NANO-LIQUID/LIQUID WAVEGUIDE COUPLING BY EVANESCENT TUNNELING EFFECT FOR BIOMOLECULE IMAGING APPLICATIONS

Y. Yang\(^1\), A. Q. Liu\(^1\) and D. P. Tsai\(^2\)
\(^1\)School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798
\(^2\)Department of Physics, National Taiwan University, Taiwan

ABSTRACT

In this paper, a nano-liquid/liquid waveguide coupling based on evanescent tunneling effect is demonstrated. For the first time, the feature size in the fluidic beyond the diffraction limit with changes as small as 1 nm can be imaged in the microchannel. The evanescent coupling length can be tuned by the flow rates and the fluids materials flexible than semiconductor ones. This implies that single molecule imaging can be achieved with the developed near field interaction technique.

KEYWORDS Liquid waveguide, optofluidic, evanescent coupling, Nanofluidics.

INTRODUCTION

Bimolecular sensor is a hot topic for today’s’ chemistry and life science [1]. However, for detection of interactions with small targets such as viruses (10–100 nm), and proteins (1–20 nm), traditional optical methods suffers big problems because of the bimolecular sizes beyond the diffraction limit. The detail information of the bimolecules contain in near field will be lost in far filed making it a big chandelles. An evanescent wave is a near field wave with the intensity that exhibits exponential decay with distance from the boundary at which the wave was formed [2]. As a result, optical evanescent sensors have received particular interest for monitoring environmental pollution and industrial processes over the last decade. Changes as small as 1 nm in principle can be detected [3] and single fluorophore imaging with 1.5 nm can be located [4]. Some systems based on it have been developed for bimolecules detection such as total internal reflection microscopy technique, surface plasmon resonance (SPR) technique and optical evanescent waveguide sensors. Among these analytical devices that can be used to analyze biomolecular interactions, waveguide sensors are a good choice and have the advantage which can have a large surface area that confers sensitivity. Unfortunately, the expensive nano-fabricated solid optical evanescent waveguides cannot be tuned such as the gap and the refractive index contrast freely to satisfied different biosamples. In this paper, we describe an pure liquid-liquid optical waveguide [5,6] sensor structure based on coupling theory. The new structure combines the merits of both the evanescent wave and the guided-wave sensors, i.e., high efficiency of sensing interaction and ease of realization. This implies that single molecule imaging can be achieved with the developed near field interaction technique.

DESIGN AND SIMULATION RESULTS

\[\text{Figure 1: Schematic illustration of dynamic nano-liquid/liquid evanescent wave coupler for sub diffraction limit feature size imaging. (a) The work principle of the evanescent wave coupling. (b) The light can be coupled from one liquid waveguide to another one by the evanescent tunnel effect even the feature size of the gap between them is beyond the diffraction limit. (c) Microchannel design. A pair of parallel 3D waveguides will be formed in the evanescent region. The feature size of the nano-gap between the two liquid-liquid waveguides can be tuning by flow rates.}\]
The schematic illustration of the dynamic nano-liquid waveguide coupling is shown in Fig. 1. Evanescent wave is a near field standing wave with the intensity being exponentially decayed along the perpendicular distance from the boundary of the waveguide. Evanescent coupling can only occur when the gap between the two parallel waveguides is sufficiently small (no more than several wavelengths) as it shown in Fig. 1(a) [2]. In this condition, the evanescent field from one waveguide reaches the other ones with negligible decay, and couples to the other waveguide. By measuring periodic coupling length \( l \) as shown in Fig. 1(b), the evanescent field can be rebuilt and is significant to identify changes as small as 1 nm [1]. Therefore, the object with feature size beyond the diffraction limit can be imaged. Fig. 1(c) shows the microchip design to accomplish this nano-liquid waveguide coupling. Four flow streams are pumped into the microchannel from the inner and outer inlets, respectively. The refractive index contrast in this simulation is \( \Delta n = n_1 - n_2 = 0.001 \) and the exciting wavelength is 514 nm. With the gap of 10 \( \mu \)m, the evanescent wave decays before reaching the other waveguide, and therefore no coupling happen (Fig. 2(a)). When the gap is reduced to 1 \( \mu \)m and 200 nm (beyond diffraction limit), coupling occurs with decreasing coupling length (Figs. 2(b – c)). When the input wavelength changes from 633 nm to 400 nm, coupling occurs with longer coupling length (Figs. 2(d – e)). Lastly, the coupling occurs as well with a compression of the waveguides size of \( w_1 = 5 \, \mu \)m (Fig. 2(f)). These results imply that the fluidic condition in the microchannel can be rebuilt by investigating the coupling images.

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Figure 5: The couple length $l$ shift by tuning the gap between the two parallel liquid-liquid waveguide. The orange area represent the feature size is below the diffraction limit.

waveguide couples and reaches to the other. Using fluorescent dye (Rhodamine 6G), the measured coupling length is approximately 4.5 mm, which means that the gap in the Fig. 3(b) is less than 200 nm. Figure 5 shows the couple length is associated with the gap between the two parallel liquid-liquid waveguides. The orange area represents the feature size is below the diffraction limit but is identifiable by the evanescent coupling images.

CONCLUSIONS

In conclusion, a nano-liquid waveguide coupling via evanescent tunneling effect for microfluidic imaging beyond diffraction limit is demonstrated. With the dynamic reconfigurability, the liquid devices has broad applications in biomolecular imaging.

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REFERENCES


CONTACT

* A. Q. Liu, Tel: +65-6790 4336; Fax: +65-6793 3318; Email: aqliu@ntu.edu.sg