Printing non-circular microlenses

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Combining photoresist polymers, lithography, and ink-jet printing allows fabrication of microlenses with unique features.

Microlenses are used in a myriad of applications, ranging from cellphones and cameras to micro-opto-electro-mechanical systems (MOEMS) and high-resolution imaging platforms for biological applications. Normally, circular microlenses result in circular light spots. However, certain advanced micro-optical systems demand non-circular lenses, for instance, to correct optical defects or enhance new applications such as lab-on-a-chip systems. Despite progress in microfabrication techniques, preparing such structures at the microscale remains a challenge.

Direct printing has emerged as a promising option for scalable fabrication of non-circular microlenses, and ink-jet printing (IJP) allows us to dispense small drops of a lens material in liquid form onto a surface. A subsequent curing step yields solid transparent microlenses with a curvature radius that depends primarily on the contact angle between the substrate and the dispensed droplet.

This technique can merge adjacent drops into microlenses with non-circular shapes, but it has two drawbacks. First, it relies on precise control of the surface wettability, which may vary over time. Second, the landing position of the dispensed droplets must be precisely controlled for accurate alignment. To overcome these limitations, we have combined IJP with photolithography methods to better tune and control the shape of the deposited lens material.

To this end, we have fabricated ‘platforms’—prestructured substrates that define the contour shape and edge angle (E_a) of the deposited material, as shown in Figure 1—with the desired contours on the substrate. We subsequently printed liquid lens materials with micrometer precision.

We tested this process using two different substrates. We first used a silicon (Si) substrate patterned by photolithography and reactive ion etching to make Si platforms. We deposited a carefully controlled number of drops of SU-8 photoresist polymer precursor solution (InkEpo, from micro resist technology GmbH) onto the platforms to achieve the required volume and E_a. Afterwards, the deposited polymer was cured by UV exposure and thermal treatment. Figure 2 shows that controlling the number of printed drops allowed us to control E_a while keeping the diameter of the final lens-shaped drop on the substrate constant. The Si platforms successfully defined the contour shape and E_a of the deposited material, but the Si is not transparent and thus not suitable for use as part of a lens for visible light. We therefore also fabricated platforms from SU-8 by photolithography on glass wafers.

We used this technique to directly print arrays of polymer microlenses with uniform circular diameter shapes. Figure 3(A) shows a scanning electron microscopy (SEM) image of a section of an array containing 900 microlenses fabricated with a yield of greater than 98%. Figure 3(B) shows a CCD camera image of the focal plane of a microlens array fabricated on transparent SU-8 platforms.

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We also printed the InkEpo lens material onto platforms with non-circular—i.e., toric, elliptical, and double ellipse—contour shapes: see Figures 4 and 5. The toric lens focuses the light into a circle, whereas the elliptical lens produces an ‘interval of Sturm,’ comprising a vertical line focus, the circle of least confusion.

**Figure 2.** Evolution of \( E_a \) versus the number of drops deposited on 100\( \mu \)m-diameter platforms. The optical pictures show side view images of the InkEpo structures after curing.

**Figure 3.** (A) Microlens array fabricated on 900 silicon platforms. (B) CCD image of the focal plane of a microlens array fabricated on SU-8 platforms.

**Figure 4.** Schematic of (i) toric, (ii) elliptical, and (iii) double ellipse microlens shapes.

**Figure 5.** CCD images of the focal planes formed by the (i) toric, (ii) elliptical, and (iii) double ellipse microlenses.

(a blurry focal point), and a horizontal line focus. Finally, the double ellipse produces a double interval of Sturm, in other words, a square-like, a dot-like, and a rhombus-like focal plane.

In summary, we have demonstrated the general versatility of IJP on lithographically prepatterned platforms for fabricating complex micro-optical structures. In particular, we can produce

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microlenses with arbitrarily designed shapes. Our next step is to demonstrate that this technique can also control focal length and to apply it to specific applications.

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