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Microlens array produced using hot embossing process

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Abstract

In this paper, the fabrication of molds that are suitable for the production of microlens arrays using the replication technique is discussed. Variation of parameters in the replication process were investigated. A focused ion beam was used to fabricate the microlens cavities on three materials, with silicon showing the best result. Hot embossing was used to produce replicated polycarbonate lens array. The temperature of the mold and the embossing force were the two parameters varied. The microlens array produced using the embossing replication process demonstrates the possibility of nanometre fabrication. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Microlens array; Focused ion beam; Hot embossing

1. Introduction

The increase in research into control-by-light systems has widened the market for the use of microlens array. Indeed, microlens array has a large field of application; for example high-speed photography, telecommunication industry that couple light in and out optical fiber waveguides and optical communication [1]. Also the use of optical control systems over their electrical counterparts offers a large number of advantages such as immunity to electromagnetic interference, safety in flammable areas, weight and cost savings, etc. Many methods of fabricating microlens were presented. Some examples are contactless embossing molding [2], the melted photoresist method [3] and microjet fabrication [4]. In this research, a focused ion beam is used to produce lens pattern on a mold material, which will then be used for embossing to produce microlens array.

Focused ion beam (FIB) technology is well known and widely used in semiconductor manufacturing. The FIB system uses liquid metal gallium as the ion source. In the ionization process, gallium

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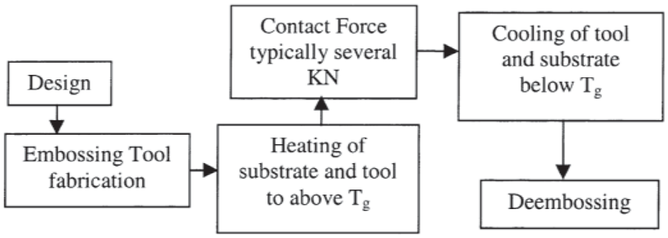

Fig. 1. Steps involved in hot embossing process.

atoms tend to lose one electron, thus becoming singly-charged positive ions. Being charged particles, ions can be accelerated, focused and controlled by electrostatic fields. Their relatively high mass (compared with that of subatomic particles) allows them to be used to induce the milling and deposition effects. Factors affecting FIB milling such as beam limiting aperture size, neighbouring space of beam spot, dwell time and milling sequence were reported [5–7].

Fig. 1 shows the steps involved in hot embossing. A sheet of plastic foil/material is sandwiched between a mold (embossing tool) and an optically smooth backing plate was heated under pressure to a temperature (typically >50°C) above the softening temperature (T_g) of the plastic. Higher temperatures are favourable as the lower viscosity of the polymer facilitates the molding process. After molding, the polymer is cooled down to below the glass transition temperature. The molding force is maintained during cooling in order to preserve the polymer microstructures from distortion. Once the polymer is cooled to below T_g and the pressure is released, the plastic can be separated from the mold to give a high quality copy of the planar microstructure. No material shrinkage was found during the hot embossing process [8]. A simple filling mechanism governing the flow of polymer in hot embossing was described [9]. The factors governing hot embossing were reported [10]; temperature, embossing force and time were the three main factors. This technique works extremely well for shallow microstructures (relief depths less than 1 μm). Deeper structures, where aspect ratio was as high as seven, were also reported [11]. Such an embossing technique can be carried out in the laboratory using a relatively unsophisticated hot press.

2. Fabrication of micro-molds

The manufacturing of the microlens array involved 2 steps. Firstly, FIB milling is done on a mold material. Once the pattern obtained on the mold is deemed satisfactory, it is then used as a mold to emboss the plastic lens array.

2.1. Focused ion beam milling

The material used for the mold must be polished to surface finish of below 10 nm Ra. This is because when the ion hits the surface of the material, the depth of material being removed will be affected if there are large surface irregularities. The material was ground by abrasives paper of grit size 180, 400, 800, 1000 progressively. The surface was then polished with 3- and 1-μm sized

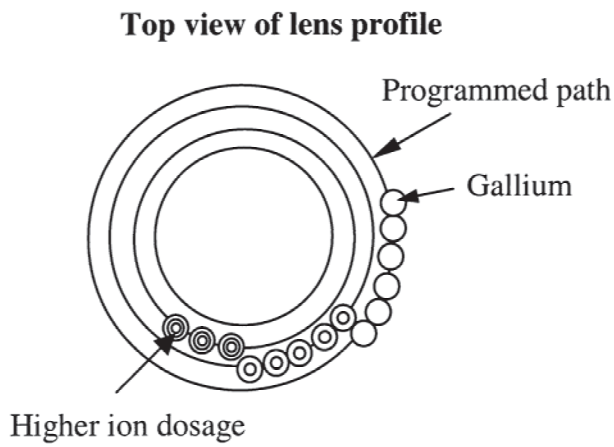

Fig. 2. Fabrication of microlens profile using FIB.

diamond paste at a rotating speed of 150 rpm. The polished material was then cleaned in an acetone ultrasonic bath.

Fig. 2 shows the lens profile generation. The inner circle path will be programmed with a higher ion dose while the ion dose in the outer circle path will be subsequently reduced. It is this varation in the ion dose that generates the depth of the lens profile. At a constant aperture, the depth increases as the ion dose increases. A higher ion dose indicates that there are a greater number of incident ions per unit area. Each of them removes particles from the material and thus generate a deeper feature. The sequence used in the fabrication of lens pattern was from periphery to the center of the profile. A 250-μm aperture size was used for the FIB system. The dwell time was set at 5 μs. Fig. 3 shows the design lens profile. The diameter is 70 μm with a depth of 3.45 μm.

Three different materials were used in the fabrication of the mold using FIB. As can be seen in Figs. 4 and 5, there are numerous small pitting holes on the mold surface. It is believed that one of the reasons for this problem is that the material is not homogenous. Another reason is because the grain

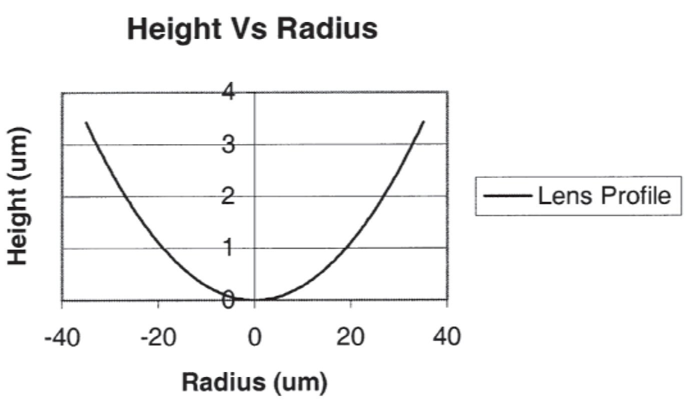

Fig. 3. Microlens profile.

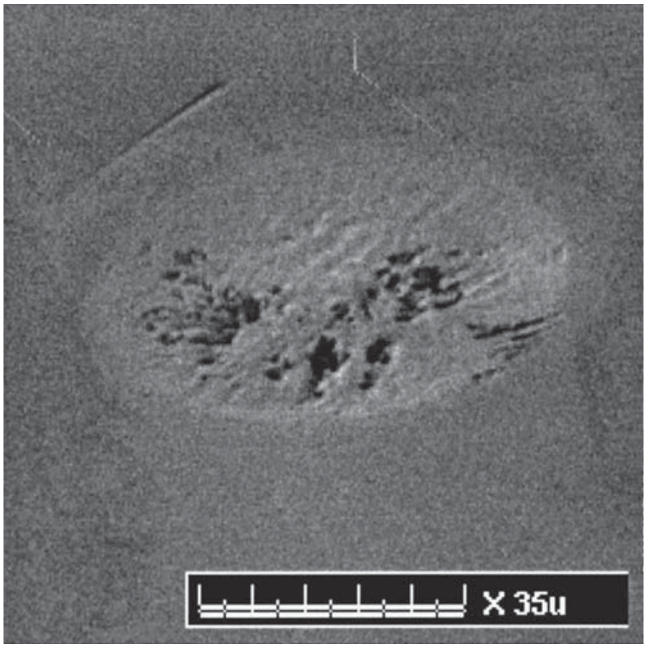

Fig. 4. SEM picture of a lens profile on pure nickel.

structure for pure nickel and stainless steel materials were too big. This causes an uneven 'tearing' effect due to the bombardment of the ions during the ion milling process. A lens profile was also milled on a silicon wafer using FIB (see Fig. 6). A surface finish of around 7 nm Ra was obtained.

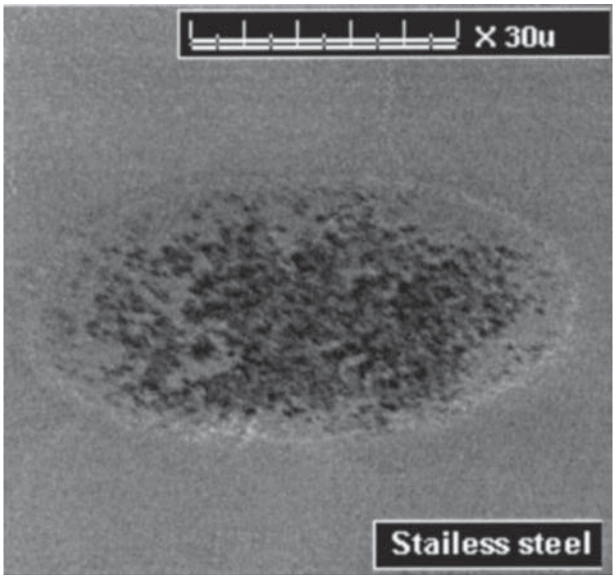

Fig. 5. SEM picture of a microlens profile on stainless steel.

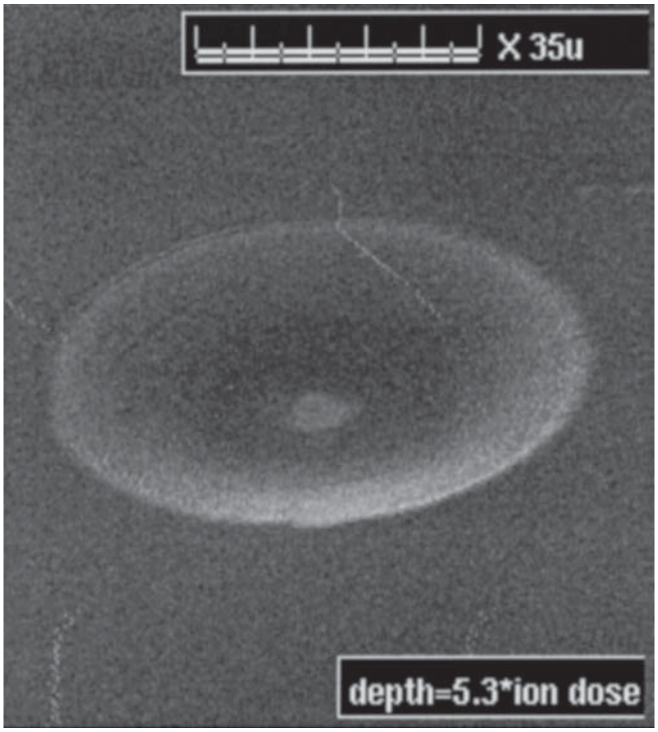

Fig. 6. SEM picture of a microlens profile on silicon wafer.

Silicon was therefore selected for the lens array mold fabrication. Furthermore, it was noted that silicon has several advantages [12]. The silicon must be thick enough to withstand the force applied during the embossing process. A 7×5 lens array was milled on a 9-mm thick silicon (see Fig. 7).

2.2. Hot embossing

In the embossing process, polycarbonate material was sandwiched between a flat nickel plate and the mold. Heat was applied to above the T_g temperature (148°C) of the polycarbonate material. Embossing force was applied and held for 20 min. The mold was subsequently cooled to 26°C with the force maintained to preserve the microstructures of the lens. Demolding was then performed. Demolding is the separation of the mold from the embossed polymer structure by a vertical movement of the mold.

3. Results and discussion

Fig. 8 shows a lens profile milled on the 9-mm thick silicon material. It can be seen that the surface profile was very well defined and the surface roughness was measured to be around 4 nm Ra.

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