plasmon Resonance (SPR). An SPR system utilizes light-prism coupling to excite the surface electrons on a thin metal film deposited on the hypotenusal face of the prism. There are quite a few drawbacks for using metal films, however. Metals are highly reactive so each time an SPR system is used a new prism must be used. These films also require particular wavelengths of incident light to excite the oscillations. Rather than using metal films, one-dimensional photonic crystals, or multilayers, can be designed to exhibit the phenomenon of surface electromagnetic waves (SEWs) or Bloch surface waves (BSWs), named after the physicist Felix Bloch who was famous for working with periodic systems. These surface waves have the same practical application as SPOs. Multilayers overcome both of the shortcomings of metal films listed here. They can be designed to work for any wavelength and are typically made of nonreactive glass. In addition to these benefits, we expect that our 3-D printed and multilayer-based flowcell sensor will be more sensitive and precise with its measurements and be far cheaper to both build and maintain compared to traditional SPR sensors.

To take measurements with our sensor we look at the reflected image of incident laser light. Our multilayer is designed to trap incident light in the last layer at a special angle; this results in a dark band in our reflected image. A diagram of the process is shown below.

As fluids or gases are put into the flowcell chamber the index of refraction, n_c, changes. The condition for total internal reflection, found from Snell's law, for the interface between a glass prism and some transmitting medium whose index of refraction varies with time is given by:

$$\sin\theta_c = \frac{n_t(t)}{n_g}$$

We obtain an expression for the angle of reflection as a function of time by the Law of Reflection:

$$\theta_r(t) = \arcsin\frac{n_t(t)}{n_g}$$

Note that this expression is for a single interface and hence does not accurately reflect our setup as we have a glass prism and a multilayer. With that said, this expression for θ_r does capture the essence of our setup; the reflected angle is a function of the index of refraction of the transmission. Using this fact we can associate variations in the flowcell chamber's index of refraction with differences in the angle of reflectance. These angular differences can be calculated by tracking the variation in the position of the dark band in the reflected image.

Now with an an expression for the rate of change of reflected angle we can measure the index of refraction inside the flowcell chamber over time. From this data we can interpolate the mutual reactivity between molecules in a reaction, or maybe the rate of mixing of sugar water at a given temperature.

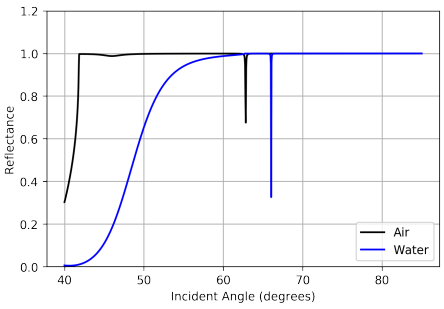
II. THEORY

The mechanism behind our biosensors operation stems from the analysis of surface waves in 1D photonic crystals given by Yeh and Yariv et al. (Appl. Phys. Lett. 32, 104 (1977)). They showed that surface waves can exist at the interface of a 1D photonic crystal and its bounding medium. The electric field of these surface waves takes the form

$$E(t, x, z) = E_k(x)$$

III. Methods

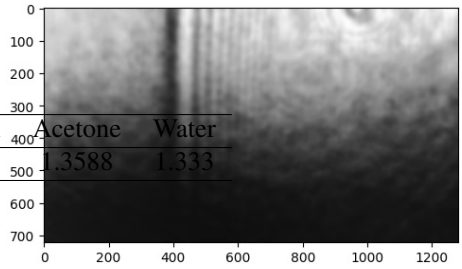
To collect data from our biosensor we first prepare the flowcell chamber with the correct substrate or liquid that acts as our reference point for measuring changes in optical properties. After the chamber is prepared we then turn on the beam and rotate it until the special angle is reached.



This is quite a precise angle so we orient the beam near the the mode $\sim 63^\circ$ from the prism's surface normal for a chamber filled with water or air using our multilayer stack as seen in ??. This plot was generated from a Python program that I wrote which use a transfer matrix method to generate reflection and transmission amplitudes for a multilayer stack like the one we use in our experiment. To confirm the light has coupled to the surface mode we check the reflected image of the beam for a dark vertical band as seen in ??.

As the index of refraction inside the flowcell chamber changes the dark band will translate left or right in our reflected image, depending on whether the index is increasing or decreasing. The shift in location of the band, in pixels, corresponds to an angular shift in the part of the reflected beam giving rise to the dark band. This is shown clearly in ?? as we see that a change from an index of 1.00 (air) to 1.33 (water) corresponds to an angular shift of about 3°.

To test our sensor, we first fill the flowcell with water and then inject different concentrations watered down ethanol, isopropal alcohol, and acetone. The table below lists the indices of refraction for all of these liquids.



	Ethanol	Isopropal Alcohol	Acetone	Water
Index of Refraction	1.361	1.3772	1.3588	1.333

IV. RESULTS

Mixtures	A	B	C
Ethanol (ml)	2	2	3
Water (ml)	10	8.3	7
Concentration (mols)	12 ml	10.3	10
Index	N/A	N/A	N/A

The table to the left lists the mixtures of ethanol used to test for a change in index of refraction (*This initial data is poorly measured and more data is being taken*). The plot below shows the different indices of refraction corresponding to mixture A being injected over the interval $[45.0, 55.0]$. Similarly mixture B was injected over the interval $[60.0, 75.0]$, and mixture C over $[85.0, 95.0]$. The dip in mode position is not expected over the first two intervals as we expect the mode to shift horizontally if the index of refraction in the chamber becomes larger than the original. However, the water used had been sitting in a syringe for a few days and may have actually increased in index of refraction, meaning that the index of the water in the chamber before injecting the first mixture may have been higher than the first two mixtures.

From this data we can infer a change in index of refraction of the medium once the index values of each mixture is known. Although we do not know the index of refraction we do know that the biosensor is highly sensitive as the index of ethanol is about 1.36 and water is 1.33 so our device is registering a change in index of at least 10^{-3}.