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Low-cost Polymeric Microlenses Array Fabricated by Silicon Wet-etch Micromachining and Polymer Spin Casting

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Abstract — **A process for large-scale fabrication of an array of divergent cylindrical micro lenses is presented. The device was fabricated employing a silicon-based micromachined mould combined with a replication technique of PMMA spin casting and a suiting post baking cycle. The resulting device is capable to split an incoming laser beam at a high fan-out angle.**

Key-words — **microlenses array, silicon-based micromould, polymer-based microlenses**

I. Introduction

The so-called surface-relief micro optical elements have found an increasing number of applications in information processing optical systems, and have been substituting conventional refractive optical elements (ROE), because of their compactness and improved performance [1].

The fabrication of diffractive and refractive micro optical elements uses integrated-circuit technology steps, such as lithography and dry etching processes. Although these techniques are suitable for fabricating a high quality surface-relief diffractive element, they are relatively expensive and time-consuming [2]. Hence, it is desirable to fabricate these devices in a less expensive way. There are several methods with a high potential for cheap mass production such as injection moulding, hot embossing, spin casting, etc. [3, 4]. In particular, spin casting is a well established technique capable of producing very high fidelity copies of high resolution, high aspect ratio gratings and other microstructures.

In this work we present a process for large-scale fabrication of an array of divergent cylindrical refractive micro lenses. The device was fabricated by first manufacturing a silicon-based micromachined mould, and then replicating it in a subsequent polycarbonate spin casting and baking step.

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This array of divergent cylindrical refractive micro lenses can be used for splitting a laser beam. This task is required for several industrial applications like movement detection and robot vision, for optical interconnects and information processing [5].

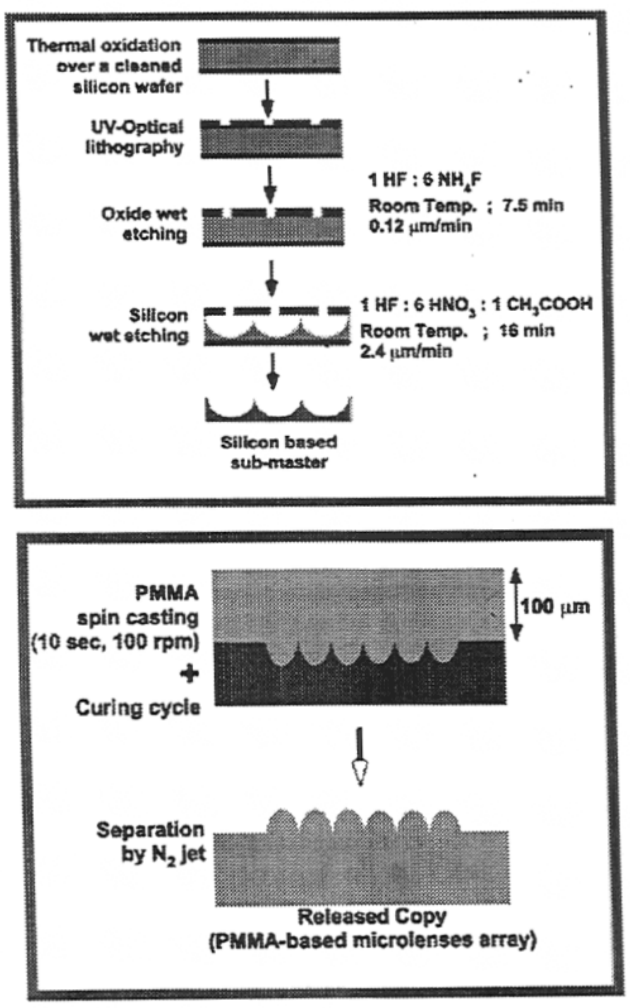

Fig. 1 - The entire process to implement a polymeric convergent microlens array; (a) fabrication of a silicon micromachined mould and (b) a copy of the resulting microrelief in a polymeric material by spin casting and baking

II. FABRICATION OF A POLIMERIC CONVERGENT MICROLENS ARRAY

The fabrication of the silicon mould consists of the following conventional microelectronic processing steps:

1) standard wafer cleaning process; 2) thermal growth of a silicon dioxide film; 3) lithography of a repetitive 90 µm line - 10 µm space structure; 4) chemical wet etching of the oxide; 5) chemical wet etching of the silicon substrate using the oxide layer as a mask. Fig. 1 shows the entire process steps to implement the polymeric convergent microlens array.

A 3-inch diameter, (100), 1-20 Ω.cm resistivity, n-type doped, 381 ± 50 µm thick, silicon wafer was used to manufacture the mould. A conventional Piranha - RCA sequence for wafer cleaning was used [6].

The thermal oxidation was performed in a conventional furnace, at 1150 °C, during 36 hours, resulting in a 0.9 µm thick silicon oxide film.

The lithography was performed using a contact printer. The photo resist (TOKYO OHKA OFPN 800) was spun at 2500 rpm during 20 s, and submitted to a prebake at 105 °C for 90 s, resulting in a thickness of 1.2 µm. The wafer was exposed during 14 s (at a power density of 25 mW/cm^2), developed in a HPRD-402 OCG positive resist developer at a proportion of 2 Developer : 1 DI-water and submitted to a post-bake at 120 °C for 35 minutes.

The first wet etching, needed to open the oxide windows, see fig. 1, was performed using a composition of 6 NH_4F + 1 HF, during 10 minutes, at room temperature, with an oxide etch rate of approximately 0.1 µm/min.

The wet etching of the silicon substrate was performed using a solution to chemically polish silicon substrates [7] that consists of 1 HF + 6 HNO_3 + 1 CH_3COOH, at room temperature, resulting in an etch rate of approximately 2.4 µm/min. After a few minutes, the resist was removed from the surface and after approximately 15 minutes the oxide mask has been entirely etched away. A final dip in a diluted HF solution was done to clean some residual oxide material remaining after the silicon etching. With this 100 µm periodic structure, it is possible to implement a continuous surface-relief of approximately 30 µm deep, with approximately cylindrical cross section, see fig. 2.

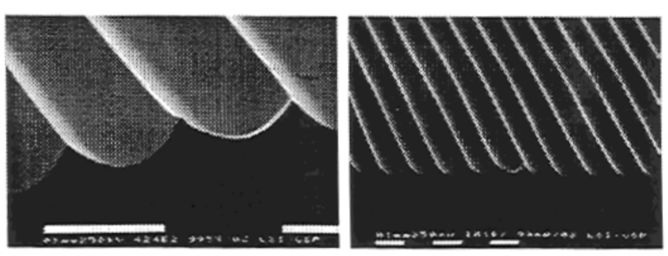

Fig. 2 – Scanning Electron Micro graphs showing the details and an overview of the silicon-based micro mould for generation of an array of cylindrical micro lenses.

Once the mould has been fabricated using the micromachining technology, it can be used for purposes of large-scale production. Replication by polymer spin casting is a very inexpensive way to produce micro optical devices [4].

The replication method consists of the following sequence. Firstly, the 20% (by weight) polymethyl methacrylate (PMMA 2041, Evalcite) was diluted in a solution of 1 part of methyl isobutyl ketone and 1 part of Xylene. Then the polymer was spun at 100 rpm during 10 s, and the sample was submitted to a curing cycle. The polymer temperature must be slowly raised up to a little more than its glass transition temperature (Tg), which was determined in earlier work : 120°C [8].

The curing cycle consists of four temperature ramps: initially the sample temperature was increased from room temperature to 25 °C, in 20 minutes; temperature was raised until 40°C, at 0.5 °C/min (first temperature ramp) during 30 minutes, then this rate was doubled (second temperature ramp) and the temperature reached 100 °C in 60 minutes. The third temperature ramp (0.5 °C/min) was applied during 40 minutes, raising the sample temperature until 120°C. Finally the fourth temp. ramp (0.75 °C/min) was applied during 40 minutes, raising the sample temperature until 150°C, when the hot plate was turned-off and the sample cooled down spontaneously.

The replica was released from the mould with the help of a tiny probe tip and a nitrogen jet.

III. RESULTS

Fig. 2 shows S.E.M. pictures of the silicon-based mould. These pictures show clearly the excellent smoothness of the mould. The diameter of the cylindrical profiles can be controlled by the etching time and the dimensions of the oxide mask.

The resulting micro relief was also analysed with a step height meter. Fig. 3 shows a cross section profile of the silicon mould and of the resulted polymeric replica. Despite

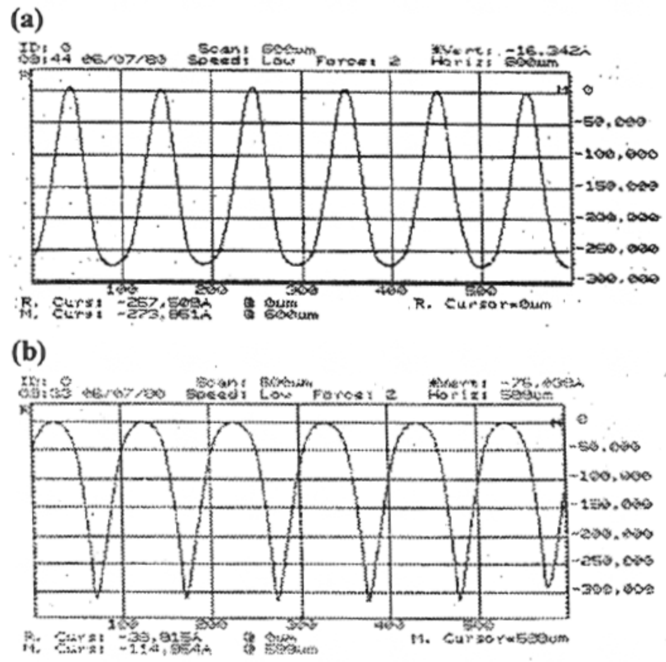

Figure 3 - A cross section profile (a) of the silicon mould and (b) of the resulted polymeric replica. The micro relief error in the replication process was very little.

the smoothing effect imposed by the non-zero dimension of the probe tip, it is possible to note that the relief was replicated with a relatively high fidelity.

IV. CONCLUSIONS

A process for fabrication of a low cost array of polymeric convergent cylindrical micro lenses was successfully developed. It consists of micromachining a mould in a monocrystalline silicon substrate, followed by a spin casting step using a PMMA polymer. The cast microlens array reproduces the mould very well and its surface is extremely smooth. This guarantees an excellent optical performance.

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