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A study on the fabrication of microlens array based on the volume shrinkage of the photoresist solution during evaporation

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ABSTRACT

This study investigates the fabrication process for microlens array using the solution of photoresist and solvent. A silicon substrate, where micro holes have been made in advance by deep reactive ion etch process, is coated with the solution of the photoresist and solvent. And the substrate is heated so that the solvent evaporates and the volume of the solution shrinks. Due to the surface tension of the liquid, the photoresist in the holes will have concave meniscus after the evaporation of the solvent, which can be used as a mold for the microlens arrays. The geometry of the microlens can be adjusted by changing the concentration of the solution, which is related to the volume shrinkage ratio during the evaporation. Experiments have shown that the microlenses with various heights can be fabricated out of the same substrate. This study is expected to provide a new fabrication method which enables great flexibility of designing microlens array for various optical applications.

1. Introduction

Recent developments of the microfabrication techniques have enabled a lot of optical devices and systems in micro scale. The optical properties of the micro devices, as well as the mechanical and chemical properties, can be improved by the microfabrication process significantly [1]. Several studies have been conducted on the design, analysis [2] and modeling [3] of the microlens in order to evaluate and optimize the optical properties. Accordingly, a lot of researchers have focused on the fabrication processes concerned. However, it is not easy to obtain the micro devices which are suitable for the optical applications, using the conventional fabrication techniques such as wet and dry etch. Therefore, many researches have been conducted on the alternative or improved fabrication methods to make the micro optical devices, such as microlens arrays. Laser machining process may be one of the promising methods to fabricate the micro lens because it has good axial symmetry [4,5]. Another candidate is the ultraviolet (UV) proximity printing, which uses the diffraction effect of the ultraviolet (UV) light on the photoresist layer [6,7]. And many studies have been focused on the reflow method to fabricate curved surfaces or microlenses. Since the melt resist tends to form a hemisphere to minimize its surface energy, the reflow method is widely used for the slopes of the MEMS switches [8] and the microlens arrays [9–13]. With this method, the microlenses with long focal length, which is a few millimeters, have been made on the photoresist layer [10]. Other researchers have fabricated the microlenses in dual layers [11] or in multiple steps [12], which have complicated geometry. The droplets of the melt resist are difficult to control and they may be merged each other in the reflow process, which is the bottle neck of this method. Therefore, the behavior of the liquid droplets on the solid surface [13,14] needs to be considered carefully for the reflow method. Nonetheless, some researchers have fabricated the microlens array with quite small pitch (2.8 μm), while there is no dead space between the microlenses [15]. In addition to the reflow method, a lot of studies have been performed in order to utilize the liquid layers or droplets as the microlenses. The electrowetting principle is one of the promising methods to fabricate the microlens array because the shape of the lenses can be modulated electrically [16–18]. Similarly, the pyroelectric effect has been also investigated as the fabrication method for the microlens [19–21]. Recently, the dielectrophoresis has been studied as a method to fabricate the tunable microlenses [22,23]. And some researchers have investigated the forming method, which is based on the capillarity of the liquid polymer in the micro molds [24,25].

Since most of the microlenses are fabricated on the photoresist layer, the coating process is another issue. The photoresist can be coated with the spray [26] or dispensing process [27] in order to

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enhance the uniformity. However, the curved surfaces could be obtained with the spin coating process by making use of the surface tension of liquid photoresist, when it is coated on the micro structures [28]. With this principle, microlenses have been fabricated also by coating liquid polymer layer (poly(methyl methacrylate)) on the microstructures of solid polymer (polycarbonate) substrates [29,30]. In this study, the shape of the microlens has been obtained from the concave meniscus of the liquid photoresist. This meniscus is made when the round holes in microscale are filled with photoresist solution and then the volume of the solution shrinks due to the evaporation. After the photoresist is solidified with baking, microlenses can be fabricated by the replication, or molding, on the surfaces of the photoresist. The solutions with various concentrations have been used in order to change the volume shrinkage ratio, by which the height of the microlenses can be controlled. And it has been also investigated that the geometry of the microlenses are influenced by the depth and diameter of the holes.

2. Fabrication process and experiments

The fabrication and experimental processes are illustrated in Fig. 1. The circular micro holes are made on a silicon wafer with deep reactive ion etch (DRIE) process (Fig. 1(a)). The micro holes have various diameters from 10 to 20 μm and two kinds of substrates have been prepared according to the etching depth, which are 8 and 16 μm (Table 1). Then, the surface of the wafer is coated with the solution of photoresist (P4620, AZ Electronic Materials PLC.) and solvent (AZ-1500K, AZ Electronic Materials PLC.), by which the holes are filled with the solution. Since the volume shrinkage is expected to vary according to the photoresist content, the tests have been done with the solutions with different concentrations, which are 70, 80 and 90 wt% of photoresist. And a doctor blade is used to enhance the flatness and uniformity of the surface (Fig. 1(b)). Then the substrate is soft baked on a hot plate at 80 °C for 5 min in order to evaporate the solvent and to solidify the remaining photoresist. During the baking process, the volume of the solution is decreased and the surfaces on the circular holes are deformed as seen in Fig. 1(c). Concave meniscus is made because of the surface tension of the liquid until all of the solvent is evaporated and the surface is solidified. This substrate may be used as a mold for microlens array so it is replicated with polydimethylsiloxane (PDMS) and polymer replica (RepliSet-F5, Struers) as seen in Fig. 1(d).

3. Measurements and analysis

Fig. 2 shows the microlens arrays on the PDMS layers with various diameters and concentrations of the solution. While the diameter of the lens is decided by that of the micro hole, the height depends on the concentration of the solution. The results show that the microlenses become taller as the concentration of the photoresist decreases, and vice versa. Thus, the microlenses are close to spherical shapes for high concentration (a, b, c and d) but they become aspheric for low concentration (i, j, k and l). Another major parameter is the depth of the holes. If the depth of the micro hole is deeper, the volume shrinkage of the solution will be larger even though the concentration is the same. Fig. 3 shows the microlens arrays which have been fabricated using the substrate with 16 μm deep holes. As seen in the figure, the heights

Table 1
Specifications of the micro holes on the silicon substrate.

Diameters of micro holes (μm)	10	12	15	20
Pitches (μm)	15	17	20	25
Etch depth (μm)	8, 16			

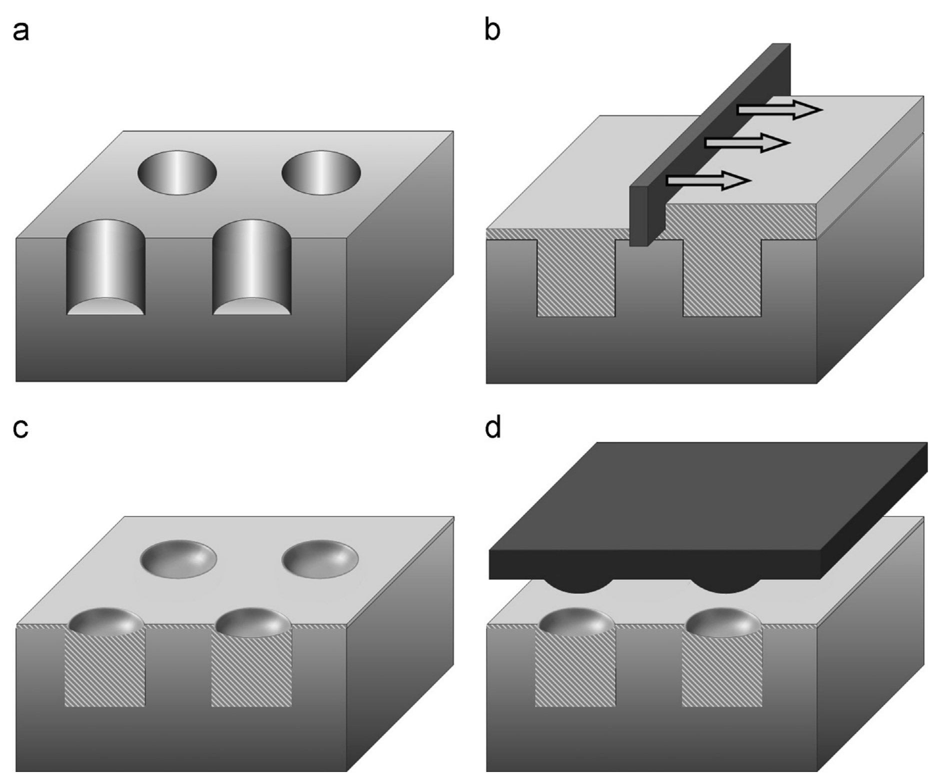

Fig. 1. Schematic of the fabrication process. (a) Preparation of the micro holes on the silicon substrate with DRIE (b) coating of the photoresist solution with doctor blade (c) formation of the round concave meniscus by baking and evaporation of the solution (d) molding of the microlens array.