Tunable Micro-Aspherical Lens Manipulated by 2D Electrostatic Forces

[1]Chang-Wei Chen and [1,2] Fan-Gang Tseng
[1]Institude of microelectromechanical Systems, [2] Engineering and System Science Depart.
National Tsing Hua University, Taiwan, R.O.C.
e-mail: fangang@ess.nthu.edu.tw

ABSTRACT

A novel method to manipulate or fabricate aspherical micro lens from photo curable polymer is proposed in this paper. Two dimensional forces, carried out by electro-wetting and electrostatic forces were applied to shape polymer liquid from hemisphere into paraboloid or near cone shape. As a result, the Strehl ratio for this lens can be varied from 0.0076 in spherical shape into 0.8362 in near paraboloid shape, suitable for optical applications desiring lenses with high numerical apertures and resolution.

Keywords: Tunable lens, Aspherical micro lens, 2D electrostatic forces

INTRODUCTION

Microlens have been employed in many applications such as telecommunication [1], optical data storage [2] and bio-detection [3]. To obtain high performance in resolving power or tracing ability, micro lens with aspherical surface and tunable focal length become very important. Spherical micro lens with tunable focal length has been demonstrated by using electro-wetting effect [4]. On the other hand, liquid filling [5] and wet etching method [6] have been adopted for the fabrication of micro aspherical surface. However, to control both of them at the same time dynamically is still not a simple task. In this study, a novel way by employing 2D electrostatic forces to manipulate liquid polymer surface dynamically to obtain aspherical micro lens with tunable focal length is proposed. This novel manipulation way can not only be employed to control the focal length and surface shape of micro lens, but also to fabricate aspherical lens after UV curing of the photo sensitive polymer.

DESIGN

In the design of a perfect lens, it is desirable to find a surface that refracts planar waves of constant phase into a single point, as shown in Fig.1a.[7][8], When light rays focus into a single point through this surface, the wave front become spherical and have the same phase. However, in lens of spherical surface, the lengths of optical paths passing through different parts of the lens among focused light rays induces spherical aberration, that is, the light rays can not focus onto a single point and produce large light spot. Therefore, aspherical surface is desired to correct the length error of optical paths for all light rays to focus into a single point.

The optical path length is defined as

$$O.P.L = \oint n \cdot ds \qquad (1)$$

where n is the index and s is the real length of lens. For ray 1 and ray 2 in Fig 1, the equivalence optical path length can be described as

$$\sqrt{(f-z)^2+\rho^2} = f + n\cdot(0-z) \qquad (2)$$

where f is the focal length, z is the lens sag, and ρ is the cross section radius of the lens. Equation (2) can be rewritten as

$$\rho^2 = (n^2-1)\cdot z^2 + 2\cdot f\cdot(1-n)\cdot z. \qquad (3)$$

By Matlab simulation, Equation (3) can be employed to calculate the desirable aspherical surface for the compensation of spherical aberration. The focal lengths are selected as 1000、500、300、100 μ mwith the same lens height of 500 μ m, as shown in Fig.1b、c、d、e. Because the lens index is higher than that of air, so the ray speed is higher in lens than that in the air. Therefore, the aspherical lens shape must be higher at the lens center region and lower at the lens edge than those of a spherical lens. According to this criterion, surface profile of asperical lens with shorter focal length will be close to a cone shape, as shown in Fig. 1 (b)-(e). OSLO was employed to simulate the lens performance which is designed by the rule. The PSF (point spread function) result is shown in Fig.1f for 500 μ m lens and its Strehl ratio reaches 0.99.

The concept of the microlens manipulation/fabrication is shown in Fig.2. Two electrical potentials were applied among the bottom ring electrodes and between the top and bottom substrates on a SU-8 liquid droplet, respectively. Therefore, we use silicon nitride as a dielectric layer and Teflon pattern for SU-8 liquid droplet self-alignment. The potential applied among the bottom ring electrodes poses electrowetting effect on the polymer droplets, lowering down the droplet contact angle with spherical surface for obtaining desired droplet height/baseline ratio for related focal length. Then the potential applied between the top and bottom substrates pull up the center part of the droplet most to form aspherical shape ranging from spheric, parabolic, into cone because of the shorter distance between the center part and the upper electrode. Therefore, we can use the electrostatic force to modify lens shapes as illustrated in Fig1. The space between the top and bottom concentric electrodes is about 1mm. Fig.3 shows the potential distribution with or without applying top potential while employing the bottom potential by ANSYS analysis. When we apply voltage between the bottom ring electrodes, the electric potential degree is along the X direction and makes the SU-8 droplet wetting on the substrate as in Fig.3a. When the application of high voltage among the upper electrode and bottom central electrode, the electric potential degree is along Y direction and makes the SU-8 droplet become taller and closer to cone shape, as shown in Fig.3b.

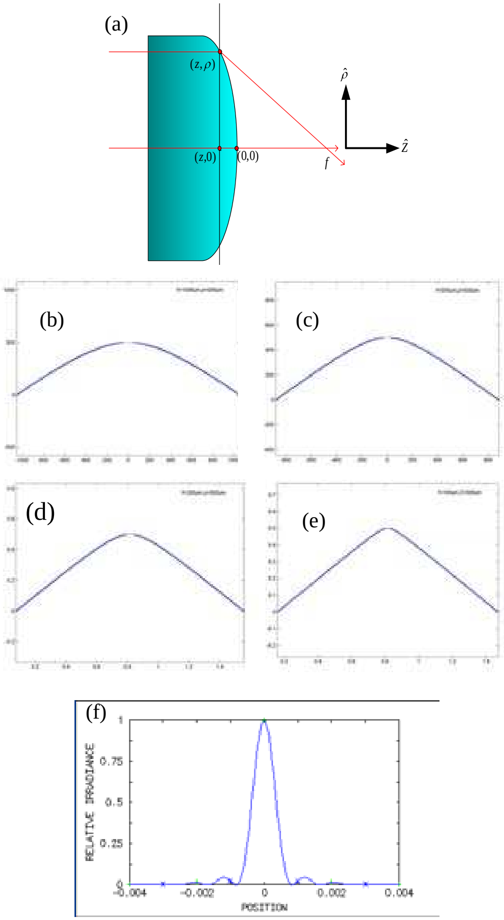


Fig.1 Aspherical surface design. (a)Optical path length difference of central ray and peripheral ray. (b)(c)(d)(e)Matlab diagram of apsherical surface profile which focal length is 1000、500、300、100 μm. (f)The point

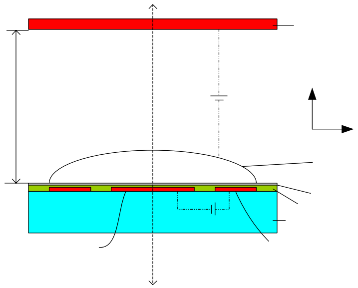


Fig.2 Manipulation of aspherical microlens by 2D potentials.

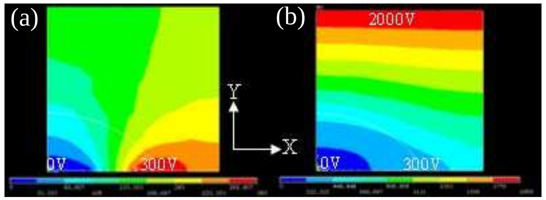


Fig.3 ANSYS simulation results of the potential distribution across micro lens(a) without (b) with top potentia

EXPERIMENT AND RESULTS

The sequence of OM images of the aspherical microlens formation by the 2D potential method is shown in Fig.4. Fig. 4a illustrates the original shape of a SU-8 droplet, while Fig. 4b depict the flattened lens with the application of bottom potential for electrowetting. Aspherical lenses were produced after the application of various top potentials in Fig.4c-e. Fig. 4 f-j demonstrated different sets of aspherical lenes with higher bottom potential. The lens baseline length changed from 1mm to 1.5mm under 300 Volts at the bottom electrodes and the lens height varying from 0.35mm to 0.3mm correspondingly. In both of the casees the lens shapes varyyfrom normal sphere to cone according to different potential states. When 2000 Volts was applied at the up electrode after applying 300 Volts at under electrodes, the lens central height varied form 0.3mm to 0.75mm and the lens become cone shape. With taller lens center the optical path lengthes become more uniform along the lens according to the constant O.P.L. theory. The lens profiles of Fig. f-j are depicted by curve fitting of 8 order polynomials and shown in Fig.5.

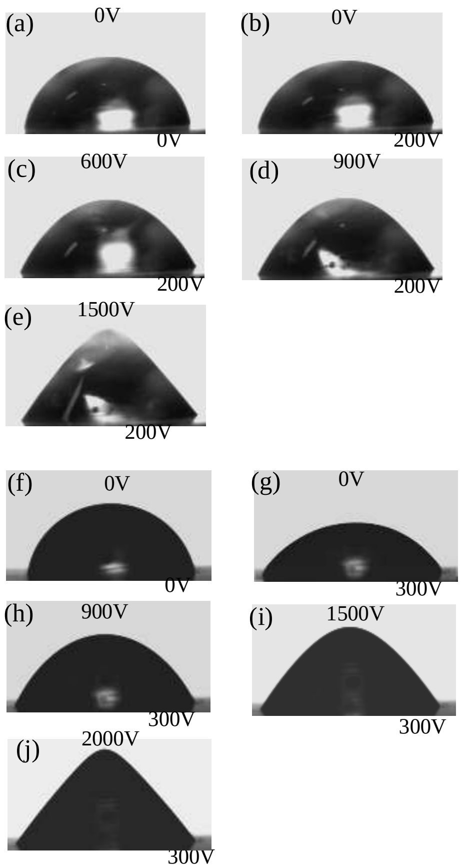
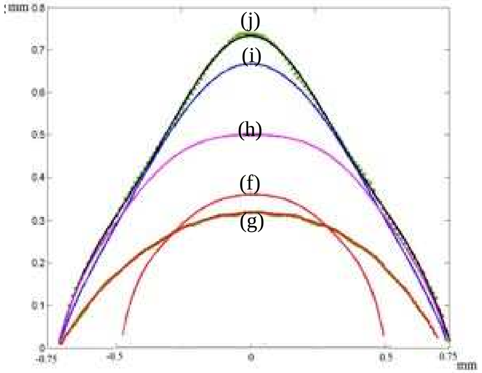


Fig.4 OM images of microlens shape. (a) The original lens. (b) The lens shape under electrowetting effect. (c)-(e) The lens shape under both the top and bottom electrostatic force effect. (f)-(j) The lens shape under higher voltage effect and have longer base length and



The OSLO simulation results of the PSF (Point Spread Function) cross section diagrams for those micro lenses are shown in Fig.6 and the strehl ratios, calculated from the PSF cross section, are varying from 0.0076 to 0.8362 and shown in Fig.7. Both of Fig.6 and 7 reveal that the highest PSF peak value and strehl ratio appears in the j type lens. This result point out that the lens performance is close to the surface profile designed by the constant O.P.L. theory.

The experimental setup for measuring the focus spot is shown in fig.8. A collimated light source impinges to a beam splitter and is reflected into a tunable aspherical lens chip perpendicularly. The focus spot is visualized with a microscope and recorded by a CCD camera.

The spot images focused by the asperical lenses are shown in Fig. 9. White light source was employed in this study. As demonstrated in Fig. 9 a-e, the focused spots become smaller when higher top voltage is applied, consistant with the simulation result. Smaller focused spots are observed by using HeNe laser as light source with a wavelength of 645nm, as shown in Fig.9f-j.

This result successfully demonstrates the capability of dynamical manipulation on micro lenses by employing 2D electrostatic potentials.

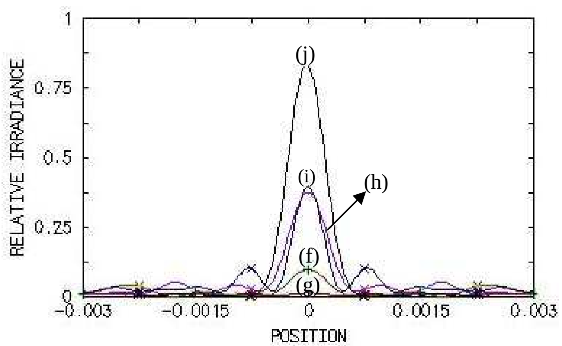
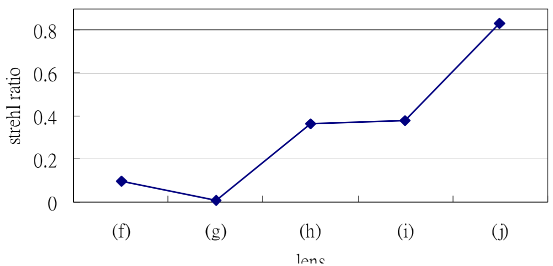


Fig.6 Simulation result of PSF cross section of lens shown in Fig.4 f-j by OSLO.



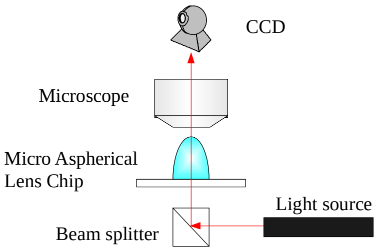


Fig.8 The experiment setup for measuring the focus spot.

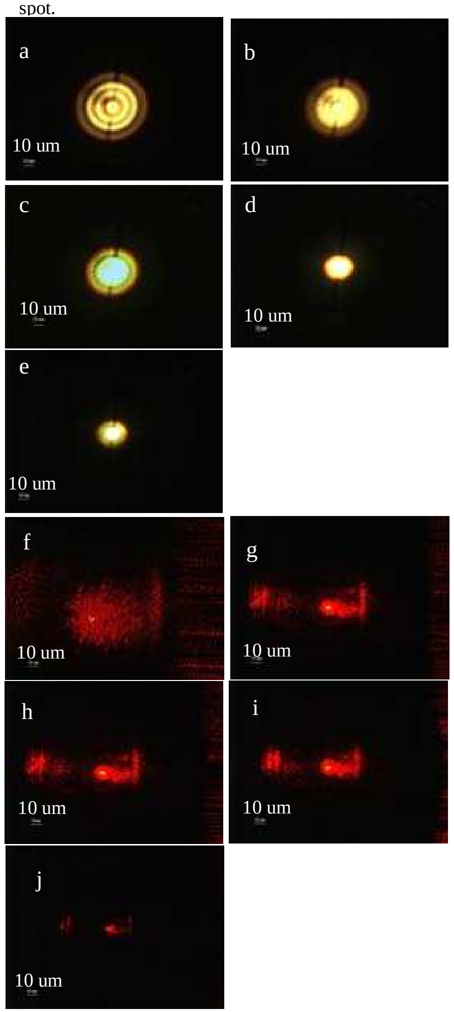


Fig.9 The focus spot image of white light (a-e) and 645nm laser (f-j) recorded by experiment setup in Fig.8.

CONCLUSION

We have successfully demonstrated a novel method to manipulate or fabricate aspherical micro lens from photo curable polymer. 2-D electrostatic forces were employed to shape SU8 droplet from sphere to parabolic or even cone shape by electrowetting and electrostatic effect together. The reshaped aspherical lenses can compensate the spherical aberration from traditional spherical micro lens. Simulation result shows that the lens performance is close to which we designed by constant O.P.L. theory. Both simulation and experiment show good agreement of the performance of the asperical lenses. The strehl ratio of the designed aspherical lenses can be improved from 0.0076 to 0.8362 for near cone shape asperical lens, very close to the ideal one.

References

[1] A. L. Glebov, L. Huang, S. Aoki, M. G. Lee, K. Yokouchi, “Two-dimensional microlens arrays in silica-on silicon planar lightwave circuit technology,” J. Microlith., Microfab., Microsyst.,2,No.4,309-318(2004).

[2] F. G. Tseng, H.T. Hu, “A novel micro optical system employing inclined polymer mirrors and fresnel lens for monolithic integration of optical disk pickup heads,” The 12th International Conference on Solid-State Sensors, Actuators and Microsystems,599-602(2003).

[3]Kuo-Yung Hung, Chang-Wei Chen, Fan-Gang Tseng,“ Self-reshapable and Ophiocoma-like Micro Optical Array for Protein Micro Array detection in Parallel,” The 8th International Conference on Miniaturized Systems for Chemistry and Life Sciences ,p.p. 479-481,Sep.26-30,Malmo,Sweden,2004.

[4] T. Krupenkin, S. Yang, and P. Mach, ” Tunable liquid microlens,” APPLIED PHYSICS LETTERS, 82,316(2003).

[5] Nikolas Chronis, Gang L. Liu, Ki-Hun Jeong, and Luke P. Lee, “Tunable liquid-filled microlens array integrated with microfluidic network,” OPTICS EXPRESS , 11, 2370(2003).

[6] D.W. de Lima Monteiro, O. Akhzar-Mehr, P.M. Sarro and G. Vdovin, “Single-mask microfabrication of aspherical optics using KOH anisotropic etching of Si,” OPTICS EXPRESS , 11, 2244(2003).

[7] D. Schurig and D. R. Smith,” Universal Description of Spherical Aberration Free Lenses Composed of Positive or Negative Index Media,” eprint arXiv:physics/0307088(2003).

[8]Min-Kang Chao and Sheng-Wen Cheng, ”ASPHERIC LENS DESIGN,”IEEE ULTRASONICS SYMPOSIUM, 1025-1028(2000).