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Development of Monolithic Piezoelectric Deformable Mirror Based on Single-Crystal Lithium Niobate

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X-ray nanospectroscopy offers the capability to analyze various information such as elements and chemical states with high spatial resolution. Enhancing the sensitivity and spatial resolution requires the use of X-ray focusing optics. Among these optics, X-ray total-reflection mirrors are promising due to their high reflectivity, low chromatic aberration, and excellent radiation hardness. However, one limitation is that the optical parameters cannot be changed depending on the sample used or the experimental conditions.

To overcome this limitation, deformable mirrors (DMs) have been developed that can change the shape of their reflecting surfaces. In particular, high-precision piezoelectric bimorph mirrors, employing piezoelectric actuators bonded to the mirror substrate, have been widely used, and have successfully changed the X-ray beam size[1]. However, conventional DMs face problems related to the amount of deformation. In the DMs, the piezoelectric element must be bonded to the mirror substrate. Therefore, the thickness of the DM cannot be reduced, imposing limitations on the extent of deformation.

To overcome this problem, we propose a novel DM based on lithium niobate (LN). LN'surface can be atomically smoothed, enabling the development of monolithic DMs where an LN plate serves as both the mirror surface and driving force for deformation[2]. We also utilized the domain inversion property of LN[3]. Heating LN near the Curie temperature allows for domain inversion along the substrate thickness direction. As a result, a practical bimorph structure could be generated within the monolithic LN (Fig.(a)). Consequently, an ultrathin bimorph mirror capable of dynamic deformation without adhesion could be constructed.

Figure (b) shows the LN DM with a thickness of 0.5 mm. The mirror was heated near the Curie temperature. The curvature of the deformation, calculated using the finite element method, was 0.14 km-1/V, which is at least 3 times larger than that of the conventional type. An experiment to change the X-ray beam size was performed at BL29XU of SPring-8. In the tightly focused X-ray mode, the mirror shape could be precisely controlled with a high precision of 3 nm, and a diffraction-limited focusing size of 200 nm in full width at half maximum was achieved (Fig. (c)). Furthermore, the DM also succeeded in forming a beam wider than 1 mm by significantly deforming into a convex shape.

References

[1] S. Matsuyama et al., Sci. Rep., 6, 24801 (2016).
[2] T. Inoue et al., Optica, Accepted (2024).
[3] K. Nakamura et al., Appl. Phys. Lett., 50, 1413 (1987).

Figure (a)Schematic diagram of the deformable mirror. (b) A picture of the deformable mirror.
(c) Measured beam intensity profile.

I plan to submit also conference proceedings

No

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