Fabrication of 3-D Periodic Photoresist Microstructures for High Fill-Factor Microlens Array Replication

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Microlens arrays (MLAs) have been used in many application fields of optical communication and display system. For a diversity of applications such as these sensors and microsystems, various shapes of high fill-factor MLAs are required. The shape-controllable fabrication methods of three-dimensional (3-D) periodic photoresist microstructures for MLA replications have been researched, including UV proximity printing[1], thermal photoresist reflow[2-3] and 3-D diffuser lithography[4]. In this work, more effective 3-D shape-controllable, thick UV lithography methods for 3-D periodic photoresist patterns are proposed and demonstrated. Then, high fill-factor MLAs are fabricated using plastic replication from these 3-D photoresist patterns.

Fig. 1 illustrates the proposed fabrication method for shape-controlled, 3-D periodic photoresist microstructures and high fill-factor MLAs. The first step is to make high-density 3-D periodic photoresist microstructures by the shape-controllable 3-D lithography using polymer dispersed liquid crystal (PDLC) films [5]. Thick photoresist molds are exposed to UV rays through the PDLC film on the photomask. The directions of UV diffusing rays through the PDLC film can be easily controlled by its bias voltages. Consequently, various shapes of high density 3-D photoresist patterns can be effectively fabricated by modulating UV diffusing rates through the PDLC film. Then, a liquid polydimethylsiloxane (PDMS) is cast on the photoresist patterns and peeled off from the photoresist molds after it is cured. As a result, the 3-D shapes of MLAs are simply regulated by varying UV diffusing rates base on the bias voltage of PDLC films. Fig. 2 illustrates the fabrication process for shape-controlled, 3-D periodic photoresist microstructures and high fill-factor MLAs with varying clear/dark pattern widths (exposed width/spacing) of photomask. As the spacing between adjacent patterns is narrower, the exposed regions are getting near. The spacing is enough small, therefore, the adjacent exposed regions are merged together, and high fill-factor 3-D photoresist patterns are obtained. The profiles of photoresist patterns and replicated microlens arrays can be effectively controlled by these overlapping distances of exposed regions.

Fig. 3 shows fabrication results of 3-D periodic photoresist patterns and microlens arrays with varying diffusing rates, which is controlled by the bias voltages of PDLC film at the same dose and photomask patterns. AZ9260 thick photoresist and the photomask with hexagonal pattern arrays were used. The increase of bias voltages reduces the UV diffusing rate. It raises vertical depths of 3-D photoresists and heights of replicated microlens arrays. Consequently, the shapes of MLAs can be controlled by the UV diffusing characteristics. Fig. 4 shows fabrication results of 3-D periodic photoresist patterns with varying overlapping distances of exposed regions, which is controlled by clear/dark pattern widths of photomask pattens at the same bias voltage and exposure dose. As the spacing between adjacent patterns is narrower, so the exposed regions increasingly overlap. Consequently, the slopes of 3-D photoresist patterns and MLAs become gentler.

We have demonstrated the shape-controllable fabrication methods of high-density 3-D periodic photoresist microstructures for high fill-factor MLAs, which is based on the shape-controllable 3-D UV lithography using PDLC films and PDMS replication method. By controlling the diffusing characteristics of PDLC film and photomask patterns, various profiles and shapes of 3-D periodic photoresist patterns and replicated MLAs can be simply and effectively fabricated.

References

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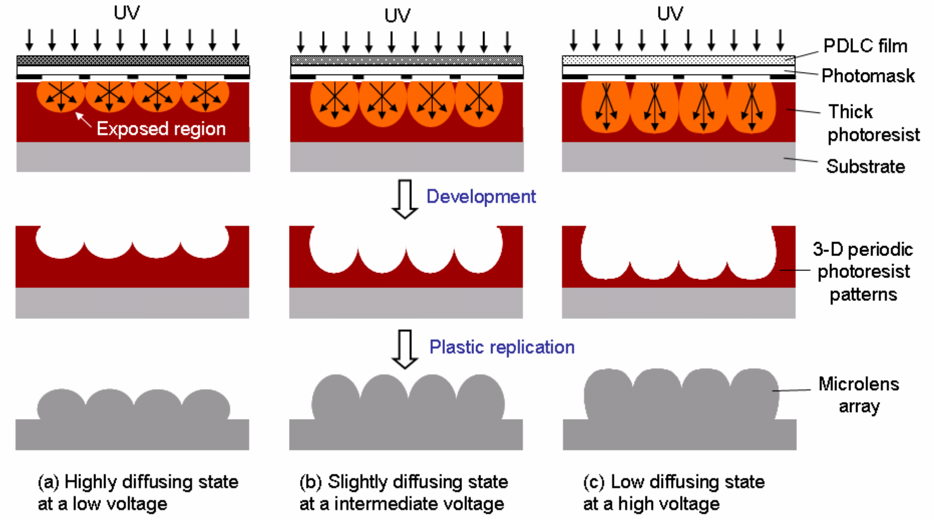
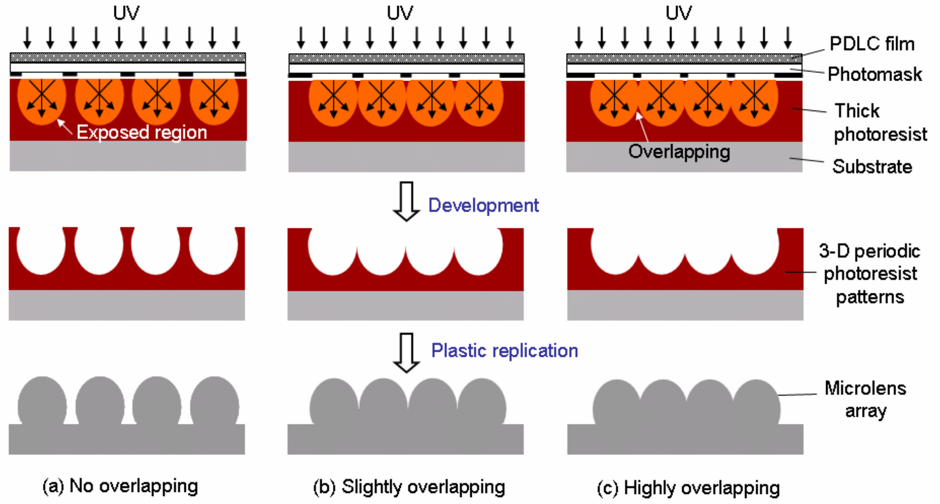


(a) Highly diffusing state at a low voltage

(b) Slightly diffusing state at a intermediate voltage

(c) Low diffusing state at a high voltage

Fig. 1. Fabrication process of 3-D periodic photoresist microstructures and microlens arrays with varing UV diffusing rates in the shape-controllable 3-D UV lithography using PDLC films

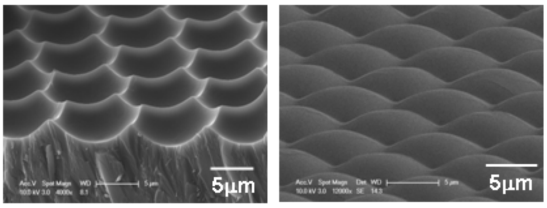


(a) No overlapping

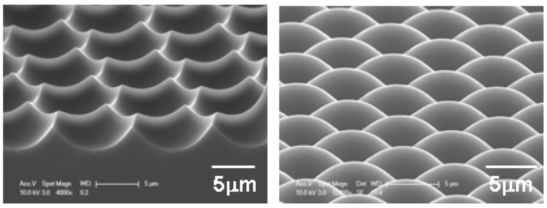
(b) Slightly overlapping

(c) Highly overlapping

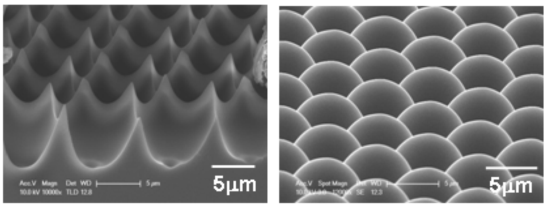
Fig. 2. Fabrication process of 3-D periodic photoresist microstructures and microlens arrays with varing overlapping distances of exposed regions in the shape-controllable 3-D UV lithography using PDLC films



(a) Highly diffusing state at a low voltage

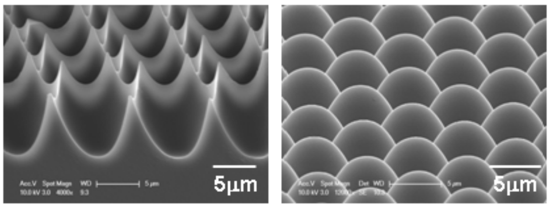


(b) Slightly diffusing state at a intermediate voltage

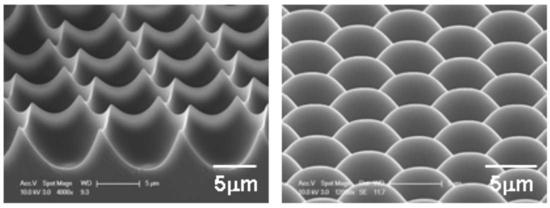


(c) Low diffusing state at a high voltage

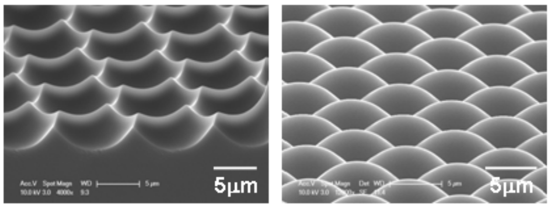
Fig. 3. SEM images of 3-D photoresist patterns and MLAs with varying UV diffusing rates



(a) Low overlapping



(b) Slightly overlapping



(c) Highly overlapping

Fig. 4. SEM images of 3-D photoresist patterns and MLAs with varying overlapping distances of patterns