A single-layer, planar, optofluidic Mach-Zehnder interferometer for label-free detection (Electronic Supplementary Information)

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Sensitivity Discussion

Increasing the interaction length (d) will increase the sensitivity of the device as described by:

$$Sensitivity = \frac{\Delta\Phi_1}{2\pi\Delta n_1} = \frac{d}{\lambda}$$

If we assume a constant λ, then theoretically, the sensitivity can be infinitely increased by increasing d. Optical absorption is a limiting factor that will prevent an infinite increase in d. At a wavelength of 488 nm, the optical absorption coefficient of PDMS is α_{PDMS} = 0.5/meter [1] and the optical absorption coefficient for DI water is α_{water} = 0.0144/meter [2]. The limit of detection of our device was 0.115 oscillations and half an oscillation indicates a change from maximum intensity to minimum intensity. Thus, the minimum detectable signal would be at an intensity of $0.23*I_{IN}$. The equation for the intensity of I_2 including optical absorption is:

$$I_2 = 0.5 I_{IN}\left(1-\alpha_{PDMS} d\right).$$

Solving this equation for d when $I_2 = 0.23 I_{IN}$ will result in the maximum allowable distance based on optical absorption, and d = 1.08 meters! This is not a practical distance for a microfluidics device. The corresponding sensitivity would be $2.2(10^6)$ oscillations/RUI! This is significantly larger than our measured sensitivity of 927.88 osc/RUI, but this number is not realistic. Such sensitivity would be too high to collect real data and the system would be limited by other factors before optical absorption as discussed next.

A more pressing limitation to using large d values would be the formation of a concentration (refractive index) gradient along the length of the channel when the reference solution is switch with the sample. Currently with d = 500 μm, the channel is short and we assume that the refractive index is uniform along the channel length during the fluid replacement process. This allows us to use interference theory to understand the output intensity. As d increases, the assumption of uniformity along the channel length becomes less valid. If the channel were long enough, the end of the channel could still be DI water and the beginning could be the undiluted $CaCl_2$ sample and a concentration (refractive index) gradient would exist along the channel length. This would complicate the optical theory used to understand the output signals and make refractive index determination more difficult. This uniformity is also dependant on the flow rate of the solution and the mixing time of the mixer. Increasing the flow rate will allow a longer d while maintaining uniformity along the channel length; however, at higher flow rates, a faster mixing time is needed to maintain uniformity along the channels width. These effects complicate the prediction of an ultimate limitation of the device. Using our experimental flow rate of 5 μl/min, the average velocity in the channel would be 0.3584 cm/s. The fluid replacement process takes approximately 40 s at this flow rate. Thus, a channel 14.34 cm long would produce a full gradient from DI water to undiluted $CaCl_2$ (end to end). In order for the assumption of uniform refractive index in the channel to be valid, d must be significantly smaller than 14 cm. This limitation at 14 cm is still far smaller than the 1.08 meters due to optical absorption. At 14 cm would be unacceptable since a full gradient would be developed, so a functional d value would need to be significantly less than 14 cm.

Justification for equal intensities of I_1 and I_2

At a wavelength of 488 nm, the optical absorption coefficient of PDMS is $\alpha_{PDMS} = 0.5$/meter [1] and the optical absorption coefficient for DI water is $\alpha_{water} = 0.0144$/meter [2]. Although the absorption coefficients are different they are both low (both are transparent dielectrics). The main reason for our assumption is the short optical path of d = 500 µm. We assumed that $I_1 = I_2 = 0.5I_{IN}$. Using the absorption coefficients for both materials and the optical path the relative intensity of I_1 and I_2 can be calculated by:

$$I_1 = 0.5I_{IN}\left(1-\alpha_{water}d\right)$$
$$I_2 = 0.5I_{IN}\left(1-\alpha_{PDMS}d\right)$$

Resulting in values of $I_1 = 0.4999964\ I_{IN}$ and $I_2 = 0.499875\ I_{IN}$, both of which can be approximated as $0.5\ I_{IN}$.

References

[1] Wu, M., Paul, K. & Whitesides, G. Patterning flood illumination with microlens arrays *Applied optics, Optical Society of America,* **2002**, *41*, 2575-2585

[2] Pope, R. & Fry, E. Absorption spectrum (380--700 nm) of pure water. II. Integrating cavity measurements *Applied Optics, OSA,* **1997**, *36*, 8710-8723