Investigating reflow and wetting of non-circular nano-pillars to study nano-scale solid immersion lens fabrication

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Summary

We investigate the reflow and wetting phenomena of non-circular, *e.g.*, triangular and square, shaped nano-pillars of PMMA to fabricate nano-scale solid immersion lenses (SILs). Electron beam lithography (EBL) and thermal reflow are the core of the fabrication process. For the optical characterization at λ = 642 nm, nano-SILs are replicated on a transparent substrate by soft lithography. The focal spots produced by the nano-SILs show both spot-size reduction and peak-intensity enhancement, which are consistent with the immersion effect.

Introduction

Mansfield proposed a new immersion technique for microscopy in 1990, which named *solid immersion lens* [1]. The SIL increases the numerical aperture [NA = n·sinθ] by a factor of n (the refractive index of the SIL), as in liquid immersion. The fabrication of SILs has been limited to macro-size due to the lack of advanced fabrication technologies. The recent advance of micro- and nano-technology facilitates the development of different types of SILs, for instance, diffractive SILs [2] and micro-scale SILs [3, 4]. In our previous work, we demonstrated for the first time the fabrication and optical characterization of nano-scale SILs down to subwavelength size [5]. In this work, we diversify the fabrication of nano-SILs by employing non-circular shaped pillars, such as 400-nm square and 600-nm triangular PMMA patterns. Standard circular patterns, *i.e.* cylinders, are considered as well. The optical response of the fabricated nano-SILs is characterized by measuring the intensity distributions of the immersed focal spots.

Experiment and results

Nano-scale pillars having several shapes and sizes are patterned by EBL: 420 - 480 nm cylinders, 400 nm square pillars and 600 nm triangular pillars, which are shown in the scanning electron microscope (SEM) images of Fig. 1.

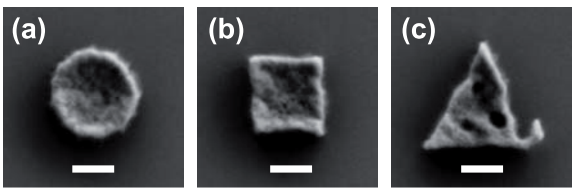

Fig. 1. SEM images of nano-pillars: (a) 450-nm circle, (b) 400-nm square and (c) 600-nm equilateral triangle. The scale bars indicate 200 nm.

We investigate the shape transformation of non-circular shaped pillars to the circular shaped SILs by reflow and wetting. Figure 2 shows the reflowed [at 130 °C for 50 min.] spherical structures from the 200-nm thick pillars of different shapes. Interestingly, the non-circular shaped pillars [Figs. 1(b) and 1(c)] are all transformed to the circular shaped patterns [Figs. 2(b) and 2(c)]. Moreover, the size of the SILs becomes comparable to each other. The volume of the pillar is assumed to play an important role in this phenomenon. When pillars of the same volume are fully melted, the surface tension seizes the expansion of the basement of the SIL to be comparable. More detailed quantitative analysis and dimensional characterization are ongoing, and will lead us to the optimal process parameters for the desired SIL shape. For optical characterizations at λ = 642 nm, the reflowed structures are replicated on the glass substrate by soft lithography. The optical response of the fabricated nano-SILs is characterized by measuring the intensity distributions of the immersed focal spots, as shown in Fig.3. All SILs exhibit comparable performance for the diminution of the spot size and an enhancement of the peak intensity although they were created from differently shaped pillars.

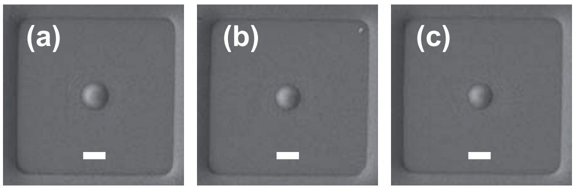

Fig. 2. SEM images of the reflowed structures from the pillars shown in Fig. 1: (a) 450-nm cylindrical, (b) 400-nm square and (c) 600-nm triangular pillars, respectively. The scale bars indicate 500 nm. After reflow, all nano-pillars are transformed into spherical shape SILs.

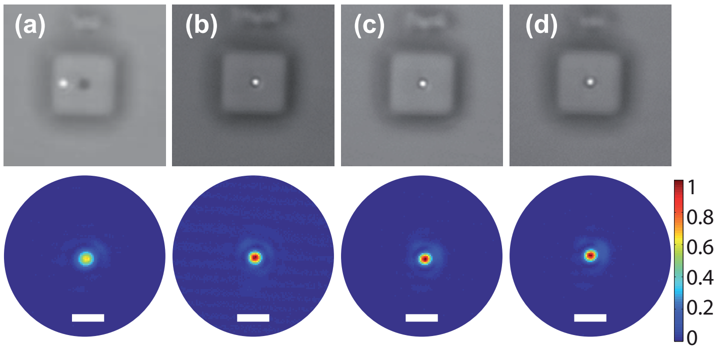

Fig. 3. CCD images and intensity distributions of the focal spots on the bottom plane of the SIL: (a) the reference spot, (b) - (d) the immersion spots through the nano-SILs corresponding to Figs. 2a - 2c, respectively. Upper row: the white spots in each image are the NA0.9 focal spots of the incident light at 642 nm wavelength. Lower row: the scale bars indicate 1 μm.

Conclusions

We demonstrate that reflow and wetting of non-circular shaped nano-pillars can produce spherical structures, which serve as nano-scale SILs. They all show the same performance as nano-SILs fabricated from a cylindrical pattern. The fabricated nano-SILs reduce the spot size by a factor of 1.33 and increase by 50% the measured peak intensity. Investigation of the optimal process parameters, by varying the size of pillars and reflow conditions, is ongoing.

Acknowledgement

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