미세입자의 자기조합기술을 이용한 미세렌즈 배열의 제조

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Microlens Array from Self-Assembly of Microspheres

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Since the late 1980s there has been an upsurge of interest in microlenses as the benefits of photonics over electronics are realized. Development in this area has been helped by the fabrication technologies originally devised for silicon wafers but which have been adapted to produce microlens arrays.[1] In turn, as the quality of the microlenses has improved because of improvements in the manufacturing technologies, new applications have been found. Therefore, the number of their applications has grown so large it is no more realistic to provide a comprehensive list.[2] Typical examples among them include beam homogenizing and fan-out elements, image transfer as used in fax machines and photocopiers, integral photography where full color three-dimensional(3D) pictures are formed. Recently, microlens array have been widely used as coupling components for matching light into the cores of optical fibres, concentrating light into active areas of CCD arrays, fan out in optical computing, and collimation of light from laser diodes.[3,4] In parallel with these new developments the ability to make large arrays of very small lenses has rekindled interest in Lippmanns integral photography and Gabors superlenses.[5]

A variety of technologies have been tried for significant improving quality of microlens array. Most microlens manufacturers have now settled for lithographic, ion exchange or diamond point turning methods to form the lenses.[6-11] However, over a limited range of diameters and focal ratios, these lithography-based techniques have particular disadvantages, although all are capable of producing very good quality diffraction limited lenses. Therefore, other technologies such as ion beam etching are being used to correct the original lens profile to form aspheric lenses and hence increase the performance of the microlenses. Furthermore, applicable materials to this method is limited to photoresist. To address these problems, soft-lithography-based self-assembly approaches have been recently proposed as alternative way by several research groups.[12-15] Whitesides et al. used selective dewetting of liquid prepolymers on a surface printed with self-assembled monolayers to fabricate arrayed microlenses of an organic polymer.[14] Due to the low viscosity of the prepolymer required by this process, the

microlenses fabricated using this method used to have relatively small curvatures and thus short focal lengths. It is also non-trivial to precisely control the optical parameters of the microlenses generated using this method. In the second mothod, Hayashi et al, self-assembled polystyrene beads into two-dimensional (2D) lattices on the glass substrates, and demondstated their use as arrays of microlenses in imaging.[15] This method, however, could only provide one specific patterned array: that is hexagonal-close-packed 2D lattice with a 6-fold symmetry. In addition, spherical microlenses are not good enough for high quality images. In more recent report by Xia et al., a self-assembly approach based on physical confinement and templating have proposed.[13] They showed that optical parameters of the arrayed microlenses and their fill factors and patterns could be precisely controlled. However, it is non-trivial to fabricate microlens array on irregular substrates.

Here, we report self-assembly approach to microlens array on complex substrates with help of soft lithographic technique. Our strategy is that initial 2D colloidal patterns are formed on patterned silicone films that have fabricated by replicating photoresist pattern on silicon wafer mold, and then colloidal particles are transferred to substrate by melting the polymer particles, which lead to hemispherical microlenses array after detaching silicone pattern. As shown in Figure 1, silicone patterns with 2D array of cylindrical holes have been fabricated by conventional soft-lithographic stamp fabrication procedure. In this process, one thing is worthwhile to note that self-assembled monolayer (SAM) of trimethylchlorosilane (TMCS, Aldrich) have covered silicon wafer to avoid chemical adsorption of PDMS to wafer and enable us to peel PDMS pattern off wafer. For 2D array of colloidal particles, we have assembled 2D capillary cell with 60㎛ thickness, in which aqueous suspension have filled capillary slab and particles has been trapped in 2D arrayed holes as previous reports by Xia group. In this self-assembly process, surface force directed to pattern by concave surface is significant for well-arranged colloidal array on pattern. Therefore, oxygen plasma have been exposed to our hydrophobic PDMS pattern for 3 min, which could modify hydrophobic surface to hydrophilic one temporarily.

Figure 2d shows the scanning electron micrographs of 2D colloidal array on PDMS pattern. Ratios of particle diameter (d) of polystyrene to dimensions of holes (the diameter D and Height H) is important parameters to determine number of particles that could be held in each hole. As shown in Figure 2a, holes diameter has been about 2㎛. For holes height, we could predict that would be 1.5ìm from photoresist (AZ5214E) film thickness used as mold of patterned PDMS, which have been produced by spincoating on wafer at 2400 rpm. By changing configuration of PDMS holes array, it is possible to create various types of colloidal patterns on our elastomeric materials. Figure 2(a-c) show typical examples of scanning electron micrographs of patterns, of which patterns in Figure 2a and c were produced through the modification of patterns in Figure 1a by changing developing time in photolithography. Figure 2 d-f shows the their corresponding colloidal patterns on them.

Trapped particles in patterned holes of PDMS have transferred to substrate by contacting and heating as shown in Figure 1g. As we have done in previous PDMS pattern fabrication

step, SAM of TMCS on glass plates have been formed for modification to hydrophobic surface, which facilitated detachment of PMDS pattern and adsorption of polymer latex particles on glass. After transfer of particle to substrates, further polymer melting by reheating enabled shape of microlens to be controlled.

In summary, we report that simple fabrication process for microlens array on arbitrary non-plat substrates through self-assembly of microspheres on patterned silicone and transfer of colloids into substrates. Our approach is much cost-efficient and simple way and most importantly, there is no size limitation unlikely conventional lithography-based microlens array fabrication. In addition, it could be extended to growth of substrate-assisted colloidal crystals in three-dimension.

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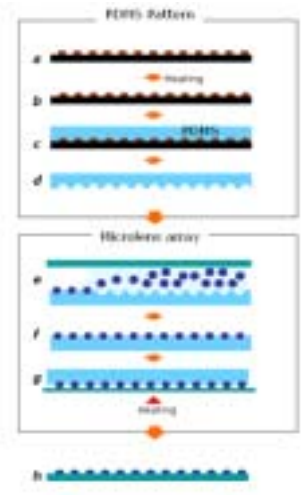

Figure 1. Schematic diagram for microlens array by self-assembly of microspheres

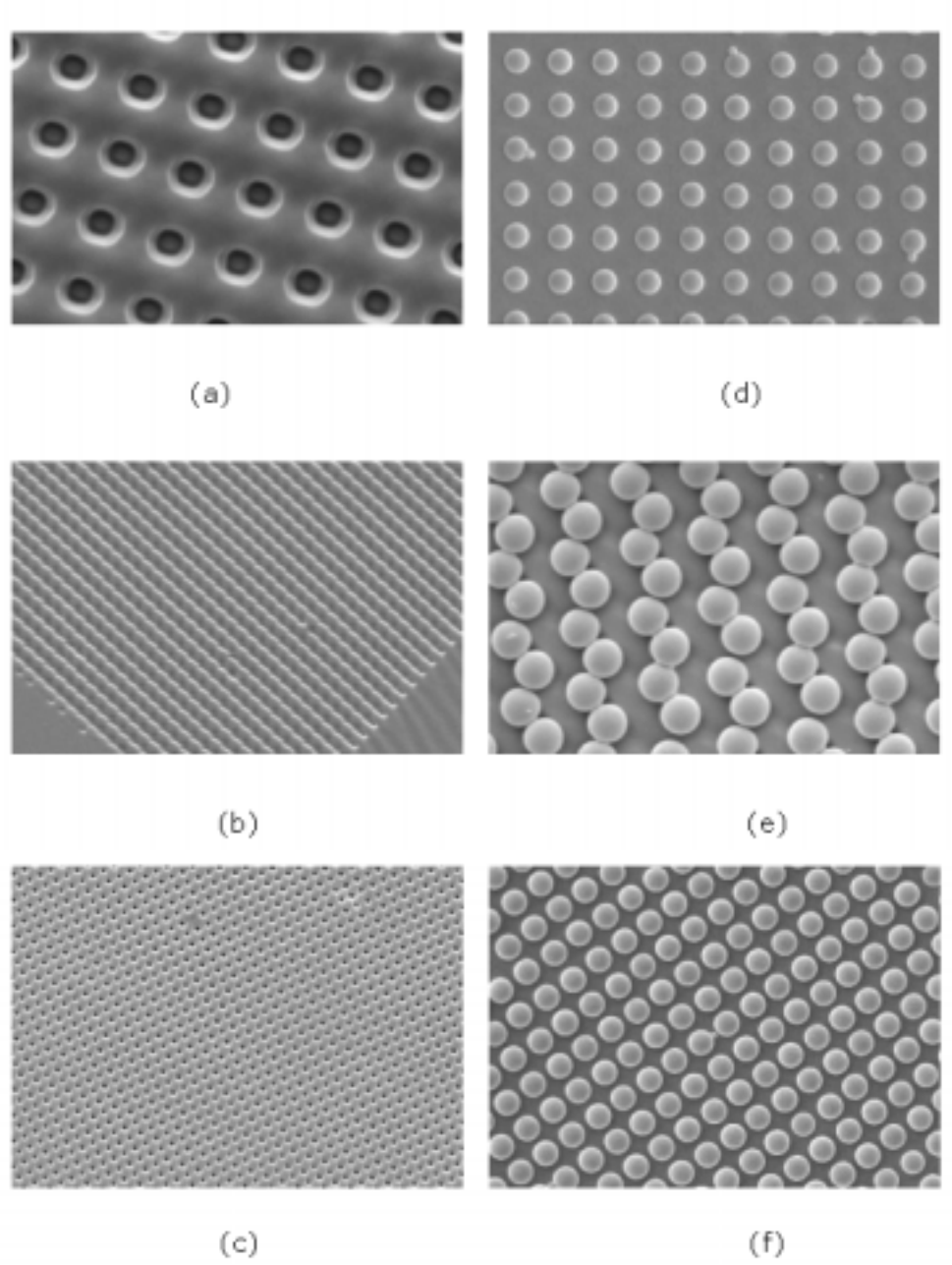

Figure 2. A silicone patterns of different periodicity and shapes (a-c) and their corresponding self-assembled colloidal particle array (d-f).