A novel approach for the fabrication of Kinoform lens for x-ray focusing by grayscale e-beam lithography

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For hard x-ray beyond 20 keV of the photon energy, conventional diffractive optics such as metallic Fresnel zone plates (FZP) are not the best choice due to their limited attenuation lengths and low diffraction efficiency. Even for a lossless material, the theoretical limit of FZP efficiency is ~40%. Instead, refractive Kinoform lens, as schematically illustrated in Fig.1 can be a promising candidate for the focusing of high energy X-ray due to its high transmission efficiency. Its theoretical limit can reach 100% when lossless materials are used. Even with metals such as Au or Ni, the efficiency can still be well above the theoretical limit of FZPs. Unfortunately, Kinoform lenses have still yet been practically applied in hard x-ray optics despite its attractive applications. The main obstacle is the technical challenge for achieving critically vertical sidewall of the 2D cylindrical lenses (Fig.1b) with the height of at least 200 μm required for practical use, even when the most advanced ICP (inductively coupled plasma) is carried out for deep dry etch on Si.

To overcome the technical difficulty, this paper propose a novel approach to fabricate Kinoform lenses by a grayscale e-beam lithography (EBL) followed by a pattern transfer process into the lens materials through either deposition or dry etch. This can be done only after the lens configuration is converted from the cylindrical shape (Fig.1a) into the one in a plate (Fig.1b). Fig.2 schematically presents the process flow for the fabrication of the Kinoform lens. In the grayscale EBL on PMMA, Monte Carlo simulation for charge distribution in e-beam exposure was first carried out and the resultant lens profile was obtained by modelling the developing process based on the measured contrast/dissolution rate curves (Fig.3). Using the theoretically simulated lithography parameters as a guide, the lens profiles in PMMA as templates are obtained, as shown in Fig.4. Subsequently, electroplating of Au was carried out to transfer the lens profile from PMMA to Au.

By summary, a novel and feasible method to fabricate Kinoform lens by a grayscale e-beam lithography process has been developed. The Kinoform template with the outermost width of 600 nm is obtained. This process has the great prospects in: the height of the Kinoform lens is no longer limited since it is laid down on a substrate during the process; there is a great freedom to choose any materials such as diamond by deposition, or even silicon if a dry etch is applied in the pattern transfer.

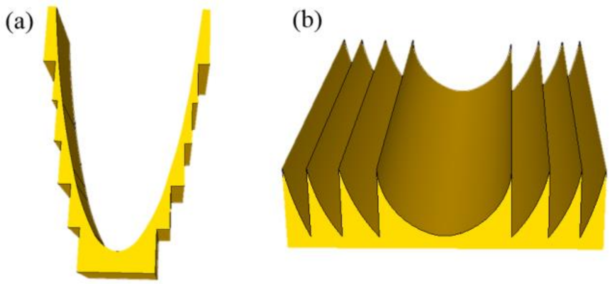

Figure 1. The conventional Kinoform lens is re-arranged in a plate, which has the same configuration as Fresnel zoen plate in which the zones have an analog profile designed to focus.

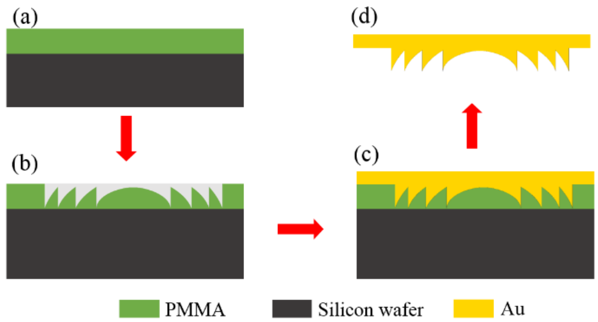

Figure 2. The process flow for the fabrication of the Kinoform lens. By converting the lens into a plate, nanoprocess can be undertaken on a plane.

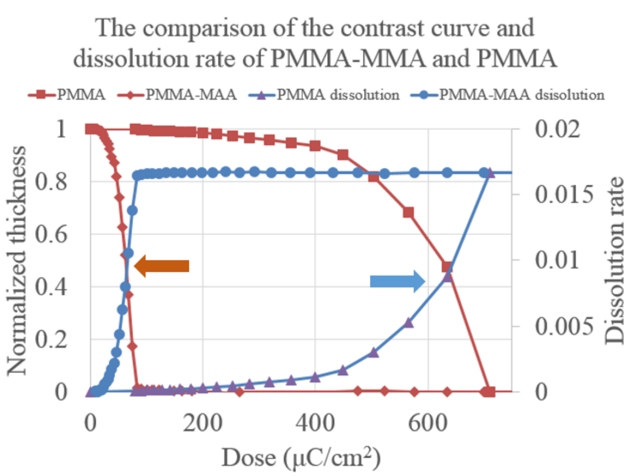

Figure 3. The comparison of the contrast curve and the dissolution rate of PMMA-MAA and PMMA which indicates the little influence of the exposure to the PMMA. The measured data were used in the grayscale EBL.

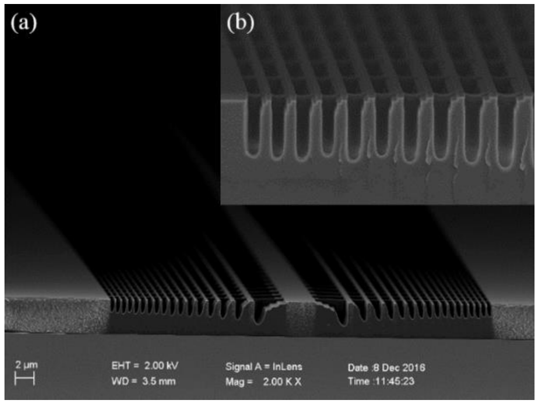

Figure 4. The micrographs by SEM for the replicated profiles in PMMA as templates for the Kinoform lens. The outermost width is 600 nm.