Two-dimensional silicon-on-glass actuator combined with a dispensed polymer microlens

Pei Li[1], *Longfa Pan*[1], *Hans Zappe*[2]

[1]*Department of Precision Instruments and Mechanology, Tsinghua University, Beijing, People's Republic of China*
[2]*Department of Microsystems Engineering – IMTEK, University of Freiburg, Freiburg, Germany*
E-mail: lipai08@mails.tsinghua.edu.cn

Published in Micro & Nano Letters; Received on 3rd May 2013; Revised on 20th June 2012; Accepted on 2nd July 2013

Actuators for objective lens positioning are indispensable components for writing and reading data to and from optical storage media. Significant advances in the technical capabilities of microlens actuators for optical heads have been achieved using MEMS technology, enabling miniaturisation and integration of optical data storage systems. In this reported work, a compact silicon-on-glass (SOG) actuator for two-dimensional (2D) positioning of a dispensed polymer microlens is developed by MEMS technology. A wafer-level process for fabrication of the SOG actuator is achieved using anodic bonding, in which a Pyrex wafer was bonded with an ultra-thin silicon wafer. Dispensed polymer microlenses are fabricated and subsequently integrated onto the 2D actuator by an automatic handling system. Typical displacements of about ±28.6 µm in the tracking direction and 3.2 µm in the focusing direction are experimentally characterised. The compact 2D SOG actuator and assembly technology may be particularly useful for expanding the application area for the optical head.

1. Introduction: Lens actuators are indispensable components for writing and reading data to and from optical storage media, which decides the performance of the read-out system. Microlens actuators and scanners have been extensively investigated using MEMS technology [1, 2], enabling miniaturisation and integration of optical data storage systems [3, 4]. Different actuation methods such as thermal actuators [5], electrostatic methods [6] and magnetic means [7] have been demonstrated for microlens tracking (horizontal) and focusing (vertical) actuators. Among them, electrostatic actuators have advantages including fast response, small size and the compatibility of materials, and are particularly attractive for microlens positioning. We have previously reported an integrated two-dimensional (2D) microlens actuator using a silicon-on-insulator (SOI) process [8]. A double-side process is employed to define the integrated comb-drive tracking and focusing actuators to achieve 2D movements of the microlens.

In this reported work, we designed a 2D silicon-on-glass (SOG) microactuator which obtains the tracking and focusing effect of a dispensed polymer microlens by horizontal comb-drives and electrostatic parallel plates, respectively. An anodic bonding-based process is optimised to define the actuator using an ultra-thin silicon wafer and a Pyrex wafer. Moreover, high quality polymer microlenses are designed, fabricated and integrated onto the fabricated 2D actuators by an automatic handling system. The polymer microlenses are profiled and typical displacements of about ±28.6 µm in the tracking direction and 3.2 µm in the focusing direction of the integrated actuator are experimentally characterised. The compact 2D SOG actuators enable miniaturisation and integration of the microactuators for high capacity and high-density data storage systems.

2. Design

2.1. Actuator: The design of the 2D micromachined SOG microlens actuator is shown in Fig. 1. The device consists of a freestanding lens holder as an upper electrostatic plate in the centre window, a bottom electrostatic plate, four tethering springs supporting the freestanding central stage, eight suspension springs and one set of opposing electrostatic comb drive actuators. The freestanding lens holder is anchored to the glass substrate through the springs. Shift of the movable combs results in a displacement of the lens holder in the horizontal direction and thus, tracking actuation of the lens is achieved. Furthermore, the set of opposing electrostatic combs can generate symmetric displacement along the tracking axis to double the motion range. The central stage and the bottom electrode are utilised as a set of electrostatic plates, which can move the central stage download, yielding focusing actuation of the microlens.

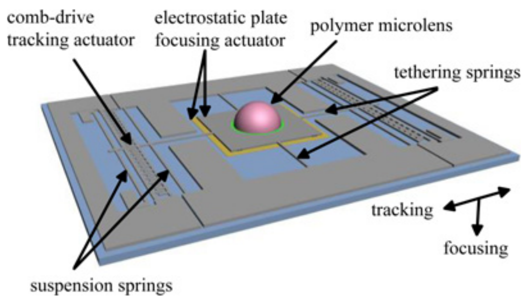

Figure 1 *Schematic structure of 2D SOG microlens actuator*

Fig. 2 shows the process flow for fabrication of the 2D SOG microlens actuator based on anodic bonding. The process used Pyrex 7740 wafers and silicon wafers as the substrates. The Pyrex was 500 µm thick and selectively etched down to 15 µm in

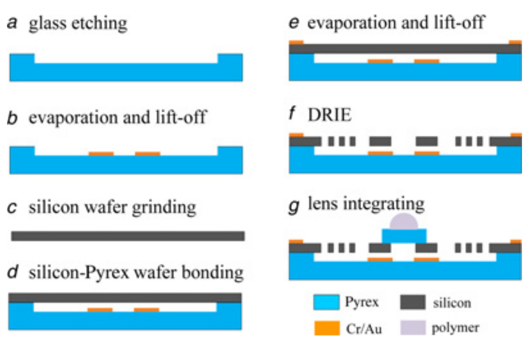

Figure 2 *Process flow for fabrication of 2D SOG microlens actuator based on anodic bonding*

doi: 10.1049/mnl.2013.0248

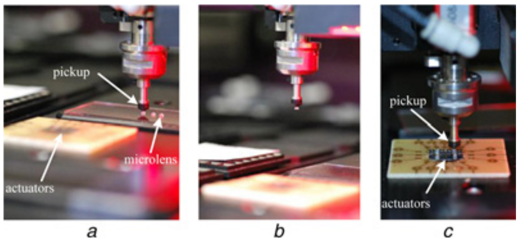

Figure 3 *Assembly process flow for microlens integration*
a Picking up the lens
b Lens attitude adjusting and moving to actuator
c Lens placing

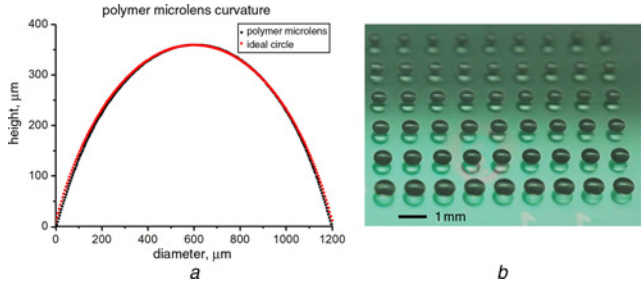

Figure 4 *Profiles of microlenses compared with ideal circle (diameter = 1.38 mm), and Polymer microlens array on glass substrate*
a Profiles of microlens compared with ideal circle
b Polymer microlens array on glass substrate

concentrated hydrofluoric acid (step a). A Cr/Au layer was subsequently evaporated to create the electrostatic lower plate for tracking movement (step b). An ultra-thin silicon wafer thinned down to 90 µm by a wafer grinder was then anodically bonded to the Pyrex using a silicon handle wafer at a temperature of 380°C and a voltage of 1 kV in the vacuum (steps c and d). Another Cr/Au layer for forming the wire bonding pads was subsequently evaporated on top of the silicon (step e). The comb-drive tracking actuator was defined on the thin silicon layer by deep reactive ion etch (DRIE), and the central lens holder as the upper plate of the electrostatic focusing actuator was released (step f). Finally, a dispensed polymer microlens was placed onto the centre of the lens holder by an automatic component handling system and glued by epoxy (step g).

2.2. Microlens: For use in an optical head, the lens must have a high numerical aperture (NA) and be reproducibly fabricated so that it can be incorporated seamlessly into the actuator system. In this work, objective lenses with high NA were fabricated on a hydrophobic surface by liquid dispensing. The polymer is dispensed automatically on a patterned glass wafer by a precisely controlled dispenser. The surface profiles are adjusted by the patterned diameter and the volume of the dispensed polymer, which is controlled by the dispensing time and pressure [9].

2.3. Microlens assembly: The polymer microlenses were then diced into single chips and assembled onto the actuator by an automatic component handling system (AMADYNE SAM 42). The microlens chip was first aligned to the centre of the lens holder by measuring and comparing the positions and attitudes with the lens holder, and then picked and placed by a vacuum pickup pump, as shown in Fig. 3*a*. The attitude of the lens was adjusted by rotating the pickup during the transporting process based on the measuring result, as shown in Fig. 3*b*. The lens was moved on top of the actuator and subsequently placed onto the lens holder of the actuator by turning off the vacuum pump while the pickup was approaching the actuators, as shown in Fig. 3*c*. The placement and rotational accuracy are ±25 µm and ±0.5°, respectively [10].

3. Results and discussion: Using the dispensing technique, we produced microlenses with diameters ranging from 0.4 to 1.4 mm adjusted by controlling the patterned diameter and the volume of the dispensed polymer forming the microlenses. Fig. 4*a* compares the surface profile of a microlens with a surface diameter (d) of 1.2 mm with an ideal circle. The surface of the polymer microlens closely approximates the circle and adequate control of the lens profile is thus confirmed. Fig. 4*b* shows an array of the dispensed polymer microlens. This repeatable and stable process for lens fabrication is promising in microlens actuator applications. Microlenses with this curvature tend to have high NA (up to 0.77) and short focal lengths (<1 mm), making them suitable for the optical system under consideration.

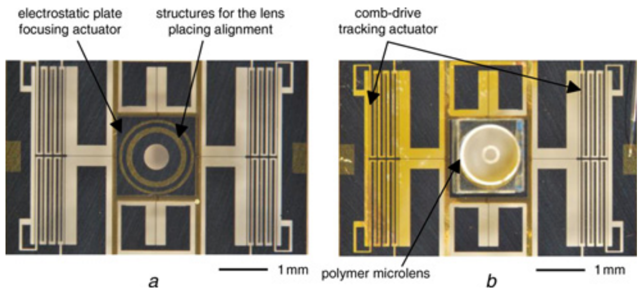

Figure 5 *Images of 2D SOG microlens actuator*
a Without lens
b With polymer microlens

Fig. 5*a* shows the image of the fabricated actuator before the polymer microlens assembly. The smooth surface of the etched Pyrex chamber was obtained after wet etching and the surface roughness is comparable with that of the original polished Pyrex surface. Moreover, further optical experiments show that the transmission is sufficient for the spectral range employed [11]. The springs and comb structures were fabricated and no fracture-related issues were found during the fabrication. The size of the device without the polymer microlens is 6.5 × 5.7 × 0.6 mm. Fig. 5*b* shows the image of the actuator integrated with a polymer microlens. Reproducible moulding and high precision assembling of the microlenses are identified, and fulfil the requirements of the microactuators used in the high capacity and high-density optical storage system, compared with the manual assembly method used in conventional actuators.

Measurements of displacements of polymer microlenses are performed by applying voltages to the comb drive actuators and the electrostatic plates, respectively. Using a custom-designed experimental setup, typical experimental displacements of about ±28.6 µm in the tracking direction and 3.2 µm in the focusing direction are demonstrated as shown in Figs. 6*a* and *b*, respectively.

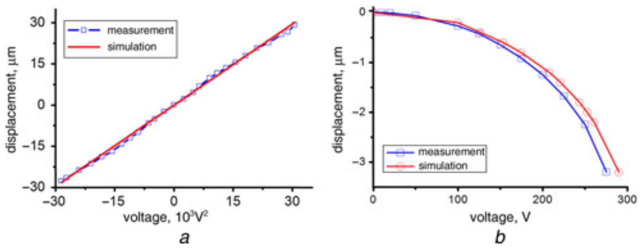

Figure 6 *Displacement of 2D SOG microlens actuator against actuation voltage*
a Tracking direction
b Focusing direction

These measured results show good agreement with the modelling simulations as shown in Fig. 6. The tracking range is comparable with the traditional tracking actuator (>25 µm in one side [12]) and the focusing range is suitable for a fine tracking servo. The device thus provides high sensitivity for microlens positioning of the optical pickup system.

The resulting voltages are most sensitive to the thickness, width and length of the tethering and suspension springs. Thus, they can be decreased by modifying the design parameters. Possible solutions are decreasing the thickness of the ultra-thin silicon wafer during grinding, which will concomitantly increase the difficulty of handling and processing, and improving the precision of the silicon etching process. These improvements will expand the application of the microlens actuators. Besides, the tuning range in the focusing direction, limited to approximately one-third of the gap between the upper and lower parallel plate, could be improved by increasing the gap.

4. Conclusion: We have demonstrated an anodic bonding based process for fabrication of the SOG microlens actuator. The actuator combines comb drives for lateral tracking with electrostatic parallel plates for focusing of a dispensed polymer microlens. Moreover, high quality polymer microlenses were fabricated by liquid dispensing technology and integrated on the 2D SOG actuator by an automatic handling system. The movements of the integrated actuators are experimentally investigated and the improvement methods are proposed. Typical experimental displacements of about ±28.6 µm in the tracking direction and 3.2 µm in the focusing direction are demonstrated. This work represents an important step towards fabrication of the optical lens actuator devices using MEMS technology and may be particularly useful for further integration of the optical head for high capacity and high-density data storage systems.

5. Acknowledgment: The authors gratefully acknowledge M. Glatthaar of the Fraunhofer-Institute for Solar Energy Systems (ISE) for performing the grinding process. The authors also thank the members of the Micro-optics group for valuable discussions on fabrication process, and the Tsinghua Visiting Doctoral Students Foundation for financial support.

6 References

[1] Bargiel S., Jia C., Barański M., *et al.*: 'Vertical integration technologies for optical transmissive 3-D microscanner based on glass microlenses', *Proc. Eng.*, 2012, **47**, pp. 1133–1136

[2] Yoo S., Ha J.G., Jin J.Y., Ji C.H., Kim Y.K.: 'Monolithically integrated glass microlens scanner using a thermal reflow process', *J. Micromech. Microeng.*, 2013, **23**, p. 065012

[3] Wu M.: 'Micromachining for optical and optoelectronic systems', *Proc. IEEE*, 1997, **85**, (11), pp. 1833–1856

[4] Hane K.: 'MEMS technologies for optical storage application'. Proc. Int. Symp. Optical Memory, The Japan Society of Applied Physics, Nagasaki, Japan, 2009, pp. 14–15

[5] Wu M., Hsiao S., Peng C., Fang W.: 'Development of tracking and focusing micro actuators for dual-stage optical pick-up head', *J. Opt. A, Pure Appl. Opt.*, 2006, **8**, pp. S323–S329

[6] Kim S., Park J., Park G., *et al.*: 'An optical flying head assembly for a small-form-factor plastic disk in PCMCIA-like drive', *Jpn. J. Appl. Phys.*, 2004, **43**, pp. 4752–4758

[7] Cheng H., Hsiao S., Wu M., Fang W.: 'Integrated tracking and focusing systems of MEMS optical head head', *IEEE Trans. Magn.*, 2007, **43**, pp. 805–807

[8] Li P., Sasaki T., Pan L., Hane K.: 'Comb-drive tracking and focusing lens actuators integrated on a silicon-on-insulator wafer', *Opt. Express*, 2012, **20**, pp. 627–634

[9] Li P., Pan L., Zappe H.: 'Microlens actuator and polymer objective lens for optical pickup'. Proc. SPIE 8782, Shanghai, China, 2013, p. 87820W

[10] SAM 42 datasheet. Available at http://www.inseto.co.uk/products/amadynesam42.htm

[11] Li P., Pan L., Zappe H.: 'Compact 3-axis actuator for positioning a polymer microlens in an optical pickup', *J. Microelectromechan. Syst.* 2013 (accepted, DOI: 10.1109/JMEMS.2013.2262599)

[12] Blu-ray Disc Association. White Paper Blu-ray Disc Format. 1.A Physical Format Specifications for BD-RE. 3rd Edition, Oct. 2010. Available at http://www.blu-raydisc.com/Assets/Downloadablefile/BD-RE_physical_format_specifications-18325.pdf