A NEW THREE-DIMENSIONAL LITHOGRAPHY USING POLYMER DISPERSED LIQUID CRYSTAL (PDLC) FILMS

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ABSTRACT

In this paper, we have proposed a new three-dimensional (3-D) lithography using polymer dispersed liquid crystal (PDLC) films. The scattering or transmission rate of ultraviolet (UV) rays through the PDLC film can be continuously controlled by varying the applied voltage across its electrodes. Various slopes and profiles of 3-D photoresist microstructures are easily and effectively fabricated by controlling applied voltages and biasing times of the PDLC film during one UV exposure step of the lithography process.

1. INTRODUCTION

Recently, it is very important to fabricate a diversity of 3-D microstructures with an inclined or rounded cross-section as well as a conventionally rectangular one. 3-D microstructures can be fabricated by lithography methods or non-lithography methods. In cases of the lithography methods such as the multi-exposure and single development method[1][2], the inclined UV exposure method[3] and the microstereolithography[4], 3-D microstructures can be fabricated very precisely, but rounded microstructures cannot be simply patterned. On the other hand, in cases of the non-lithography methods such as the thermal reflow for photoresist microlenses[5] and the stressed film bending for microswitches[6] or microshutters[7], various rounded microstructures can be realized. But it is difficult to fabricate complex and various shapes of microstructures or to control their uniformity and reproducibility.

To fabricate rounded microstructures more effectively and uniformly, 3-D diffuser lithography (adding a diffuser sheet on the photomask in the conventional lithography) was introduced[8]. This fabrication method for 3-D microstructures was widely applied to microlens arrays[8][9], stiction-free cantilevers[10], 3-D planar microlens[11], and lift-off with positive photoresist[12]. However, only using the light diffusion property pre-determined by the diffuser sheet imposes restrictions on fabricating various shapes and profiles of photoresist molds.

For the first time, we have introduced a 3-D lithography using PDLC films. PDLC films can be switched between a highly scattering state and a very clear transparent state with varying applied voltages across their indium-tin-oxide (ITO) electrodes[13].

By applying the 3-D lithography using PDLC films, more various and complex shapes and profiles of photoresist patterns than the 3-D diffuser lithography can be easily fabricated because of three major advantages listed below;

(1) Freely controlling the diffusion and transmittance rate of PDLC films with varying the applied voltage

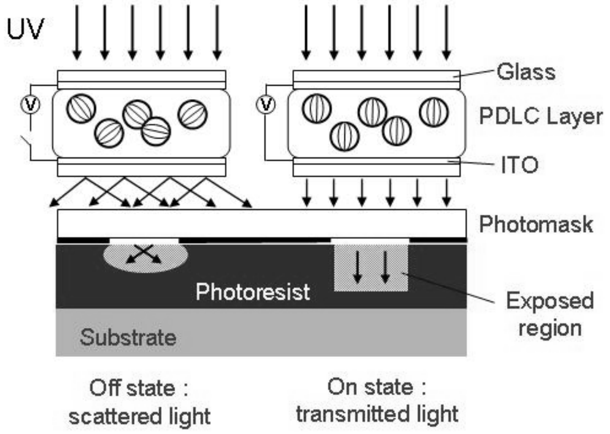
(2) Making up and controlling consecutively more than two cases of each applied voltage and its biasing time during one UV exposure step of the lithography process

(3) Patterning and addressing ITO electrodes of PDLC films

2. PRINCIPLES OF A 3-D LITHOGRAPHY USING PDLC FILMS

Fig. 1 illustrates schematic views of the operating principles of the 3-D lithography using PDLC films. The only difference of the conventional lithography is the insertion of the PDLC film on a photomask to change the UV direction incident to a photoresist layer. At this 3-D lithography process, the photoresist layer coated on the substrate is UV-exposed through the PDLC film and the photomask.

The PDLC film consists of PDLC microdroplets in a polymer network between two ITO coated glass sheets. At no bias voltage, the PDLC droplets are randomly aligned, so incident light is scattered by the droplets. This is a highly scattering state in an off bias. Thick positive photoresist mold is UV-exposed to a circular or an elliptical direction through the PDLC film and the photomask. Therefore, the rounded pattern is obtained. At a high bias voltage, LC molecules align with their long axes along the applied field direction, and the film becomes a highly transmitting state without any scattering. The photoresist mold is UV-exposed to a perpendicular direction through the PDLC film and the photomask. The patterned mold with a conventionally rectangular cross-section is formed. At an intermediate bias voltage, UV ray through the film transmits with scattering. Therefore, by changing the scattering and transmission states of the PDLC film due to its bias voltage, UV directions through the photo-mask can be controlled. Therefore, various slopes and profiles of 3-D photoresist microstructures can be simply attained by controlling its applied voltages during the UV exposure step.



(a) UV light exposure

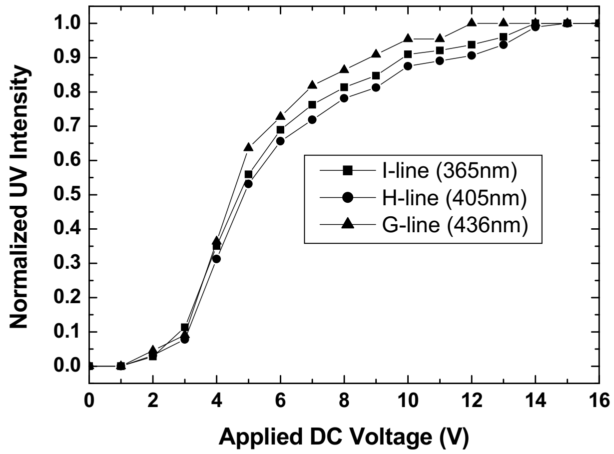
(b) Development

Figure 1: Schematic views of the operating principle of a 3-D lithography using PDLC films

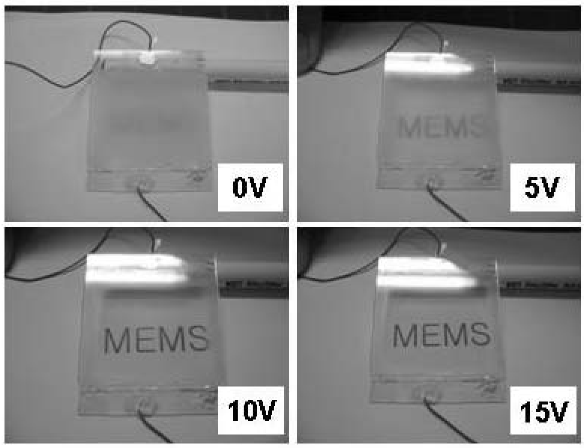
Fig. 2(a) depicts normalized UV intensities of I-line (365nm), H-line (405nm), and G-line (436nm) through a PDLC sample against its applied voltage. The scattering or transmission rate of the PDLC film is determined by the applied voltage across its ITO electrodes. In cases of their UV spectrum, normalized UV intensity curves are analogous. At the bias voltage of 0V, the UV intensity through the PDLC has the minimum transmittance of highly scattering states. However, at the bias voltage more than 15V, the UV intensity has the maximum transmittance value of highly transmitting states without any scattering.

The photographs of characters under a PDLC film against applied voltages are shown in Fig. 2(b). At the bias voltage of 0V, the characters under the PDLC film are not displayed because of its opaque scattering state. As the bias voltage is higher, they are displayed more transparently.

Table 1 describes numerical data of UV transmission intensity of minimum (at 0V) or maximum (at 15V) through the PDLC sample, and without the PDLC about the graph of Fig. 2(a). Over 20% of the UV transmittances through the PDLC film are degraded by two ITO coated glass sheets compared with UV intensities of maximum value and without the PDLC film.



(a) Normalized UV intensity through a PDLC film against applied voltages



(b) Photographs of visible light switching states against applied voltages

Figure 2: Measurements of light transmittance through a PDLC film

Table 1. The numerical data (mW/cm^2) of UV transmission intensity of minimum or maximum through PDLC film, and without PDLC film about Fig. 2(a).

UV type	Minimum through PDLC layer (at 0V)	Maximum through PDLC layer (at 15V)	Without PDLC layer
I-line	4.0	5.8	7.5
H-line	11.0	14.2	17.1
G-line	8.4	10.6	12.7

3. FABRICATION RESULTS

Fig. 3 shows SEM images of photoresist patterns formed by 3-D lithography process using PDLC films with varying the applied voltage. The thickness of AZ9260 photoresist layer on the substrate is about 20µm. The line and space of mask patterns are 30µm and 30µm in width, respectively. The PDLC film is simply located on the photomask, and the DC bias voltage of the PDLC layer is controlled during the exposure step of the lithography. The photoresist layer is exposed to 17.1mW/cm^2 of UV intensity at H-line for 40 seconds. As the bias voltage is larger, the scattering or diffusion rate is lower and the transmission rate is higher. The shapes and profiles of 3-D photoresist patterned molds are continuously regulated by the DC bias voltage applied to the PDLC layer. At the bias voltage of 15V, the rectangular cross-section of photoresist molds is attained, which is similar to the conventional lithography process.

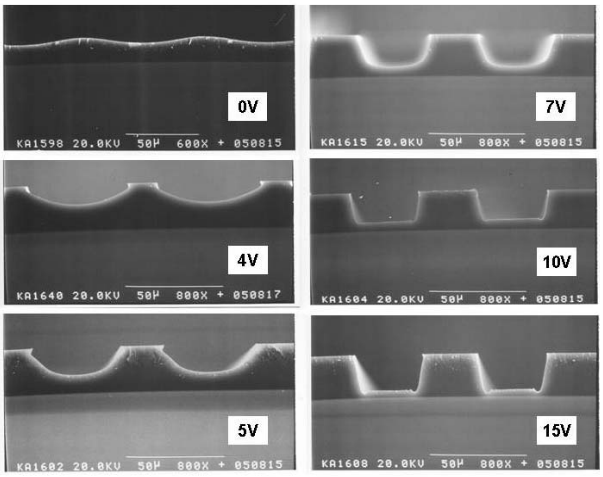
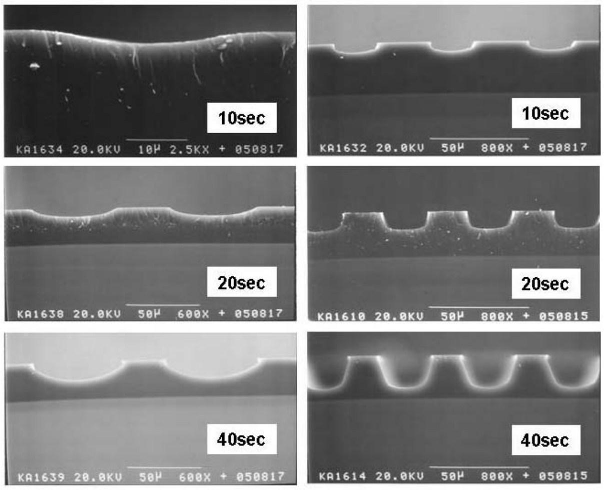


Figure 3: SEM images of the patterned photoresist cross-sections with varying DC bias voltage (H-Line 17.1 mW/cm^2, exposure time 40 seconds).

Fig. 4 illustrates SEM images of patterned photoresist cross-sections with varying UV exposure time at each bias voltage of 4V and 7V of the PDLC film. As the exposure time of UV through the PDLC and the photomask is longer, the slope of patterned photoresist molds is steeper.

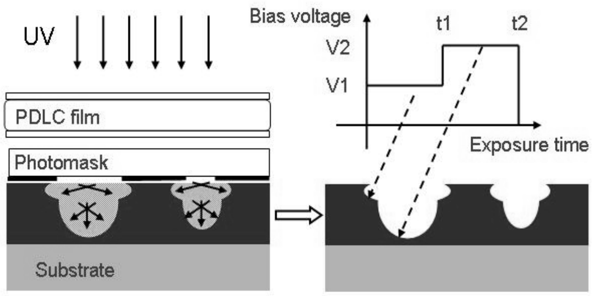
Therefore, by mixing the bias voltage to the PDLC film and its UV exposure time, a lot of various shapes or slopes of photoresists can be patterned from these fabrication results.

In addition, by applying the 3-D lithography using PDLC films, more complex 3-D microstructures can be fabricated at only one exposure process. Consecutively mixing multiple bias voltages and these exposure times as illustrated in Fig. 5(a), multiple different rounded cross-sections at once are patterned. The SEM images of 3-D photoresist molds with two different rounded cross-sections are shown in Fig. 5(b).

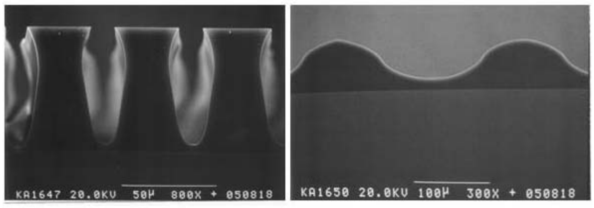


(a) DC bias 4V (b) DC bias 7V

Figure 4: SEM images of the patterned photoresist cross-sections with varying UV exposure time at each bias voltage (H-Line 17.1 mW/cm^2).



(a) Principle and process flow



0V 80sec and 7V 80sec **0V 120sec and 10V 10sec**

(b) SEM images of patterned photoresist molds

Figure 5: Mixing and controlling multiple bias voltages and exposure times during one exposure process

Besides, ITO electrodes of the PDLC film can be patterned and individually addressed. By applying different bias voltages to each patterned electrodes, partially different incidence directions of UV light through the PDLC can be designed. Therefore, 3-D microstructures of partially different shapes or profiles can be fabricated by only one exposure process as shown in Fig. 6.

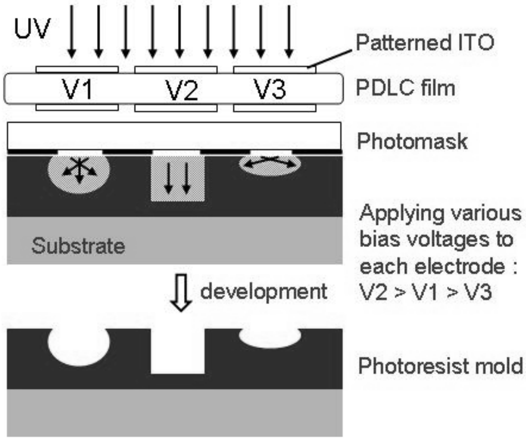


Figure 6: Addressing various bias voltage to each patterned electrode during one exposure process

4. CONCLUSIONS

In this paper, we have introduced a new 3-D lithography using PDLC films and its potential applications. We have successfully fabricated various shapes and profiles of 3-D photoresist molds from rounded cross-sections to rectangular cross-sections by controlling the bias voltages and times of the PDLC film. This fabrication method for 3-D microstructures can be utilized wide applications such as microlens array, microfludic channels, and microswitches.

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