Evanescent Field based Optofluidic Platform in TriPleX for Sensitive Absorbance Detection of Chromophores

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Integrated-optical chemical sensors are attractive candidates for low sample volume applications as they can be miniaturized rather easily and offer a high intrinsic sensitivity [1]. Part of the transduction mechanism is the very local probing of the relevant optical parameters of the sample by the evanescent field component of the propagating light at the boundary between waveguide core and sample in the region of the so-called sensing window. In this very region, the waveguide core directly contacts the applied sample. The modified Lambert-Beer formula states the relation between the evanescent wave absorbance A (=$\log P_0/P$, with P_0 and P the optical power output measured for the reference and the sample, respectively) and the concentration of the light absorbing species c by considering the evanescent wave modal fraction σ (present within the sample domain), the molar absorption coefficient ε and the path length l (Eq. 1, left part). From this it can be derived easily that the sensitivity of the measurement A/c is determined by l as well as σ (Eq. 1, right part).

$$A = \sigma\varepsilon l c \quad \rightarrow \quad \frac{A}{c} \sim \sigma l \qquad (1)$$

The current work shortly describes the design of SiO_2/Si_3N_4 waveguide based sensors, fabricated by means of the TriPleX™ technology, and their absorption sensing performance. These optical waveguides show good transparency for light of the near-infrared and the visible spectrum and, in addition, are known to have low propagation losses (<0.1 dB/cm)[2]. A new design was developed that allows for an optimal coupling to input- and output fibers (single stripe layout) and an effective sensing window definition (ridge layout) while keeping the propagation losses minimal. Furthermore, a design was used that allows for the incorporation of long waveguide lengths (50 cm and longer) inside a rather small sensing window (dimensions: 2.2x0.11 cm (lxw)) as the waveguide may loop multiple times in a form of a spiral before leaving the sensing window. This way, the path length is configurable by design over a wide range (Fig. 1).

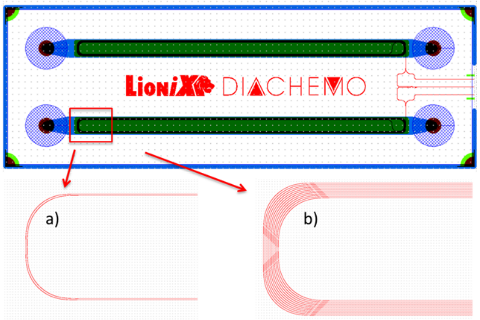

Fig. 1. Layout of the newly developed absorption sensor employing increased path length within the sensing window. Two design examples are shown corresponding to a path length of 9 cm (a) and 53 cm(b).

This generic approach helps to improve the sensitivity, as may be needed for the more demanding applications, while maintaining the chip compact. Several path lengths were realized, ranging from 2 up to 53 cm. In Fig. 2A, a chip with the path length of 9 cm is shown during in-coupling of light at different wavelengths in order to illustrate the propagation performance in the visible light spectrum. It can be observed that the propagation losses of light in the current chips increases with decreasing wavelength, which is caused by Rayleigh scattering. Currently, the maximum path lengths for light of 638, 532 and 488 nm are ~15, ~10 and ~5 cm, respectively.

In order to verify the model and to assess the value of the evanescent wave modal fraction σ, experimental testing of the sensitivity was done using the chromophore bromothymol blue (BTB). BTB is useful as a model analyte as it absorbs red light (strong absorption peak at 617 nm) as well as green light (moderate absorption peak at 532 nm). Absorbance of red light and green light was measured as a function of BTB concentration in order to determine the sensitivity. Testing was done as a function of path length in the range from 0.5-13 cm. In Fig. 2B the results are shown as were obtained on a chip with a path length of 9 cm.

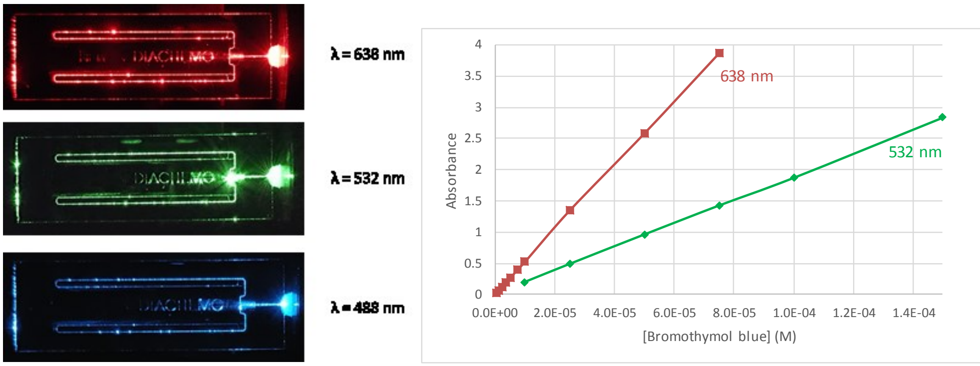

Fig. 2. Left: Photographs of one of the absorption sensor chips (path length 9 cm) with in-coupling of light at the indicated wavelength Right: Absorbance of red light and green light by bromothymol blue solutions in water (20 mM NaOH) as a function of dye concentration at a path length of 9 cm. For calculation of absorbance, background correction was applied.

Testing of a series of chips revealed a good linear correlation between the sensitivity and the path length as predicted by the modified Lambert-Beer formula (Eq. 1, right part). Furthermore, values of ~0.2 were derived for the evanescent wave modal fraction σ, which compared well with simulation results. Detection limit for BTB is well below 0.5 µM when using sensor chips with 9 cm path length.

References

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[2] K. Wörhoff, R. Heideman, *TriPleX: a versatile dielectric photonic platform*, in Advanced Optical Technologies 4, pp. 189-207, 2015

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