Integrated optical Mach-Zehnder interferometer as a sensor for chemicals

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Introduction

An interferometer is a device that uses the interference of light waves for measurements. Small variances in the optical path length caused, for example, by a variation in the refractive index (RI), influence interference. This principle can be used to characterise chemical samples. An example of an interferometer is the Mach-Zehnder interferometer (MZI), the concept of which was described in 1891/92. The light beam is split twice and then recombined to produce a specific interference pattern. Is a chemical sample placed in one pathway the pattern is changing.[1] An interpretation of this concept is the integrated optical Mach-Zehnder interferometer (IOMZI) which can be made of Si_3N_4 fabricated on the support of SiO_2 using techniques such as photolithography. The IOMZI works in a manner similar traditional MZI. Applications, such as concentration measurement and specific detection of proteins or gases, have been reported. Depending on the design, very small differences in RI ($\Delta = 10^{-5}$ RIU) can be detected. In addition to their high sensitivity and selectivity, label-free detection, cost-efficient production, small size, and high functionality are the main advantages of an IOMZI.[1,2,3]

A new approach involves IOMZIs made of near-surface waveguides fabricated by femtosecond laser-writing. The interferometers were placed inside a fused silica chip. The application of near-surface waveguides for sensing liquid samples has been tested and described in the literature. In this study, IOMZIs composed of two near-surface waveguides are tested for the first time. No similar examples have been reported in the literature. The capability of IOMZI as a sensor for chemical samples was investigated.[4,5]

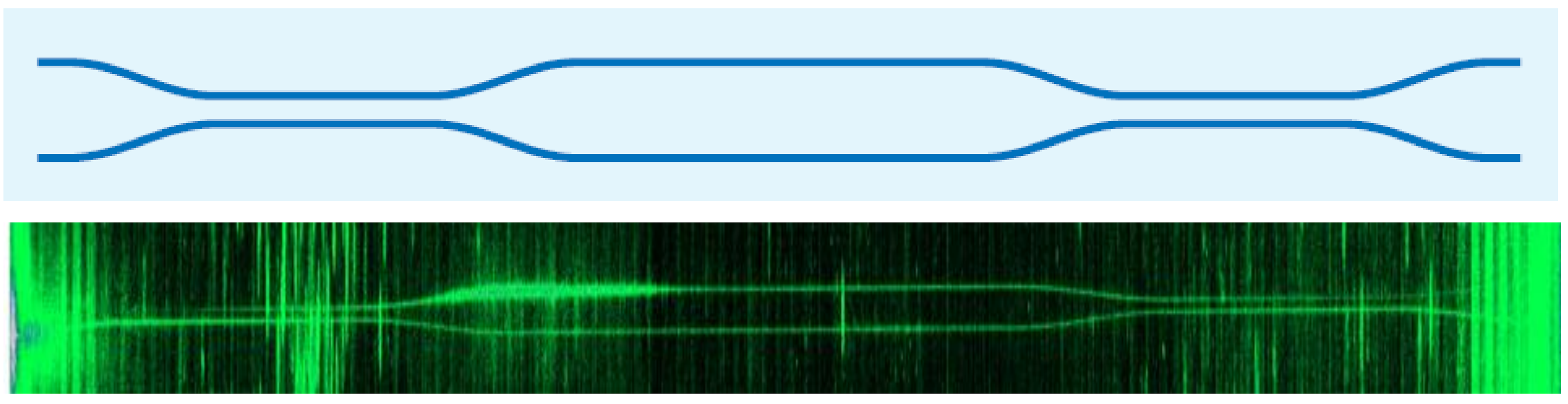

Fig. 1: Scheme (up) and fluorescence picture in false color (down) of an integrated optical Mach-Zehnder interferometer.

Results

Experimental setup, measurements and evaluation

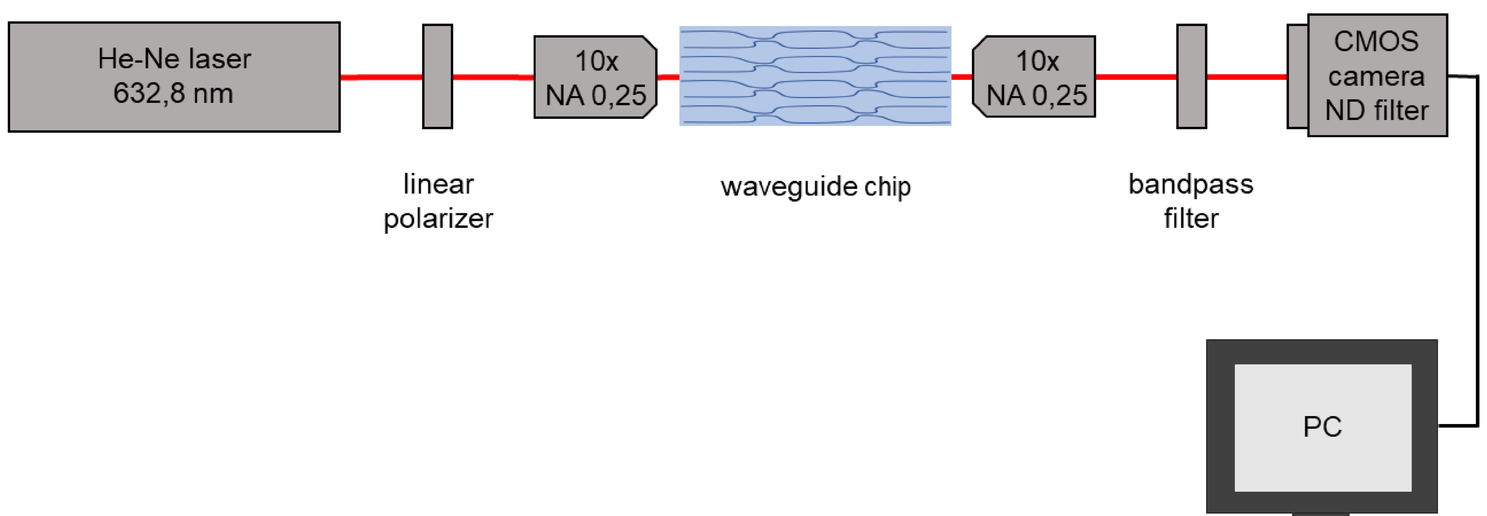

Fig. 2: Scheme of the experimental setup.

Light was coupled in one of the both waveguides and evenly distributed on both waveguides. The transmittances of both waveguide signals change in opposite directions by the same amount when a sample is placed in the sensor area. The transmittance change is described by the difference ΔT, see Fig. 3a. The performances of the three chosen IOMZI were tested using solvents covering a large RI range. The IOMZIs were located at different distances from the waveguide chip surface. With rising RI the ΔT is rising in a linear manner, see Fig. 3b.

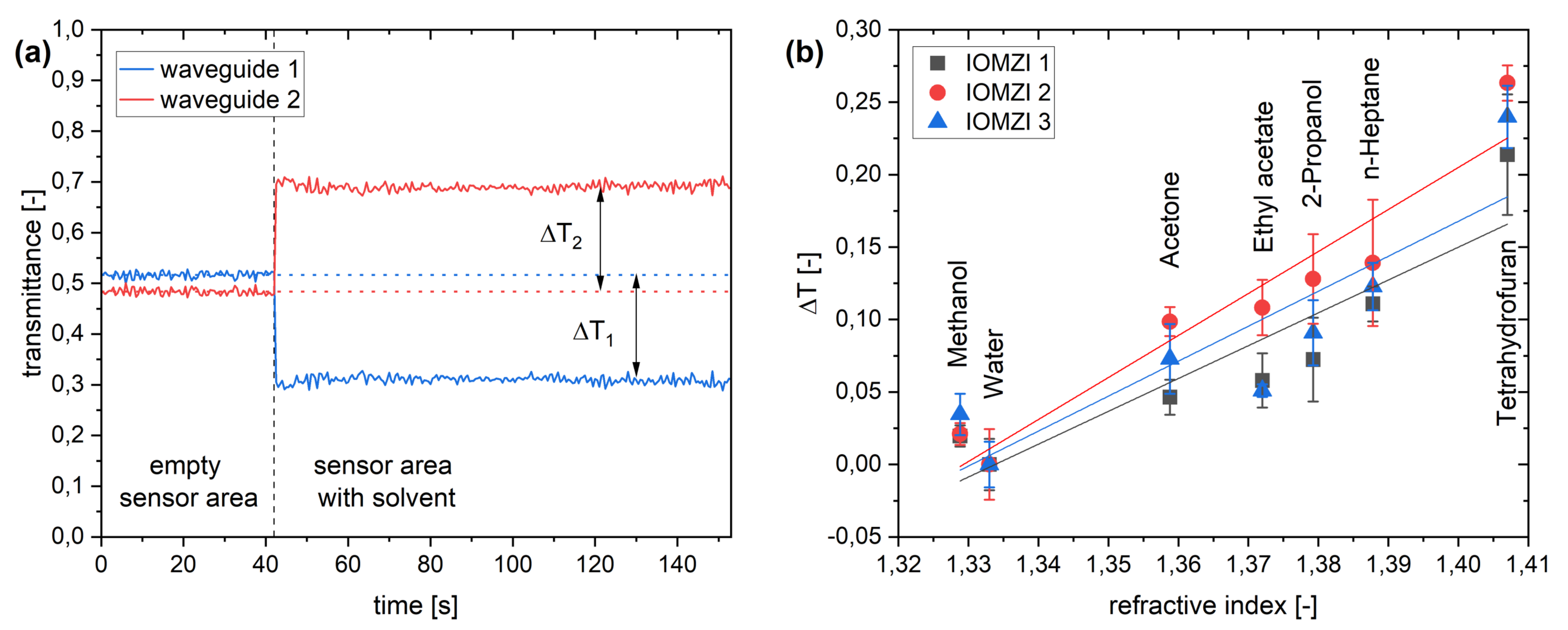

Fig. 3: (a) Timeline of transmittance with applied solvent and (b) refractive index dependence of measurements. (T = 22±1 °C, V = 20 µl, N = 5, mean±SD)

Experiments with aqueous solutions

In the second step, serial dilutions of carbohydrates, alcohols, salts, and acids dissolved in pure water were measured using IOMZI-3. The samples were applied to a measuring cell composed of PTFE sealing tape. Each serial dilution was measured thrice.

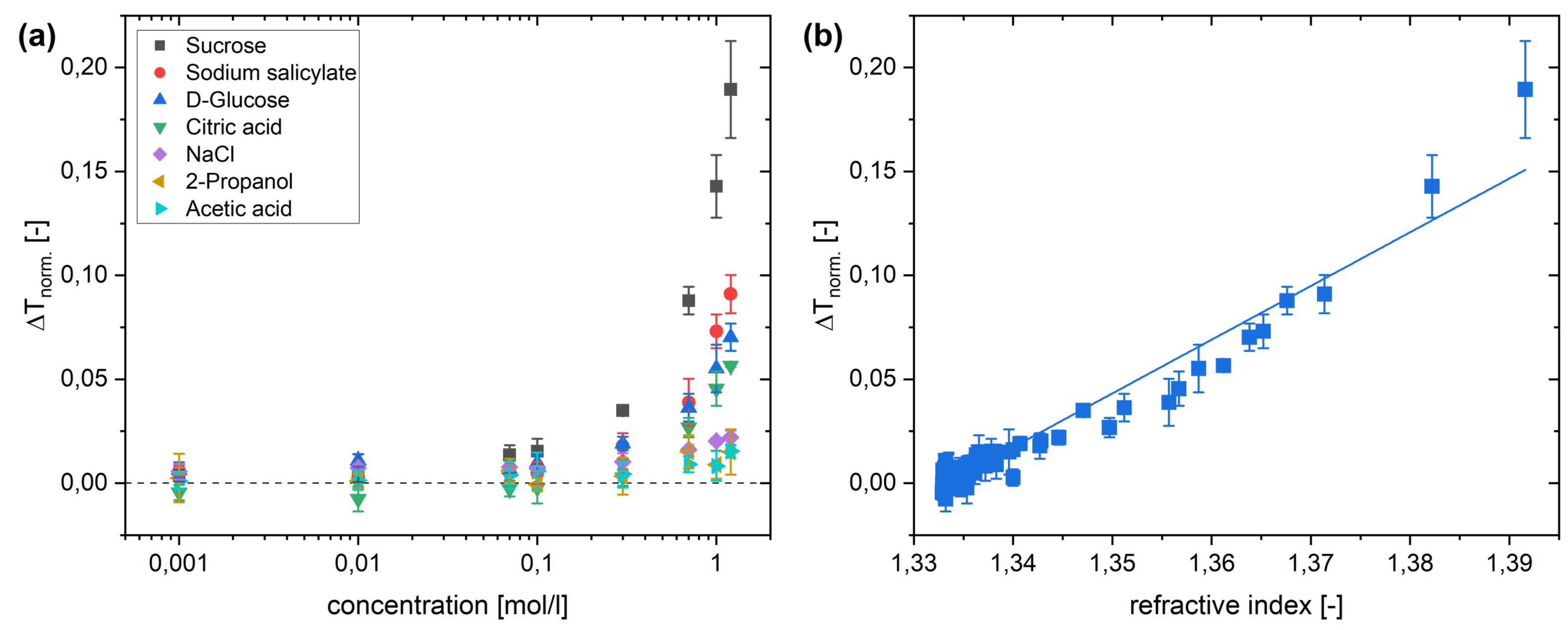

Fig. 4: (a) Concentration and (b) refractive index dependence of measurements with IOMZI-3. (T = 22±1 °C, V = 180 µl, N = 3, mean±SEM)

The response of the IOMZI depended on the concentration and refractive index of the solutions. Solutions with a higher RI (sucrose) showed a better response than solutions with a low RI (NaCl, 2-Propanol, Acetic acid), see Fig. 4a. The response at low concentrations is equal to the response of the water samples (dashed line). Is ΔT plotted against the RI of the measured solutions the linear response of the IOMZI gets visible, see Fig. 4b.

Summary

Organic solvents and aqueous solutions were investigated using laser-written Mach-Zehnder interferometers comprising near-surface waveguides. A linear dependency of the calculated transmittance difference on the refractive index was observed. This study shows that the novel concept of near-surface interferometers can be used to measure properties such as the concentration of aqueous solutions.

References

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