Hybrid refractive-diffractive microlenses in glass and lithium niobate by focused Xe ion beam milling

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Combination of refractive and diffractive components in a single optical element provides miniaturization of optical systems and enhancement of their performance. Thus, hybrid singlet lenses with diffractive structures added on top of the refractive curved surface were shown to have reduced chromatic and spherical aberration.[1,2] Optical systems based on such hybrid lenses have reduced dimensions as they require less lenses for aberrations-correction. Diffractive elements provide additional possibilities of light manipulation and enable realization of miniaturized multi-focal systems, spectrometers and other devices.

Glass hybrid lenses are typically realized by diamond turning or glass moulding. These technques, however, are less applicable for the fabrication of lenses in brittle materials, such as lithium niobate, or microlenses (hundreds of µm diameters or less). On the other hand, direct writing techniques, such as Focused Ion (typically Ga) Beam (FIB) milling, offer a high resolution and a flexibility in patterning on curved lens surfaces made of a great variety of materials. The disadvantages of FIB milling are its slow speed and Ga implantation that may alter or degrade the optical performance of fabricated components. FIB systems based on high brightness plasma ion sources provide more than an order of magnitude increase in milling rates with noble gas ions (e.g., Xe) compared with Ga FIBs. Here, we demonstrate the feasibility of a rapid, direct milling of hybrid refractive-diffractive microlenses in glass and lithium niobate using >60 nA of Xe ion current. Microlenses with >200-µm diameter were milled and diffraction gratings were realized on top of their curved surfaces (Figure 1). The performance of the lenses was characterized by mapping the transmitted intensity at different positions. Due to the introduction of diffraction gratings on the surface of the lenses, their optical performance is modified with emergence of additional focal spots spatially separated by distances consistent with the theoretical and simulated values. The results indicate the applicability of the plasma focused ion beam systems for rapid fabrication of high quality hybrid optical elements directly in hard substrates.

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[1] Z. Liping, L.Y. Loy, Z. Yan, Y. Zhisheng, SPIE **3897**, 624 (1999)

[2] S. Vazquez-Montiel, O. Garcia-Lievanos, J.A. Hernandez-Cruz, Adv. Optical Technol. **2010**, 783206 (2010)

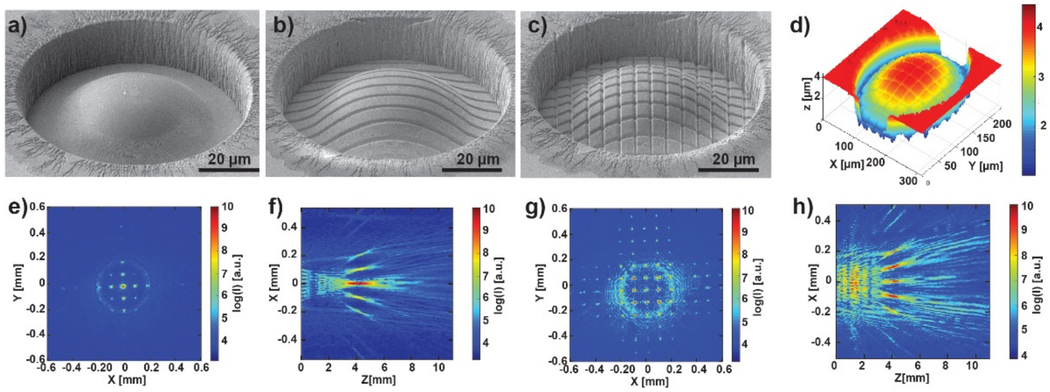

Figure 1: Hybrid refractive-diffractive microlenseses and their performance: (a) A microlens directly milled into a glass substrate using 30 keV focused Xe beam with (b,c) one-dimensional and two-dimensional gratings produced on the curved surface of the microlens, respectively. (d) Optical profilometry image of a hybrid lens with a 200-µm diameter and a 4-µm sag height. (e) Intensity map at the focus produced by hybrid glass microlens 220-µm in diameter and with a 200-nm deep two-dimensional grating on the curved surface. (f) Profile cross-section of the intensity map along the beam propagation direction. The microlens characterization in (g,h) is similar to (e,f) but with the two-dimensional grating depth of 540 nm.