A DOUBLET MICROLENS ARRAY FOR IMAGING OF BIOLOGICAL MICRON-SIZE OBJECTS

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ABSTRACT

We propose a novel fluidic assembly-based microfabrication approach for obtaining low-cost, high numerical aperture (NA), doublet microlens arrays. The proposed doublet architecture consists of glass microspheres trapped on a predefined array of silicon microholes and covered with a thin polymer layer. An array of ~56 μm in diameter microlenses with a numerical aperture of ~0.495 were fabricated using this approach. We demonstrated magnified, brightfield as well as fluorescent image formation of micron-size objects directly on a CCD sensor using such a microlens array. The proposed microlens array can be readily employed for applications involving imaging of biological micron-size objects.

KEYWORDS: Doublet Microlenses, Numerical Aperture, Imaging, Fluidic Assembly

INTRODUCTION

The development of high optical performance, inexpensive microlens arrays that can replace expensive high-end macroscopic lenses has been an intense area of research in the past two decades [1-3]. For typical lab-on-chip applications that require imaging, these microlens arrays are desired to have high light collecting ability indicated by their numerical aperture (NA) while their fabrication process should allow large scale microfluidic/optical integration. Although the above microfabrication approaches yield high NA microlenses, none of these microlenses have been shown to form image on their own on an imaging sensor without the aid of additional optical elements.

This work demonstrates a novel microfabrication approach for obtaining low-cost, high-NA, doublet microlens arrays for imaging micron-sized objects without the need of any additional lenses. They are made out of glass microspheres with a transparent polymer (PDMS) spun on them and their optical performance (resolution, NA) is equivalent to the optical performance of a conventional microscope objective, enabling at the same time imaging of a large number of micro-objects.

THEORY

The proposed doublet microlens array consists of glass microspheres, fluidically assembled on top of an array of wafer-through microholes (Figure 1). The microhole array captures/places the microspheres in a pre-defined pattern, while creating a clear optical path for the light to reach the imaging sensor (e.g. CCD). The microlens array collects light emitted by micron-size objects that sit on its flat surface. As the micron-size objects are placed on an imaging plane slightly below the focal plane of the microlenses array, a magnified image is formed at the imaging sensor.

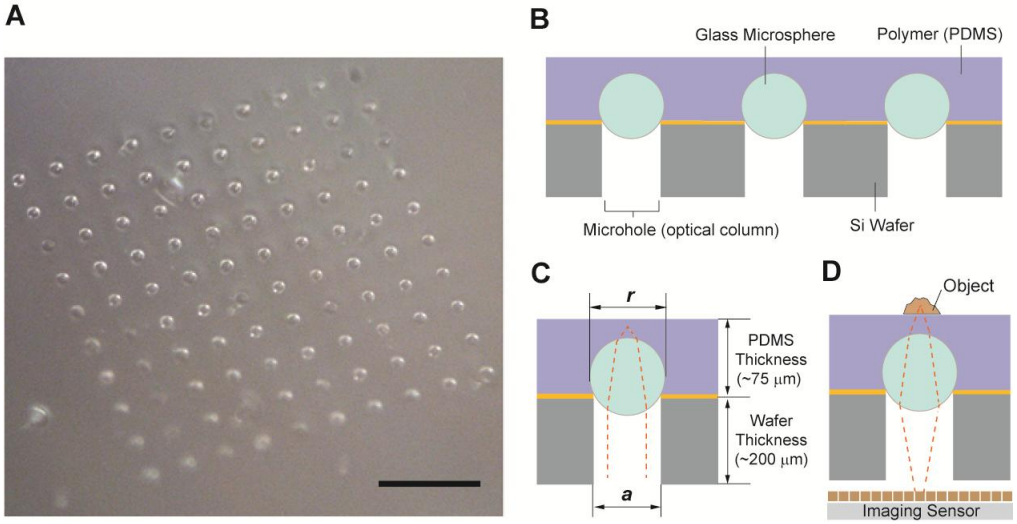

Figure 1: (A) A 10x10 array of high numerical aperture, doublet microlenses (diameter, r = 56 μm). Scale bar, 500 μm. (B) Schematic of the cross section of the microlenses array. (C) A collimated beam of light incident on the microlens is focused at a point below the top surface of the flat polymer (PDMS) layer. (D) Mechanism of image formation using the doublet microlens array. The object is placed on the surface of the microlens which forms a magnified image directly on an imaging sensor.

MICROFABRICATION OF THE MICROLENS ARRAY

The microfabrication of the microlens array involves three steps (Figure 2): i) microfabrication of the microhole array, ii) assembly of glass microspheres on the array, and iii) formation of the microlenses by spinning a PDMS layer on the captured microspheres. Specifically, a 2 µm thick PECVD silicon dioxide is initially deposited on a ~500 µm thick silicon wafer. An array of 56 µm diameter microholes is then patterned and etched on the oxide layer using photolithography and reactive ion etching (RIE). Deep reactive ion etching (DRIE) is further employed to fabricate through-wafer circular microholes in the silicon substrate. Subsequently, the silicon substrate is thinned down to 200 µm using a combination of lapping and chemical-mechanical polishing (CMP). An aqueous solution containing glass microspheres (60 µm nominal diameter; Catalog No. 02718-AB, Structure Probe, Inc.) is then dispensed on the oxide-coated silicon surface. A suction force is subsequently applied from the opposite side of the substrate to assemble and trap the glass microspheres atop of the microhole array. Doublet microlenses are finally obtained by spinning and curing a ~75 µm thick (spun at 1600 rpm) PDMS layer on top of the array.

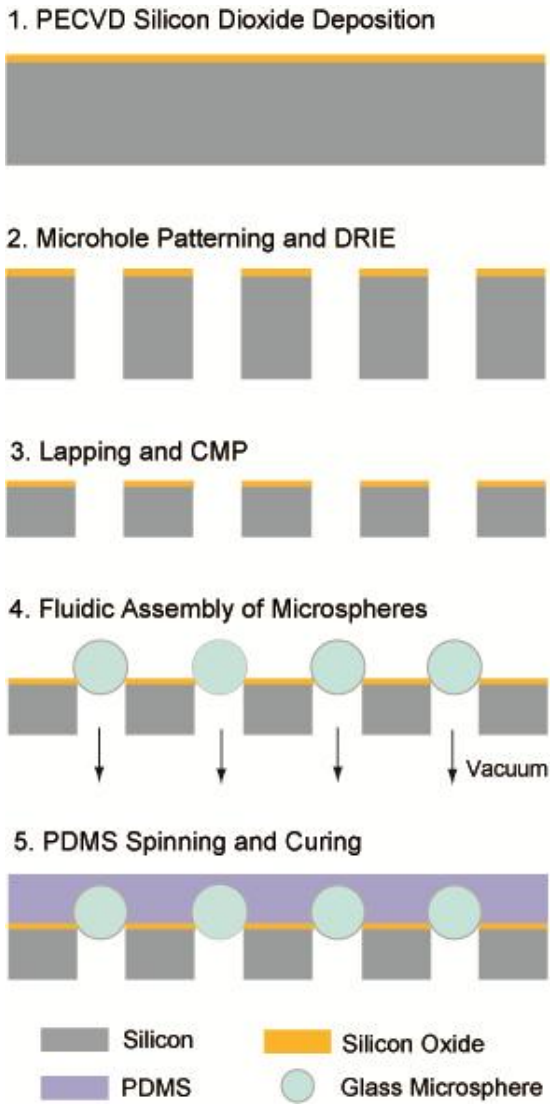

Figure 2: Microfabrication process of the doublet microlens array. Key concept is the fluidic assembly of glass microspheres (step 4).

RESULTS AND DISCUSSION

We performed optical simulations to estimate the numerical aperture (NA) of the microlenses as a function of the microhole diameter (a) to microsphere diameter (r) ratio (Figure 3). Our microfabricated microlenses (a/r = 0.93) had a NA of ~0.495. It should be emphasized that microscope objectives with a NA of 0.3-0.4 are commonly used for imaging of cells and tissues.

We used the doublet microlens array to image resolution patterns etched on a chrome layer, previously deposited on a glass substrate (Figure 4 (I), (II) and (III)). A 640x480 CCD sensor chip, dismantled from a web camera and a custom experimental setup utilizing x-, y- and z-axis manipulators, were used to acquire images after aligning the patterns-microlens assembly with the CCD sensor chip. The microlens array easily resolved 1 µm resolution patterns while the theoretical resolution was calculated to be 0.49 µm (at 480 nm wavelength). We also demonstrated the formation of magnified, fluorescent image of 4 µm in diameter polystyrene beads after inserting a thin (~100 µm) long-pass emission filter between the microlens array and the CCD sensor (Figure 4 (IV)). These results validate the potential of the microlenses for imaging biological micron-size objects (cells, tissues etc.) directly on the CCD sensor.

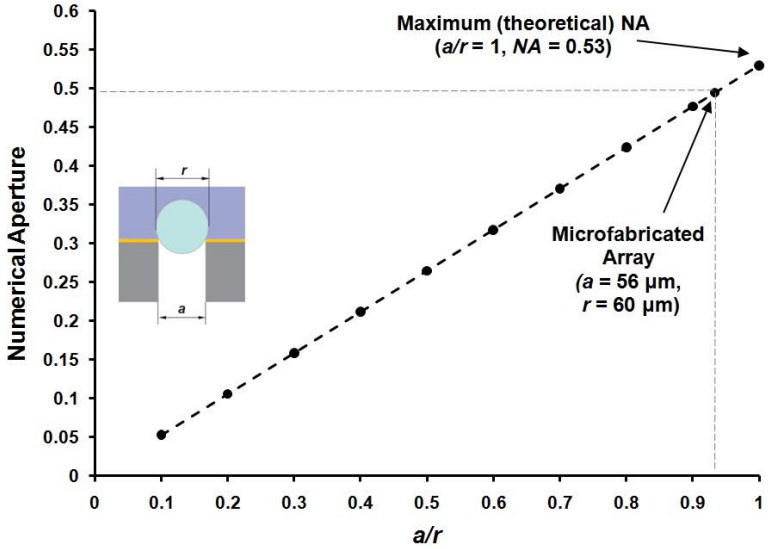

Figure 3: Simulation results depicting the dependence of the NA on the microhole to microsphere diameter ratio (a/r). Optical simulations were performed using OSLO software.

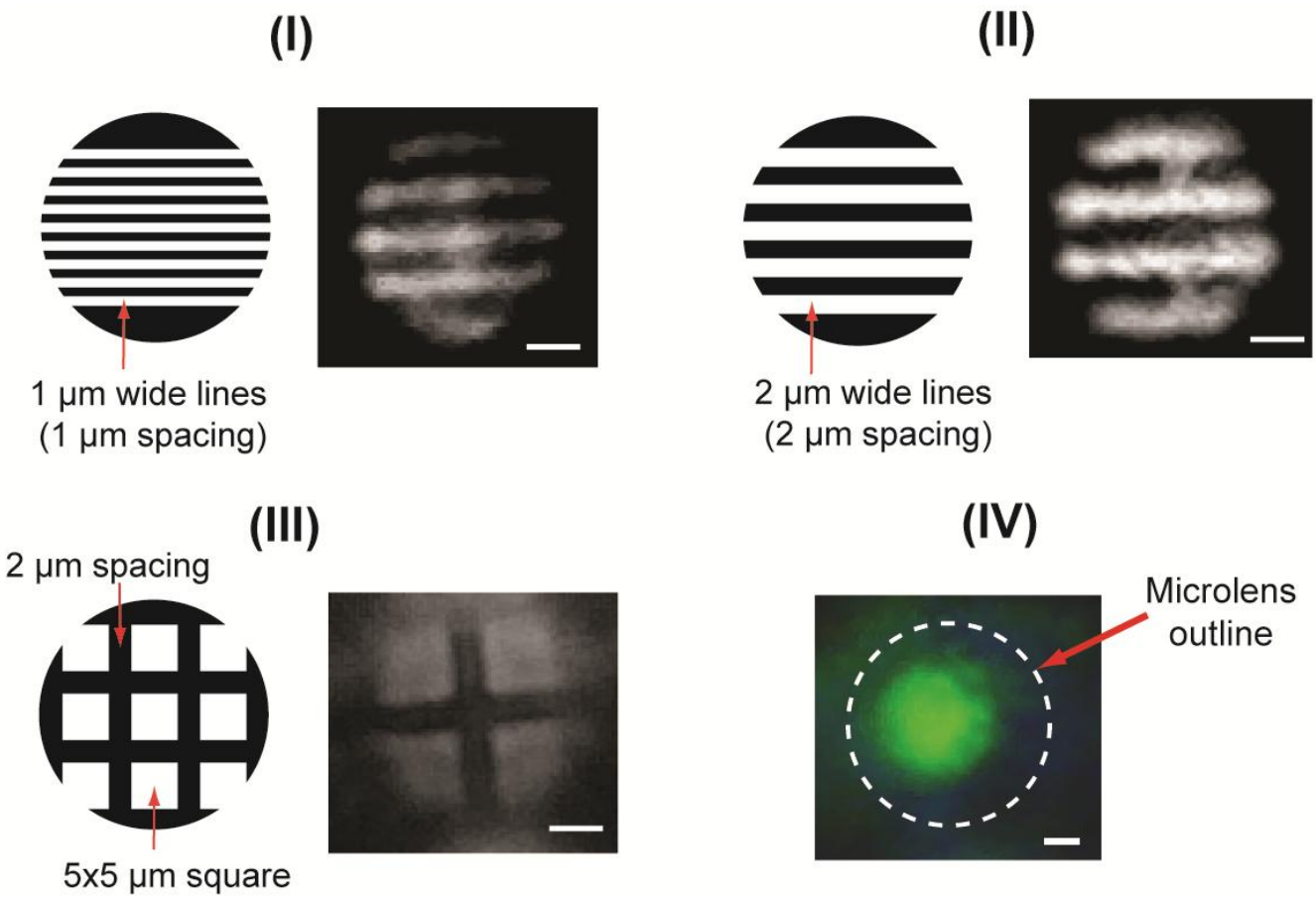

Figure 4: (I) & (II) Brightfield, transmission images of 1 and 2 µm line resolution patterns respectively using a 56 µm diameter microlens (NA~0.495). Equally spaced, 1 µm wide lines are clearly resolved by the doublet microlens. Scale bar, 20 µm. (III) Brightfield, transmission image of a 5 µm square grid. Scale bar, 20 µm. (IV) Fluorescence image of a polystyrene bead (4 µm in diameter). The bead is magnified by a factor of ~6. Scale bar, 10 µm.

CONCLUSION

We developed a novel doublet microlens array microfabrication approach for the direct visualization of micron-sized objects. Using these microlenses, we have demonstrated direct image formation on a CCD sensor without additional optical elements. We envision that the proposed microlenses arrays can provide a cheaper alternative to bulky and expensive microscope optics in applications involving on-chip imaging of biological microobjects without compromising the optical performance. Integration of this technology with various photonic and microfluidic devices will facilitate the development of next generation of integrated lab-on-chip systems.

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