LENS ARRAY BY ELECTROSTATIC PATTERNING OF DIELECTRIC MICROSPHERES IN A PARYLENE-C WELL TEMPLATE

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ABSTRACT

We present the fabrication of a microlens array which can be integrated into a microfluidic device. In the demonstrated technique, a microwell array is firstly fabricated in a Parylene-C layer by a standard cleanroom process. Afterwards, the optically transparent dielectric microspheres with high refractive index are patterned inside the well template by utilizing an electrostatic technique. The mechanism of microsphere patterning is studied, and the lens effect of the microsphere is experimentally verified in a water-based medium. We also present a detailed two-dimensional numerical optical simulation study on the patterned microspheres using the Finite Element Method (FEM).

KEYWORDS: Microlens array, Dielectric microspheres, Microfabrication, Parylene-C

INTRODUCTION

Microlenses that are integrated on microfluidic chips enable several important optical features, such as profiting from a large local numerical aperture (NA) and high light collection efficiency, so that, for example, the optical read-out in an immunoassay is facilitated and the detection limit decreased [1]. Optically transparent microspheres with high refractive index act as ball lenses and show strong capability in focusing light. Using microspheres to build a compact system integrated with microfluidics inevitably will be of benefit to the field of life sciences, diagnostics or environmental monitoring. In this study, an electrostatic technique for fabrication of a microlens array by printing single dielectric microspheres into a patterned microwell template is proposed. The immobilized microspheres can focus the illumination, such as the optical signal originating from the presence of fluorescent markers beneath a microlens, into a very narrow region with high optical intensity, which is also known as a 'photonic nanojet' [2]. The working principle of the microlens array is schematically illustrated in Figure 1.

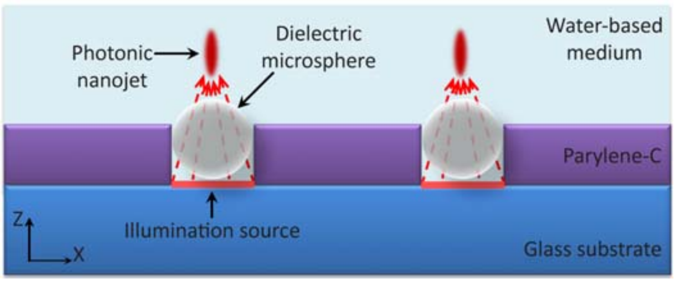

Figure 1: Schematic illustration of the microlens array, generated by patterning dielectric microspheres into a microwell array, the latter being fabricated in a Parylene-C layer on a glass substrate. Due to their high refractive index, the microlenses can be used in a water-based medium. When the microsphere is illuminated by a light source from below, it focuses the light into a small region, also named 'photonic nanojet'.

EXPERIMENTAL

A Parylene-C layer (~ 2.8 μm in thickness) is coated on a glass wafer by a chemical vapor deposition process. Afterwards, standard photolithography and inductively coupled plasma etching processes are used to generate the microwell array in the Parylene-C layer. The microwells with diameter of 3 μm are arranged in a hexagonal pattern and separated in x- and y-direction by an interspacing of 20 μm. The glass wafer is then diced into small chips and ready to be used for microspheres patterning. The microspheres are efficiently trapped inside the microwells by transporting a droplet containing suspended microspheres over the microwell surface. 3 µm carboxyl-functionalized microspheres based on melamine resin are chosen as the microlenses due to their high refractive index (n = 1.68) and low light absorbance. By controlling the size of the microwells precisely, single microsphere patterning per well can be achieved.

RESULTS AND DISCUSSION

In order to elucidate the microtemplate trapping principle, the carboxyl-functionalized melamine microspheres are dispersed in dilution buffer with different pH values. The dilution buffer is prepared by mixing different amount of hydrogen chloride (HCl) or sodium hydroxide (NaOH) into phosphate buffered saline (PBS). The microlenses are then patterned by transporting a droplet of the dilution buffer containing suspended microlenses over the microwell surface at a velocity of ~ 20 µm/s. The number of the patterned microspheres is counted from the same surface area of different chips for experiments at different pH values, which is shown in Figure 2. From the figure, the number of the patterned microspheres decreases when the pH value increases. By comparing the isoelectric point of the microsphere, the Parylene-C layer and the glass substrate, our result suggests that the microspheres patterning is based on electrostatic interactions (as illustrated in Figure 2(i) and 2(ii)). Moreover, the consolidation of the microspheres within the microwells is also provided by electrostatic interaction between the microsphere and the microwell, as well as the closely matching geometric features.

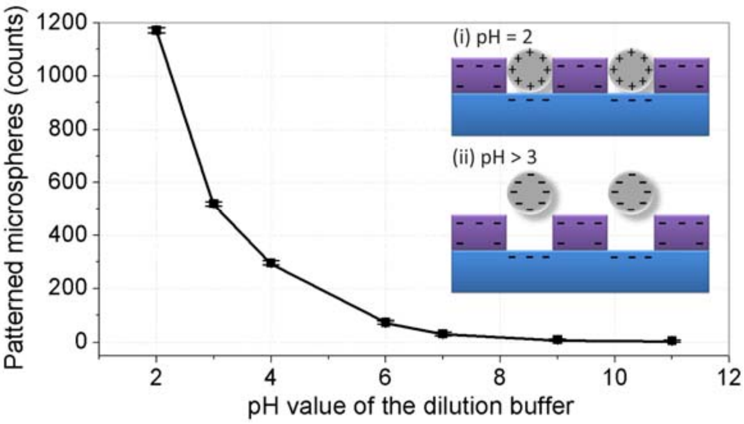

Figure 2: Number of patterned 3 µm carboxyl-functionalized melamine microspheres over an area on the Parylene-C layer with 1180 microwells when using dilution buffer at different pH values. Points represent the average, error bars the variance, while the line is a guide to the eye. The insert figures are schematics of the microsphere patterning at different pH conditions. (i) In buffer with pH = 2, the microsphere is positively charged and is attracted to the negatively charged microwell. (ii) In buffer with pH > 3, the negatively charged microsphere is more repellent to the microwell.

To verify the lens effect of the microspheres, the microlens array is immersed in PBS buffer. Figure 3 shows that the microspheres focus the light into their focal plane with enhanced optical intensity indeed. The light intensity obtained from the focus of the microlens is ~ 3× of which from the place without the microlenses. Moreover, a two dimensional numerical study using FEM on the electromagnetic field distribution in the vicinity of a melamine microsphere is presented. The result shown in Figure 4 indicates that the spherical microsphere plays the role of a microlens, and focuses the radiation into an extremely small region of enhanced intensity, effectively producing a photonic nanojet. The intensity of the focused light is ~ 4× that of the illumination, which basically matches the result obtained from the experiment.

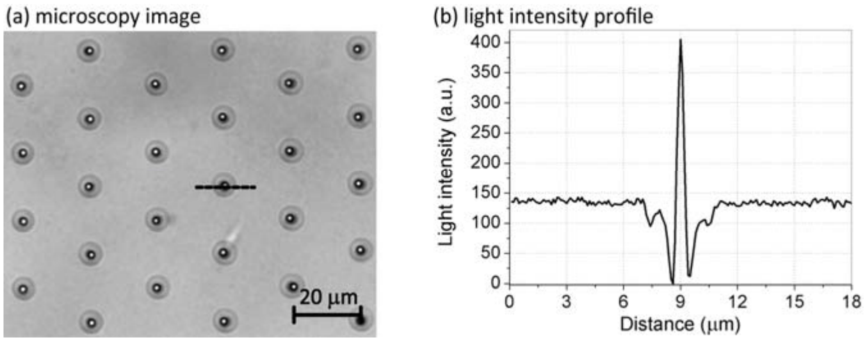

Figure 3: (a) Microscopic image obtained from a 32× objective (NA = 0.4) objective, which focuses onto the microsphere focal plane. The light intensity along the dashed line in (a) is shown in (b). The intensity within the photonic nanojet is about 3 times the background.

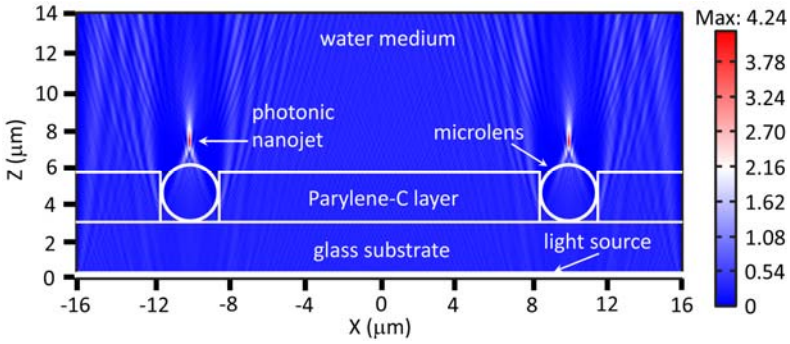

Figure 4: FEM simulation (Comsol Multiphysics) of the light propagating through the glass substrate, the Parylene-C layer and two dielectric microspheres, which are immersed in water medium. The microspheres are used as microlenses to focus the illumination light coming from below the glass substrate.

CONCLUSION

In conclusion, we propose a technique for generating a microlens array by patterning single dielectric microspheres into a microwell array with very high loading efficiency (> 99% when pH = 2). The large field-of-view of a simple low-magnification microscope objective allows many light focusing spots to be observed at once, and a statistical study of the optical signal is possible. We think that our approach offers high potential for improving the detection sensitivity in many analytical applications.

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