A LIQUID-WAVEGUIDE-BASED EVANESCENT WAVE SENSOR FOR HIGH SENSITIVITY REAL TIME DETECTION AND LABEL FREE BIOSENSING APPLICATIONS

X. C. Li¹, ², Y. C. Seow², J. Wu¹, K. Xu¹, J. T. Lin¹ and A. Q. Liu²†

¹Key Laboratory of Optical Communication and Lightwave Technologies, Beijing University of Posts and Telecommunications, P R. CHINA
²School of Electrical & Electronic Engineering, Nanyang Technological University, SINGAPORE 639798
(†Corresponding author. Tel: +65-6790 4336; Email: eaqliu@ntu.edu.sg)

ABSTRACT
This paper reports the measurement of refractive index (RI) of buffer solution using the evanescent wave (EW) based on liquid waveguide sensor using microfluidic chip technique and employing the charge-coupled device (CCD) detection technique. The sample is injected into one cladding channel, and then the profile of the modal power distribution changes due to the change of RI, i.e. the intensity area, are used to determine the sample’s RI. The sensitivity is $9 \times 10^{-5} \mu \text{m}^{-2}$. Moreover, the CCD detection technique is easy and real-time measurement. It is promising for cell biophysical, label-free detection and diagnostic applications.

KEYWORDS: Liquid Waveguide, Evanescent Wave and Refractive Index

INTRODUCTION
Solid waveguide EW sensors use the optical waveguides as the transduction element. Light propagating through an optical waveguide consists of the guided field in the core and the exponentially decaying tail of the evanescent field in the claddings. Once the RI of the sample changed, the optical transduction properties (e.g. phase, intensity and absorbance) will changed accordingly. The interaction lengths in these

Figure 1. (a) Schematic diagram of liquid waveguide sensor, (b) Cross section view of transparent window, $n_1 > n_2 \geq n_3$. 

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sensors are in the order of a centimetre. The liquid waveguide is an optical waveguide that the core and the claddings are realized by liquids. The liquid waveguide has the lower interfacial loss compared with liquid/solid interface waveguide which makes the chip size reduced greatly [1]. Most of the biological and chemical samples are liquids or solutions. Therefore, the biological or chemical interactions can be monitored continuously using the liquid waveguide.

**THEORY**

Figure 1(a) shows the ligued waveguide based EW sensor which consists of a microchannel, three inlets, a light input coupling and output detection system. The magnitude of the RI of the different layers of the liquid waveguide has the following order: \( n_1 > n_3 \geq n_2 \), where \( n_1 \), \( n_2 \), and \( n_3 \) are the RI of the core layer, reference cladding layer and the sensing cladding layer of the waveguide, respectively. The distance to which the EW extends beyond the core-cladding interface is described by the penetration depth, \( d_p \) which is the distance where the evanescent wave decreases to \( 1/e \) of its value at the core-cladding interface. The penetration depth is given by:

\[
d_p = \frac{\lambda}{2\pi \sqrt{n_{co}^2 \sin^2 \alpha - n_{cl}^2}}
\]

where \( \lambda \) is the wavelength of the light source, \( \alpha \) is the angle of the incidence light at the core/cladding interface. When \( n_{cl} \) is increased, \( d_p \) is increased and subsequently the intensity area is increased.

**EXPERIMENTAL RESULTS AND DISCUSSIONS**

The liquid waveguide sensor has a length of 1.5 cm, a height of 80 µm and a width of 100 µm. The core layer consists of calcium chloride (CaCl_2) solution with RI of \( n_1 = 1.446 \) (5 mol/L), the reference cladding layer consists of deionized water with RI of \( n_2 = 1.333 \), and the sensing cladding layer consists of CaCl_2 solution with different RI. The flow rate of the core and the claddings are 20 µl/min and 40 µl/min, respectively. The light source is He-Ne laser (638nm) and is coupled into the liquid waveguide by optical fibre. A calibrated CCD array is used for image detec-

![Figure 2](image)

*Figure 2. Modal power distribution with different RIs (n3) (a) 1.34, (b) 1.35, and (c) 1.38. (d) Measured power distribution at the same position with different n3.*
tion through a transparent window at the other end of the liquid waveguide. All of the images are taken at the same exposure time and focus length. The temperature is considered to be constant in this experiment.

It is noted that the width of the whole light intensity distribution increases with the different RIs, as shown in Figs. 2(a), (b) and (c). Fig. 2(d) shows the cross-sectional of the light intensity distributions. Each curve is divided into three areas, which deal with the cladding-core-cladding sense layer. The left side is the reference layer and the right side is the sensing layer. Compared with the width of the left side, it can be seen that the greater the RI of the sensing layer, the broader the width the left side. From Eq. 1, as the RI of the sample increases, $d_\rho$ is increased. Therefore, the profile of the right side area varies with different RI. Fig. 3 shows the measurement results of the light intensity area with the variation of $n_3$. The curve is divided into two parts. When the RI of the CaCl$_2$ is lower than the RI of the PDMS (1.408), the relationship between the RI and the area of the light intensity is linear and the slope is 11174. The detection sensitivity is $9 \times 10^{-5} \mu$m$^{-2}$. When $n_3$ is higher than that of the PDMS, the sensing layer is a guide layer to the PDMS. The guide intensity increases greatly that there is a ‘jump’ in the curve. The relationship between the RI and the area of the light intensity is then exponential and the decay constant is 0.01.

CONCLUSIONS

The liquid waveguide based evanescent wave sensor in a microfluidic chip is designed and fabricated using PDMS microfluidic chip technique. The intensity area increases with the increment of the RI, which is explained by the penetration depth. The sensitivity is $9 \times 10^{-5} \mu$m$^{-2}$. This simple and real-time liquid sensor is suitable for use in diagnosis, environmental monitoring, food safety testing and chemical reaction analysis.

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Figure 3. Measured intensity area with different RIs.