A THERMALLY TUNABLE MICROLENS ARRAY ON INDIUM TIN OXIDE GLASS

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ABSTRACT

We present a polydimethylsiloxane (PDMS) microlens array on a glass substrate. By adjusting the temperature with indium tin oxide (ITO) microheaters, the properties of the individual microlenses are actively tuned without mechanical movement. We characterize the temperature-dependent changes of the microlenses by focal length and magnification measurements. Experimental results demonstrate that the thermally tunable microlenses can potentially be used for biological imaging and other applications.

KEYWORDS: Biological imaging, microlens, thermal expansion, tunable lens

INTRODUCTION

Tunable lenses are important for biological imaging, and traditionally involve mechanical motion that may be complicated and difficult to realize [1]. Thermal actuation offers an attractive solution to address these limitations. We recently reported a thermally tunable microlens using SU-8 and gold heaters [2], but due to the relatively small thermal expansion coefficient of SU-8, the lens required rather high temperature changes (100 ^{o}C). The placement of the opaque gold heater away from the microlenses also limited temperature control accuracy and efficiency. In this paper, we present an array of thermally tunable microlenses fabricated from polydimethylsiloxane (PDMS) [3, 4] on indium tin oxide (ITO) microheaters, and demonstrate its utility for biological imaging. Thanks to the large thermal expansion coefficient of PDMS, the microlenses are capable of operating at relatively low, physiologically relevant temperatures. Simplicity in design and operation also allow the microlenses to be easily integrated into microsystems.

Design

The thermally tunable microlenses are based on the thermal expansion of PDMS. When the temperature is increased, the radius of curvature of the microlens will change, thereby causing a change in its focal length. Due to a relatively large thermal expansion coefficient, the PDMS microlens can be thermally tuned at low temperatures. A transparent ITO film is patterned to form spiral-shaped micro-heaters and temperature sensors directly beneath the PDMS microlenses for efficient and accurate temperature control (Figure 1). Also significant is that each individual microlens in the array can be independently controlled by the underlying ITO microheater. By applying varying voltages to the ITO heaters, the profile of the microlenses, and hence their focal lengths, can be changed correspondingly. The mi-

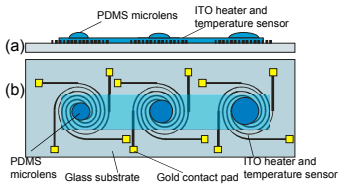

Figure 1. Schema of microlens array design: (a) side and b) top views.

crolens temperatures can be assessed by monitoring the changes in resistance of the ITO temperature sensors.

EXPERIMENTAL

To fabricate the microlens array, the ITO thin film on a glass substrate was patterned by wet etching to form microheaters and temperature sensors. AZ P4620 photoresist was spin-coated and patterned on silicon to form an array of microposts, which were thermally reflowed into spherical profiles. These features were used as a mold to produce corresponding concave, spherically shaped cavities in a PDMS sheet. The resulting PDMS sheet was used as a second mold, onto which PDMS was cast to fabricate an array of PDMS microlenses. Finally, the PDMS microlens array was bonded to the ITO-glass substrate (Figures 2).

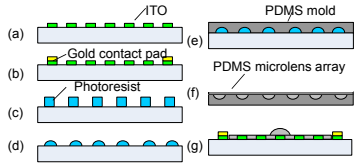

Figure 2. Fabrication of (a) ITO microheaters; (b) gold contact pads; (c) AZ P4620 posts; (d) reflow of AZ P4620; (e) first PDMS molding; (f) second PDMS molding to produce microlenses; (g) bonding of microlens to the ITO glass.

The tuning capability of the microlenses was first characterized by measuring the changes in their focal lengths. A collimated light beam was directed through a microlens and allowed to converge at its focal point (Figure 3a). By measuring the distance between the lens's focal point and the optical center, the focal length was obtained.

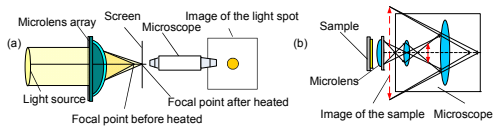

Figure 3. Experimental setups for (a) focal length and (b) magnification measurements.

We then investigated the temperature-dependent magnification factors of the microlenses by imaging gold patterns at varying temperatures. The gold patterns on a glass slide were placed in close proximity to the microlens chip and observed by an inverted microscope (Figure 3b). The images obtained from a microscope with and without using microlenses were compared. Finally, images of mouse kidney cells were obtained with the microlenses, using a similar setup in which a mouse kidney cell slide was employed as the experiment sample (Figure 3b).

RESULTS AND DISCUSSION

We tested an array of three microlenses, which had base diameters of 200, 300 and 400 μm, respectively. We first performed measurements of the focal length of each microlens (Figure 3a) and observed that as the temperature varied from 24 ^{o}C to 37 ^{o}C, the focal length increased steadily by 5.1%, 3.5%, and 2.6%, respectively (Figure 4a). The increase in focal length with temperature reflected an increase in the microlens's overall radius of curvature, which was consistent with the synchronous thermal expansion of the microlens and its base.

We then used the microlenses to image gold thin film patterns. The magnification exhibited in images of the thin film pattern was determined with respect to direct microscope images of the pattern obtained in the absence of the microlens chip.

Monotonic decreases of magnification with temperature were observed (Figure 4b), which was consistent with increases in focal length. It can also be seen that the microlenses with smaller diameters had larger magnifications due to their smaller radii of curvature and focal lengths. Overall, our focal length and magnification measurements at physiologically relevant temperatures suggest the suitability of the microlenses for biological imaging. To demonstrate this, mouse kidney cell images obtained with and without using the microlens are shown in Figure 5d-5i.

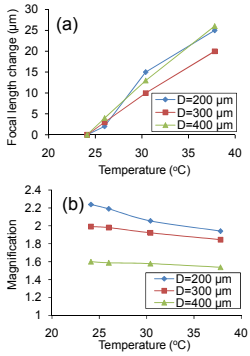

Figure 4. Characterization of a microlens array: thermally induced (a) focal length change and (b) magnification. At 24 °C, the focal length was 490 μm for the 200 μm microlens, 575 μm for the 300 μm microlens, and 1010 μm for the 400 μm microlens.

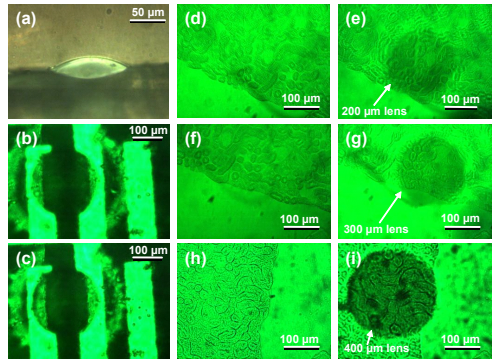

Figure 5. Magnification measurements: (a) side-view image of a 200 μm microlens; and images of a gold thin-film pattern at (b) 24 °C and (c) 37 °C. Imaging of mouse kidney cells by the microlens array: (d) with and (e) without the 200 μm microlens; (f) with and (g) without the 300 μm microlens; and (h) with and (i) without the 400 μm microlens.

CONCLUSIONS

We designed, fabricated and characterized a thermally tunable microlens array on indium tin oxide-coated glass by focal length and magnification measurements. Mouse kidney cells were imaged using these microlenses. The thermally tunable microlenses can be potentially used for biological imaging and other applications.

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REFERENCES

[1] L. Dong et al., "Variable-Focus Liquid Microlenses and Microlens Arrays Actuated by Thermoresponsive Hydrogels," *Adv. Mater.*, 19: 401-405, 2007.

[2] X. Huang et al., "Thermally Tunable Polymer Microlenses," *Appl. Phys. Lett.*, 92: 251904, 2008.

[3] J. Chen et al., "Variable-Focusing Microlens with Microfluidic Chip," *J. Micromech. Microeng.*, 14: 675-680, 2004.

[4] T. Lin et al., "Concave Microlens Array Mold Fabrication in Photoresist Using UV Proximity Printing," *Microsyst. Technols.*, 13: 1537-1543, 2007.