Maskless Lithography Based on Digital Micro-Mirror Device (DMD) with Double Sided Microlens and Spatial Filter Array

Article · December 2017

DOI: 10.12783/dtetr/ameme2017/16261

Dinh Duc Hanh

National Cheng Kung University

2017 2nd International Conference on Applied Mechanics, Electronics and Mechatronics Engineering (AMEME 2017)
ISBN: 978-1-60595-497-4

Maskless Lithography Based on Digital Micro-Mirror Device (DMD) with Double Sided Microlens and Spatial Filter Array

Duc-Hanh DINH, Hung-Liang CHIEN and Yung-Chun LEE*

Department of Mechanical Engineering, National Cheng Kung University, Tainan, Taiwan

*Corresponding author

Keywords: Maskless lithography, Microlens array, Excimer laser micromachining, UV-LED.

Abstract. A ultra-violet (UV) maskless lithography system is developed for arbitrary UV patterning. The system consists of an UV illumination system, a digital micro-mirror device (DMD), a projection system, and a double-sided microlens and spatial filter array (D-MSFA). The DMD acts as a virtual mask for generating arbitrary patterns by individually turning on or off of each micro-mirror. The projection lens projects the image of DMD onto the D-MSFA, which consists subsquently the fisrt microlens array (MLA_1), the pinholes array, and the second microlens array (MLA_2). The MLA_1 focus the light from DMD to its corresponding pinhole, and the MLA_2 projects the image of pinhole array onto a substrate to form a point array of UV light. The profiles of microlenses are designed optimized to chieve smallest focused spot size. A method has been developed to fabricate the D-MSFA and to ensure high microlens profile accuracy and excellent alignment between microlens arrays and pinhole array. The obatined UV spot sizze is 10 μm measured at FHMW level, and the system can generate arbitrary patterns with a minimum linewidth of 5.2 μm.

Introduction

Photolithography is a key technology in semiconductor industry, and there are a wide range applications require high-quality lithography such as micro-electromechanical systems, microfluidics, micro-optics elements. Conventional lithography technologies are based on transferring image from a photomask to a photoresist (PR) layer. However, the cost of mask fabrication is very high and therefore becomes the bottle-neck of microfabrication technologies [1]. To eliminate the photomask mask and reduce the running cost, maskless lithography based on digital micro-mirror device (DMD) has been emerging in recent years. It uses "binary" mirror pixels to achieve arbitrary patterns [2], however the feature size is just around 50 μm. DMD can also generate grayscale mask patterns through computer control, and has been used for fabricating 2D/3D micro structures [3-4]. Yang et al [5] used a mercury arc lamp, a DMD, an integrated microlens/spatial-filter array (MLSFA), and some projection lenses to achieve maskless patterning with a feature size down to 1.5 μm. However, the above mentioned maskless lithography systems typically consist of a complicated de-magnifying and expensive projection lens systems, which results in significant UV energy lost and lower system throughput.

To overcome these issues, instead of using complicated projection lens system, we propose the use of a double-sided microlens and spatial filter array (D-MSFA) for maskless lithography. The maskless lithography system based on a DMD and a double-sided microlens and spatial filter array is illustrated in Fig. 1(a). The system consists of an UV-LED illumination system, a DMD, an image projection lens, and a D-MSFA. The image projection lens project the UV light reflected by the micro-mirrors of the DMD on to the surface of their corresponding microlenses. The D-MSFA is schematically shown in Fig. 1(b). It basically has three components, the first microlens array (MLA_1), the second microlens array (MLA_2) and the pinhole array which is sandwiched in between the two microlens arrays. The first microlens array focuses light onto its corresponding pinhole. Pinholes work as spatial filters, which ensure the circular shape and uniform spot size are obtained at the focal plan of MLA_2. The MLA_2 then projects the pinhole image onto the substrate surface.

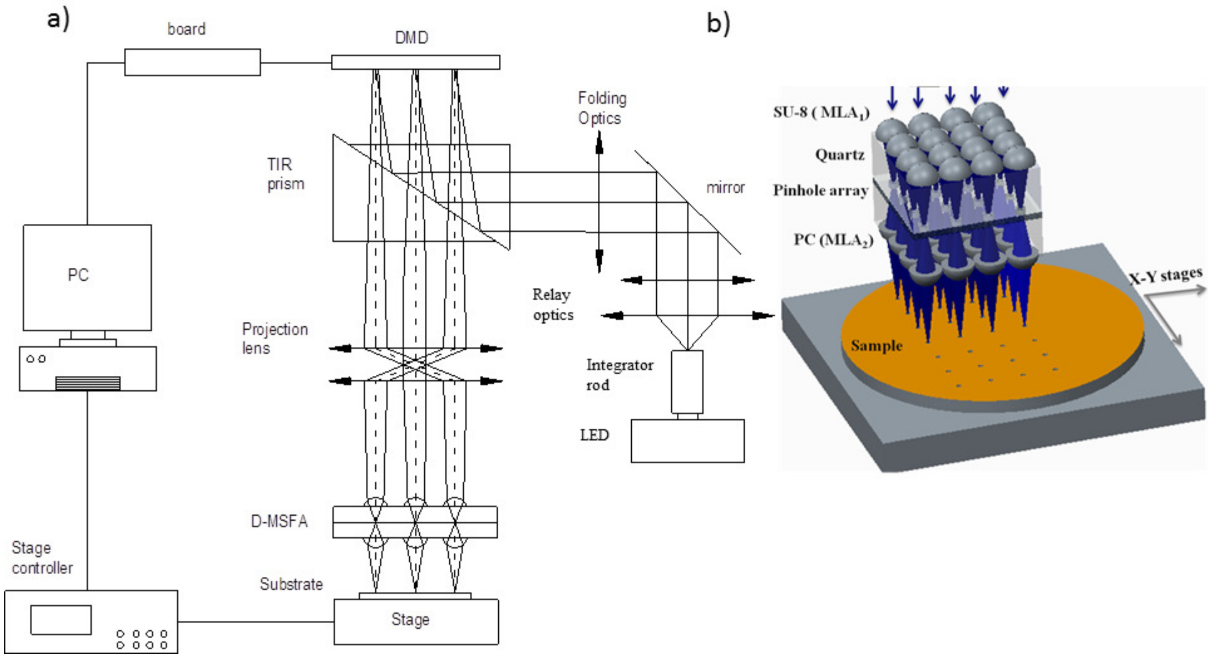

Figure 1. (a) Schematic of the maskless lithography system and (b) illustration of D-MSFA.

Design and Simulation

As showed in Fig. 1(b), the D-MSFA consists of two microlens arrays for UV light focusing and imaging. In order to achieve highest performance and UVimage resolution, optical system design software, Zemax Optics Studio (Zemax LLC, Kirkland, WA, USA), is employed to design and optimize the lens surface profiles of both lens arrays. A layer of 16 μm thickness of negative PR SU8 3015 (MicroChem Corp., MA, USA) is firs spin-coated on the 250 μm thickness of quartz substrate surface to fabricate MLA1. A polycarbonate (PC) substrate of thickness 250 μm is chosen to fabricate the MLA2 and it is connected at the periphery of the pinhole array area by optically cleared adhesive (OCA) tape of thickness 30 μm. The focal plane of MLA_2 is chosen as 180 μm, and the pinhole diameter is 7 μm. The aperture size of microlens is 110x110 μm^2, which corresponds to an array of 8x8 DMD micro-mirrors. Figure 2 illustrates the arrangement of D-MSFA in Zemax software.

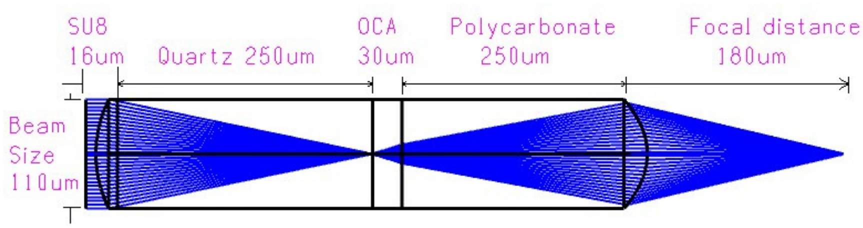

Figure 2. Optics Studio simulation of D-MSFA and microlens profile for focusing the UV light into arrayed spots.

Polynomial functions have been chosen for optimizing the aspheric microlens profiles because they are compatible with the biaxial laser dragging method in excimer laser micromachining [6], which are used to fabricate both MLA_1 and MLA_2. The polynomial function has four coefficients as shown in Eq. (1).

$$Z(x,y) = \alpha_1 x^2 + \alpha_2 x^4 + \alpha_3 x^6 + \alpha_4 x^8 + \alpha_1 y^2 + \alpha_2 y^4 + \alpha_3 y^6 + \alpha_4 y^8, \quad (1)$$

where $Z(x, y)$ is the sag height of lens, and α_1 to α_4 are coefficients for both x-axis and y-axis profiles. After numerical simulation in OpticStudio, optimized values of those coefficients are obtained for MLA_1 and MLA_2 and are listed in Table 1.

Table 1. Coefficients of polynomial function for the surface of MLA_1 and MLA_2.

Coefficients	*x/y* profile			
	α_1	α_2	α_3	α_4
MLA_1	4.2432	7.1907	1248.9386	260274.2731
MLA_2	-7.8286	-1.6695	-506.1937	-162191.0065

The normalized intensity distribution of the focused spot was computed by Zemax software. The focused spot size is around 1.15 µm at 13.5 % ($1/e^2$) of normalized intensity value as shown in Fig. 3(a). However, the simulation given above is done by assuming that the MLA_1 perfectly focused incoming light into a point, which is not real in practice. Therefore, another simulation, which considerate pinholes as objects of the MLA_2 and MLA_2 project image of these pinholes onto the substrate, was done in non-sequential mode of the Zemax software. The intensity distribution is shown in Fig. 3(b), and the focused spot size is around 5.5 µm at 13.5% ($1/e^2$) of normalized intensity value.

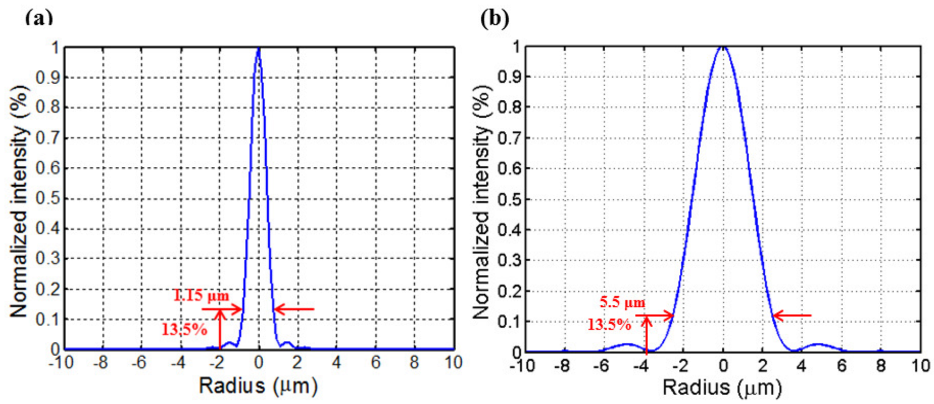

Figure 3. Intensity distributions of focused spot simulated in (a) sequential mode and (b) non-sequential mode of Zemax.

D-MSFA Fabrication

To Fabricate D-MSFA, the pinholes array is first fabricated on a quartz substrate by conventional lithography process. After that, SU 8 photoresist is spin-coated, hot baked, and UV light exposed on the other side of the quartz substrate for fabricating MLA_1. Finally, a PC plate of 250 µm in thickness is chosen as theMLA_2 material and is attached to the pinhole array of the quartz surface by OCA tape.

Both microlens arrays, MLA_1 and MLA_2, are fabricated using excimer laser biaxial dragging method. To fabricate the MLA_1, the optimized profile from Table 1 is converted to the contour pattern in the photomask used for *x*- and *y*-axis laser dragging. After fabrication MLA_1, the same process is applied to fabricate the MLA_2 on the PC surface. The profile accuracy of fabricated microlens was measured by a laser scanning confocal microscope. The difference between the designed lens profile and the actual machined one, that is, the machining error, is displayed in contour plots in Fig. 4(a) and 4(b) for MLA_1 and MLA_2, respectively.

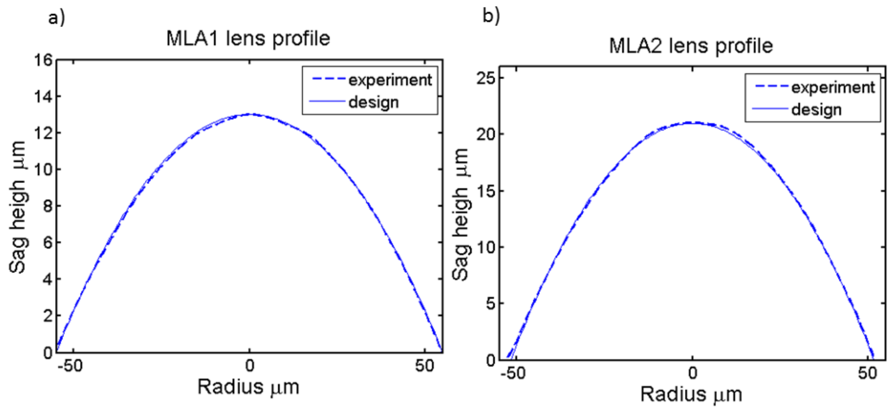

Figure 4. Machining microlens profile of (a) MLA_1 and (b) MLA_2.

The alignement between two microlens arrays and pinhole array are critical. The alignment is based on pinhole array which is clearly visible by the CCD camera. Firstly, a photomask of *x*-profile is projected by some laser pulses on SU 8 surface, the misalignment between photomask image and pinhole array can be measured by CCD camera and corrected by adjusting the stage position. After confirming the perfect position, *x*-profile photomask is used for dragging along *x*-direction. The sample is then rotated 90^o for alignment and dragging along *y*-direction to finish fabrication MLA_1. The sample is then fliped and the same process is applied to fabricated MLA_2. The misalignment between MLA_1 and MLA_2 with pinhole array are showed in Fig. 5(a) and 5(b), respectively, and the misalignment is in the range of 1.5 µm.

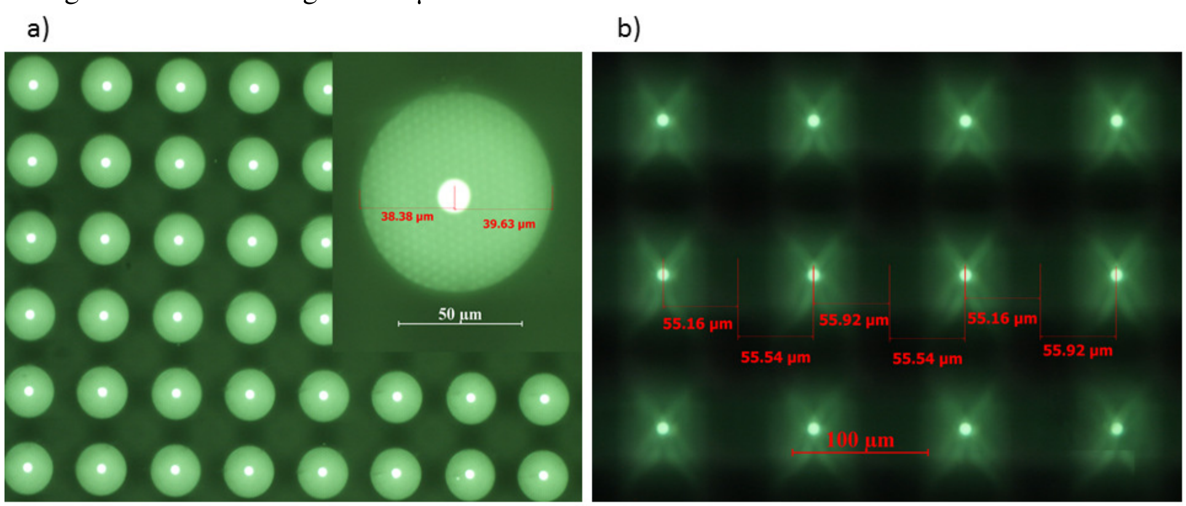

Figure 5. The misalignment between (a) MLA_1 and (b) MLA_2 with pinhole array.

After fabrication, the UV spot size focused by MLA_2 is measure by an optical microscope. The focused spot array and intensity distribution is showed in Fig. 6. It shows the focus spot size is around 10 µm at full-width at half magnitude (FWHM) in light intensity level.

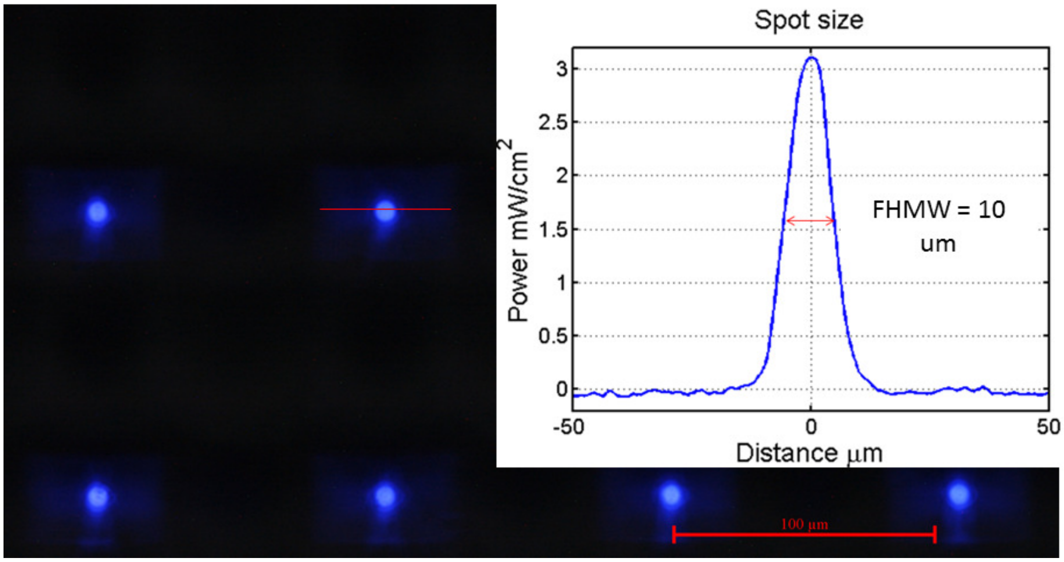

Figure 6. Experimentally measured focused spots.

Experimental Results

Since the microlens array focuses incoming light into an array of UV light spots, they are disconnected. Therefore, a spot array scanning technique is used to overlay the array of spots to link lines and other patterns by flipping the DMD micromirrors while moving the substrate on a stage [7]. To evaluate the resolution of the system, positive photoresist S1813 (Shipley Company, USA) was spin-coated on a 2” wafer for UV expose. The lithography result is shown in Fig. 7 which shows vertical lines with a smallest linewidth of 5.2 µm.

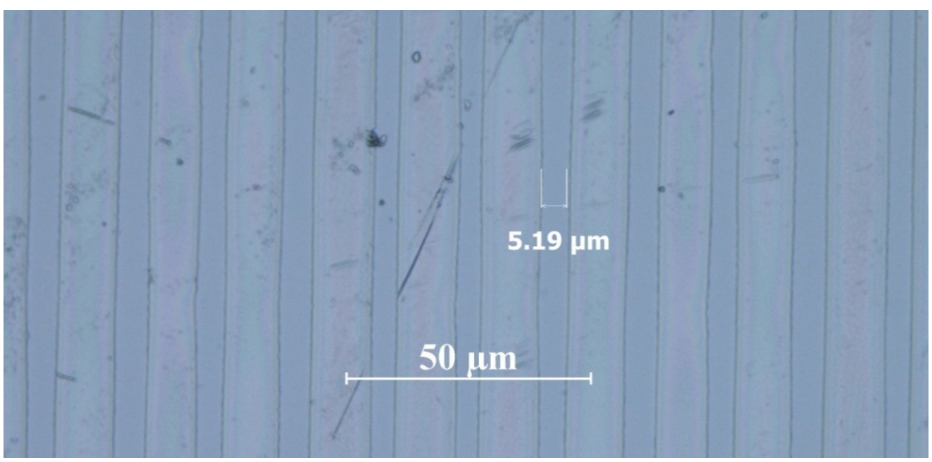

Figure 7. Image of vertical lines patter exposed by developed maskless lithography system.

To demonstrate the flexibility of the developed maskless lithography system, a pattern of a printed circuit board (PCB) has been written. Figures 8(a) and 8(b) show the original image of the PCB and fabricated PCB pattern on wafer respectively.

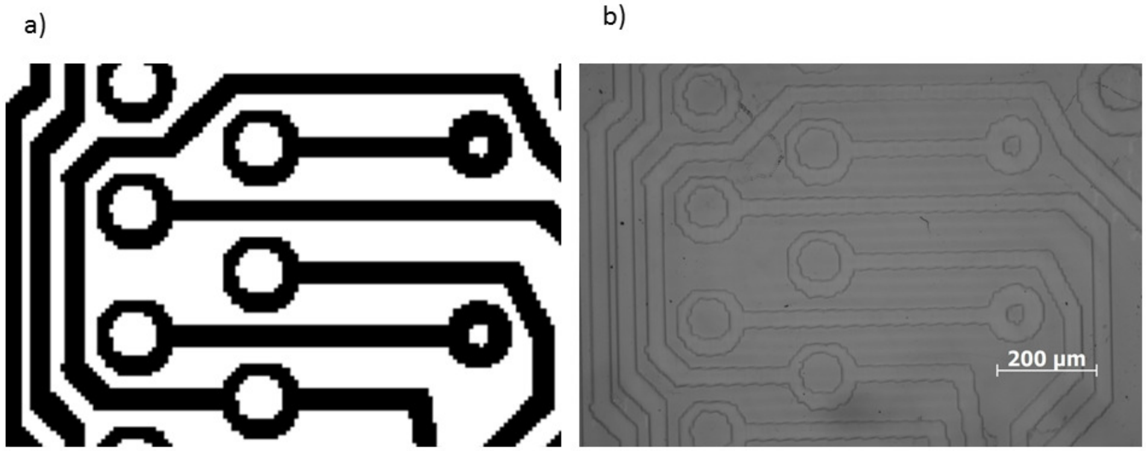

Figure 8. (a) Original image and (b) fabricated PCB pattern.

Conclusion

This work proposes a new approach for maskless lithography based on digital micromirror device and a double sided microlens and spatial filter array. This new type of D-MSFA consists of a pinholes array sandwiched in between two microlens arrays. One microlens array focuses incident UV light into pinholes while the other one image these illuminated pinholes into an array of focused UV light spots for direct patterning on PR layers. A method is developed to fabricate D-MSFA with high profile and alignment accuracy. By applying the spots scanning technique, combines with the flipping of DMD micromirrors at high speed along with the moving of substrate on a translation stage, the system can generate arbitrary patterns with a minimum line width is about 5.2 µm. Since one microlens array corresponds to an array of 8x8 DMD mirrors, by instantaneously changing the number of mirrors corresponding to each microlens, one can also fabricate 3D micro-structures easily and conveniently.

References

[1] T. Ito and S. Okazaki, Pushing the limits of lithography, Nature 406 (6799), 1027–1031 (2000). [doi:10.1038/35023233].

[2] Eric J. Hansotte, Edward C. Carignan and W. Dan Meisburger, High speed maskless lithography of printed circuit boards using digital micromirrors, Proc. SPIE 7932, 793207 (2011) [doi: 10.1117/12.875599].

[3] Chi Liu, Xiaowei Guo, Fuhua Gao, Boliang Luo, Xi Duan, Jinglei Du, Chuankai Qiu, Imaging simulation of maskless lithography using a DMD, Proc. SPIE 5645, Advanced Microlithography Technologies (2005) [doi: 10.1117/12.577352].

[4] Ding X Y, Ren Y X and Lu R D, Maskless microscopic lithography through shaping ultra violet laser with digital micro-mirrors device, Optics and Photonics Journal, Vol. 3 No. 2B, 2013, pp. 227-231 [doi: 10.4236/opj.2013.32B053].

[5] Kin Fong Chan, Zhi Quian Feng, Ren Yang, Akihito, Ishikawa, Wen Hui Mei, High-Resolution Maskless Lithography, Journal of Micro/Nanolithography, MEMS, and MOEMS 2(4), (2003).

[6] Wang S Y, Simulated enhancement of the axial symmetry of a micro lens array with a modified mask by using an excimer laser dragging process, J. Micromech. Microeng. 16, 631–9 (2006)

[7] W. Mei, Point array rnaskless lithography, U.S. Patent No.6, 473, 237 B2 (2002).