INTEGRATION OF MULTI-ASPHERICAL LENSES AND OPTICAL FIBERS ONTO A PDMS MICROFLUIDIC DEVICE FOR FLUORESCENCE-BASED DETECTION

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ABSTRACT

PDMS multi-aspHERical lenses system with optical fiber for fluorescence-based detection are studied to increase the focusing effect and the detection resolution. The multi-aspHERical lenses were designed by computer assisted optimization and fabricated into a microfluidic device. The performance of the multi-aspHERical lenses was investigated by applying to on-chip capillary electrophoresis. Since PDMS multi-aspHERical lenses magnified the width of the light emitted from the fiber to 0.5 times, the sensitivity and the resolution were comparable with those of conventional microscope detection.

Keywords: fluorescence detection, optical fiber, lens

1. INTRODUCTION

Various microfluidic devices for biochemical and chemical analysis such as on-chip capillary electrophoresis (CE), gene amplification, etc. [1] have been developed. In most cases, fluorescence-based schemes are used as detection methods. The analysis device itself becomes smaller, while external apparatus such as light source, photodetector and optical interface, are still bulky. There are some approaches to develop on-chip light source and photodetector for compact system, however, they are still under development and not cost effective for disposable use [2]. It is, therefore, strongly desired to develop a practical portable detection method, which is reliable, simple to use and cost effective for disposable applications. As one of possible approaches, it was proposed that optical fiber was connected to PDMS microfluidic devices with a simple coupling lens to introduce excitation light [3]. This method exhibits ease to introduce excitation light without any use of microscope, and improvement of detection sensitivity. However, it still requires optical microscope for detection. Moreover, the simple spherical coupling lens shows some aberrations that decrease the focusing performance for excitation. In this work, we mainly focus on: 1) improving the efficiency of excitation by incorporating aspherical lenses, which shapes are optimised with computer simulation, 2) realizing totally microscope-less system for fluorescence excitation and detection with optical fibers.
2. EXPERIMENTAL

To design the PDMS multi-aspherical lenses, PDMS refractive index (RI) was measured by Abbe Refractometer (ATAGO CO., LTD.) at wavelength 589 nm changing samples temperature. In addition PDMS RI. of several curing condition were measured to find out whether curing condition will affect PDMS RI. A commercial optical design software of CODE V® (Optical Research Associates) was used for computer assisted optimization to realize beam waist as narrow as possible to concentrate beam energy. The performance of the optimized multi-aspherical lenses was investigated by applying to on-chip CE analysis. The device were also equipped as schematically shown in Fig. 1. It consists of channels (100 μm width, 60 μm depth), for CE multi-aspherical lenses and inlets where excitation and detection fiber are inserted. The device was fabricated conventional micromolding of PDMS. To visualize optical paths inside the device, a fluorescent dye was mixed into prepolymer PDMS. The excitation and detection fibers are fusing each other interleaving the flow channel between them. The angle of detection fiber was designed 30 degrees from the optical axis of excitation light to avoid the excitation light coming into detection fiber.

The core diameter of optical fibers was 50 μm or 100 μm. One ends of each exciting and detection optical fibers are inserted into the inlets of the device. The other ends were connected to a light source and a photo multiplier tube (Hamamatsu Photonics K.K.), respectively. A 100 bp DNA ruler (Bio-rad) was separated by on-chip CE with conventional cross-injection. The hydroxy ethylecellulose solution (1wt% in x11BE buffer) was used as a sieving matrix. The sample DNA was fluorescent-labeled by SYBR Green I.

3. RESULTS AND DISCUSSION

As shown in Fig.2, RI. of PDMS is about 1.410 at room temperature and it decreases gradually as temperature increases. Furthermore, we confirmed PDMS RI. was hardly affected by curing condition. Since CE is conducted at room temperature, we used RI. 1.410 at wavelength 589 nm for calculation by simulated light rays.

The multi-aspherical lenses for excitation fiber was designed to achieve twice intensity of the light emitted from optical fiber, which corresponds to 0.5 magnifications. A shape aspherical surface is usually described by the profile \( z(h) \) given by,

\[
z = \frac{ch^2}{1 + \sqrt{1 - (k+1)h^2}} + ah^4,
\]
where $h$ represents a lateral position, $c$ is curvature, $\alpha$ is an aspherical coefficient and $k$ is a conic coefficient. Then we designed lenses using conditions that the core diameter of optical fiber is 110 µm, fiber NA is 0.25 and the magnification is 0.5. These are slightly larger than the actual sizes of core diameter 50 µm or 100 µm and NA 0.22, and, therefore, permit small drift of the fiber position. Figure 3 shows an example of light paths simulations with the conditions of the actual fiber. Since these lenses are cylindrical, the cross sections of the lens curvature are all the same along normal direction to the chip surface and the lenses can focus light only in a 2D plane.

The light paths were successfully visualized in the fluorescent PDMS device as shown in Fig. 4. The fibers with 50 µm and 100 µm core size were inserted as shown in Fig. 4 (a) and (b). The patterns of the light paths through each PDMS multi-aspherical lenses show good agreement with the simulated ones. The NA of the image looks smaller than that of simulated one. It would be caused by the Gaussian like intensity distribution of the light emitted from optical fiber, where the emitted light in the outer part is far

Figure 2. Influence of curing condition on the PDMS R.I.
120deg. 20min (astersisk), 90deg. 75min (circles), 60deg. 240min (triangles).

Figure 3. Modeling of light rays propagating through the PDMS multi-lens array. 0.5 magnification, 50µm core fiber, NA0.22.

Figure 4. (a)Top view of the device with the 50 µm diameter core fiber enlightening the fluidic channel by lenses of 0.5 magnifications. Bright part is fluorescent dye mixed in PDMS. (b)with the 100 µm diameter core fiber.
weaker than that in the center area of the fiber. The width of light emitted through the lens were about 50 μm and 25 μm. It means this system can detect down to 25 μm band formed in CE separation. However, since it is difficult to make the CE band flat, we used the larger core fiber with 100 μm in diameter for excitation and collection fibers, where it is easier to couple the light from a light source to an optical fiber.

Figure 5 shows an experimental result of the 100 bp DNA ruler separation. The sensitivity and the resolution were comparable with those of conventional microscope detection.

4. CONCLUSIONS
We have designed and experimentally demonstrated the lens-coupled fiber detection system for on-chip fluorescent analysis without any use of microscope setup. The multi-aspherical lenses for fiber coupling is designed and optimized with a commercial optics software. The fabricated lenses well corresponds to the simulated design and shows good resolution. The present optical setup, in principle, does not requires any elaborate alignment of each component and fluidic channels, and can easily be extended to parallel or multi-channel detection systems. The analogy of optical design described here is not only use for fiber coupling, but also applicable the arrangement of on-chip optical device, such as photodiode, light emitting diode, etc. in the future development.

REFERENCES