Development of Monolithic X-ray Achromats

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X-ray optics are essential components for X-ray techniques with many applications in biology, energy and materials science. Diffractive and refractive lenses suffer from chromatic aberration, thus only focusing X-ray radiation from a narrow energy range at the same focal position. An achromatic X-ray lens can be realized by combining a refractive and a diffractive element, as proposed in [1, 2]. Recently, we have demonstrated the first experimental realization of this concept [3] using two elements fabricated in two separate substrates. The diffractive element is fabricated by high-resolution electron beam lithography and gold electroplating; the refractive part is produced by two-photon polymerization 3D printing. The two separate components of the achromat were then aligned in a synchrotron X-ray beam using independent piezo stages.

Here, we describe the fabrication process of a monolithic achromatic X-ray lens (figure 1), in which case, the diffractive element and the refractive lens are produced on the same substrate. First, the diffractive element is fabricated on silicon nitride membrane slightly larger than the diameter of the lens. Then, the refractive lens is produced on top of the diffractive part with the supporting structures outside of the silicon nitride membrane. This avoids the formation of bubbles during the two-photon polymerization process that were observed on the silicon nitride membrane due to the presence of the electroplating seed layer made of gold. This new fabrication strategy allows the alignment of both lenses with a much better accuracy, hence enabling a much better performing X-ray achromat. The fabricated devices were characterized in synchrotron beamline by scanning transmission X-ray microscopy and ptychography, as shown in figure 2. In particular, the monolithic X-ray achromat delivered a focal spot size of 250 nm, that is, a factor of two smaller than the focal spot size achieved using two separate elements [3]. Thus, such a monolithic achromatic X-ray lens extremely simplifies the alignment required during its implementation in the experimental setups and paves the way for a broader use of such a concept for high-resolution X-ray imaging.

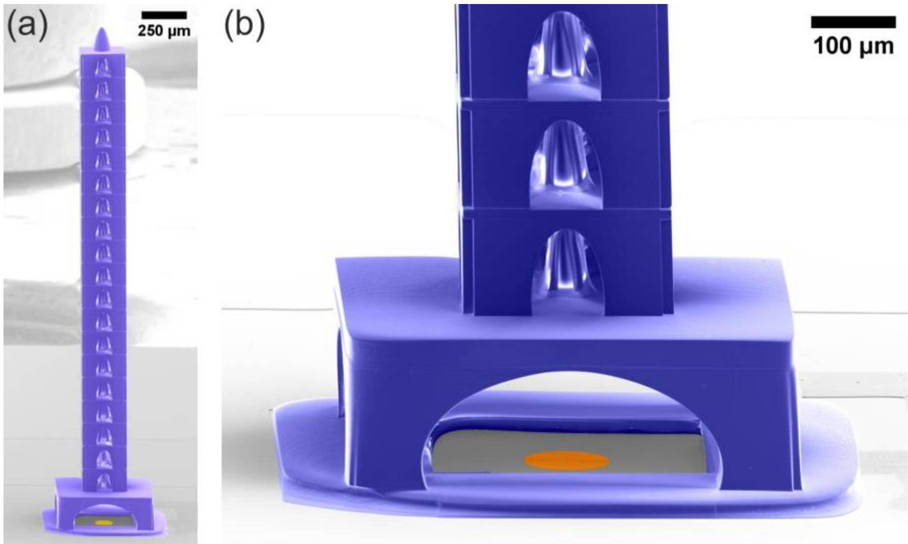

Figure 1: Scanning electron microscopy of a monolithic X-ray achromat (false colour added for displaying purposes). The diffractive element (yellow) was produced on the center of silicon nitride membrane. The refractive part (blue) made of stack of parabolic lenses is fabricated on the top of the diffractive element. The overview of the whole structure is shown in (a). The detail of the bottom part is shown in (b).

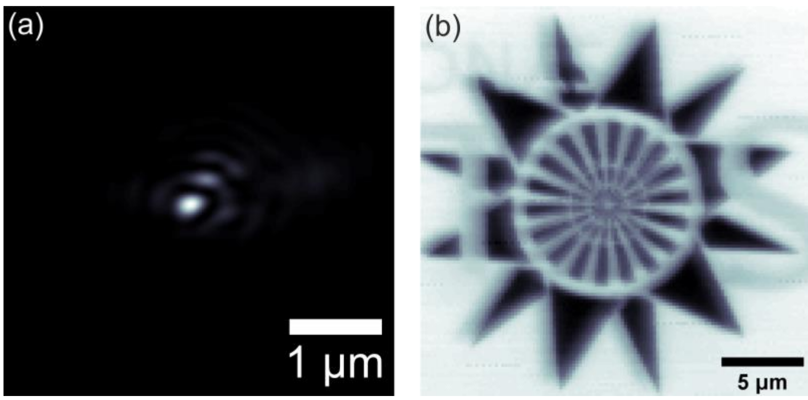

Figure 2: (a) X-ray focal spot of 250 nm delivered by the monolithic X-ray achromat. (b) Scanning transmission X-ray microscopy image of test structure acquired with the monolithic X-ray achromat used as focusing lens.

References

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[3] A. Kubec, M.-C. Zdora, U. T. Sanli, A. Diaz, J. Vila-Comamala, C. David, *An achromatic X-ray lens*. Nat. Comm. **13**, 1-7 (2022).