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Multifunctional Optophoresis for Biomolecular Detection by Using Integrated Silicon Photonic Waveguide Arrays

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Abstract: A multifunctional optophoresis for biomolecular detection in integrated silicon photonic chip is demonstrated. Sample fractionation part is to avoid contamination and reduce interference. Signal is enhanced 5 more times after integrating sensors with waveguide arrays.

OCIS codes: (350.4855) Optical tweezers or optical manipulation; (130.6010) Sensors

1. Introduction

Silicon photonic ring resonators are an emerging class of analytical technologies that use evanescent field wave to sensitively measure the slight difference in the surrounding environment. The wavelength shift induced by local refractive index change is used as indicator in the system. These devices can be served as sensors for a wide variety of chemical or biomolecular detection in clinical and environmental fields [1]. In the detection process, sample preparations such as pre-concentration and fractionation are required to minimize the noise and increase the accuracy in detection [2]. However, multiplexing steps are involved in the process to increase the complexity of operation. Therefore, in this paper, an integrated silicon photonic waveguide array is proposed for continuous and automatic sample preparation on one chip. Two parts of waveguide arrays are designed for fractionation and concentration with detection of target sample, respectively. By using the multifunctional waveguide array, it eases to operate and facilitates to enhance signal-to-noise ratio and to lower limit of detection (LoD) for biomolecular rapid detection.

2. Results and Discussions

For real biological or environmental sample, there are some insoluble particulates which result in the undesired noise, like sand grain or silt in lake water. Therefore, it is necessary to fractionate the undesired particles from the original sample to lower the interference during the analyte detection [3]. Figure 1(a) shows the 3D schematic illustration of the integrated silicon photonic waveguide arrays. The original sample with various sizes of biomolecules is injected by pump and flows through the channel. Due to the different intensity of optical force experienced on the various size of nanoparticles, 200 nm and 500 nm nanoparticles are sorted and separated by waveguide arrays [4]. Therefore, the undesired particles with the size larger than 500 nm can be sorted out and withdrew from the side channel.

Fig 1. (a) 3D schematic illustration of an integrated silicon photonic waveguide arrays. (b) Microscopic image of the detection region integrated with waveguide arrays.

After the sample fractionation, the target sample flows through the detection region which is composed with a silicon photonic-based ring resonators integrated with four sets of the waveguide arrays. Figure 1(b) shows the microscopic image of the detection region integrated with waveguide arrays. These waveguide arrays surrounding the micro ring resonators are designed to concentrate the target sample on the detection region. It can increase the interaction between the target analytes and the active sensing sites on the surface of ring resonators to enhance the

performance of detection. By tuning the optical power on the waveguide arrays, it has a great potential to operate and concentrate nanoparticles with the size in sub-nanoscales. Besides, due to the localized concentration in the detection region, the detection signal can be enhanced without using the porous sensing structure for increasing the active surface area [5] or any other additional binding agents such as polystyrene beads [6] or HRP conjugated agent [7]. Therefore, the overall detection time will not be extended for additional reaction steps. And the complicated fabrication technique is not necessary to form the porous structure.

Fig 2. Simulation result of (a) the distribution of optical field on the waveguide arrays; (b) particle initial position and (c) particle distribution and trajectories through the time.

Figure 2 shows the simulation result of the distribution of optical field on the waveguide arrays. Due to the gradient of optical force, the nanoparticles are pushed toward the center of detection region. After the nanoparticles flow through the waveguide array and experience under the optical force, the concentration of nanoparticles in the detection region is increased by at least 5 times when the single waveguide array part area equals to detection region. The multiplication factor can increase more when the waveguide array part area is much more larger than detection region.

3. Summary

An integrated silicon photonic waveguide arrays for biomolecule detection is designed, fabricated and demonstrated. By using multifunctional waveguide arrays, it is successful to integrate the sample fractionation, concentration and analyte detection on one chip. With the localized sample concentration in the detection region, signal enhancement based on waveguide arrays can be more stable than involving additional chemical-based enhancement methods. Therefore, it has a great potential to apply for online, real-time and high sensitivity of biomolecular preconcentration and rapid detection.

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