A LIQUID WAVEGUIDE BASED TWIN MACH-ZEHNDER INTERFEROMETER FOR REAL TIME PARTICLE SORTING

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ABSTRACT
This paper reports the real time particle sorting technique using the twin Mach-Zehnder interferometer (MZI) based on the liquid waveguide that is integrated onto a single microfluidic chip. The particle is injected into either arms of the coupler between the two MZIs and the different position of the particle can induce the different phase change of the coupler that induces the difference in the interferometer pattern and the output intensity. It can detect the particle of 3 - 4 µm diameter in real-time which chip is promising for particle, cell and molecular sorting applications.

KEYWORDS: Liquid Waveguide, Mach-Zehnder Interferometer, Refractive Index

INTRODUCTION
A silicon-based waveguide Mach-Zehnder interferometer (MZI) is commonly used as a biosensor with very broad applications in biochemical and biological field. The interferometer is used as a hybrid package to assemble the silicon-based waveguide with the microflow system onto a miniature instrument. The refractive index limit for detection is around 10⁻⁸. In this paper, a liquid-waveguide-based (LWG) twin MZI is presented. The medical and biochemical fluid sample can be
injected into the cladding or the core layer of the LWG easily. The position of the particle in the different waveguide can affect the output light power intensity based on the high sensitivity of the MZI. Thus, the twin MZI can be used as a biosensor for particle sorting that is discussed in details.

THEORETICAL ANALYSIS AND DISCUSSION

Figure 1(a) shows the design of the LWG based twin MZI. Each single MZI consists of three parts: a 3 dB coupler, the arms and a recombination (3 dB coupler) output. The 3 dB coupler is the important component of the LWG based MZI which allows light to couple from one waveguide to another waveguide with equal light energy. Therefore, the twin MZI has a total of five couplers, i.e four 3 dB couplers and one coupler between the two MZIs which is the main part of the sensor. The particle is injected into either waveguide 2 or waveguide 3 so that different position of the particle can induce the different phase change of the coupler. Subsequently, the phase change induces the difference in the interferometer pattern and the output intensity. The interferometer signal is then detected by a CCD via the cylindrical lens or directly by the power meter.

Based on the couple mode theory, the output power of single MZI can be given as:

$$P_{out} = P_{in} (1 + \Delta \varphi)$$  \hspace{1cm} (1)

where the phase change, $\Delta \varphi = \frac{2\pi L_{int} \Delta N_{eff}}{\lambda_o}$, $L_{int}$ is the interaction length of the guided wave with the particle, $\lambda_o$ is the wavelength used, and $\Delta N_{eff}$ is the change of the effective refractive index which is depending on the size and the position of the particle in the waveguide [1]. Figure 1(b) is the sketch of real-time particle sorting. Because of the presence of the particle in waveguide 2, the output intensity is changed. Subsequently, the monitoring circuit is to generate a signal to the control circuit. A voltage is presented in the channel which can push the particle into waveguide 3. Once the particle goes into waveguide 3, the output light power intensity is changed again.

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The simulation of the light transmitting in the twin MZI is shown in Fig. 2. In the simulation, the wavelength is used 1.3 µm with the width of the waveguide as 5 µm, the length of the 3 dB couplers is 5 mm, the length of the arms as 3 mm and the particle diameter is 4 µm. The refractive index of the background, the core and the particle are 1.330, 1.442 and 1.460, respectively. The light is injected through waveguide 2 and waveguide 3. As shown in Fig. 2, the light propagation and the output light power intensity is different when the particle is along in the different liquid waveguide.

Figure 3 shows the relation between the intensity and the position of the particle in waveguide 2 (square), the cladding between waveguide 2 (triangle) and waveguide 3 (circle). It is noted that when the particle is in the cladding between waveguides 2 and 3, the intensity of the two outputs are the same. When the particle is in waveguide 2 or waveguide 3, the output intensity is opposite. The maximum difference is 0.4 and the minimum difference is 0.2.

Figure 4 is the relation between the particle diameter and the output intensity at the same position in waveguide 2. It can be seen that the limitation of the particle diameter is 3 - 4 µm. However, this limitation can be improved by using longer wavelength or smaller size of the microchannel.

CONCLUSIONS

A LWG based twin MZI is designed, fabricated and demonstrated, which is used to detect the position of the particle based on the high sensitivity of the MZI. It provides a new detection technique for the particle sorting such as the medical and biochemical applications.

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