# Nanofabrication of x-ray zone plates using ultrananocrystalline diamond molds and electroforming

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## ABSTRACT

X-ray zone plates are diffractive lenses composed of concentric rings whose periods change along the radii. Each ring acts as a phase shift element. The size of their focal spot is proportional to the outermost ring width. Zone plates are among those very few optics that can focus to the diffractive limit in the hard x-ray. The optimal efficiency of a zone plate is determined by the thickness of the phase shifting rings, which ranges from hundreds of nanometer to several microns, depending on the material and working wavelength. Therefore, the major challenge in the fabrication of hard x-ray zone plates with 50-nm resolution is the high aspect ratios required to provide the desired phase shift.

To fabricate high-aspect-ratio zone plates in high-density metals such as Au, the final zone plate structure is formed by electroplating the metal into a nanofabricated mold of a high-resistance dielectric [1]. This high-aspect-ratio mold structure must maintain its mechanical stability during subsequent processing. Molds structures for current commercially produced zone plates are made by either direct patterning in organic resist by electron-beam lithography (EBL), or by pattern transfer into an organic layer by oxygen reactive ion etching (RIE) [2]. More recently, HSQ has been used as a resist material for the mold structure [3]. All of these materials tend to be limited in their mechanical stability. Moreover, the material must be removed prior to using the zone plates with intense x-rays because of radiation-induced damage. Diamond, on the other hand, is a dielectric with superior mechanical properties and radiation hardness and thus is ideally suited as a mold material for zone plate fabrication. Ultrananocrystalline diamond (UNCD), in particular, can be grown in thin films with the controlled stress and small grain size necessary to allow fabrication of nanoscale molds for high-resolution x-ray zone plates. Here, we demonstrate the ability to fabricate linear zone plates with UNCD and gold electroforming in the UNCD mold.

UNCD is deposited by microwave plasma chemical vapor deposition to provide uniform layers on silicon substrates or window materials [4]. A thin film of metal, such as W or Ti, provides a surface that allows high-density seeding to enhance nucleation for the growth of the UNCD film, as well as to act as the plating base for subsequent electroforming. The zone plate fabrication process flow is shown in Fig. 1, which reveals a cross-sectional view across the zone plate. The zone plate patterns are defined in spin-cast HSQ resist by EBL (Fig. 1b). The pattern is transferred into the UNCD using an oxygen RIE etch that provides high anisotropy with good selectivity for UNCD over HSQ (Fig. 1c). The resulting UNCD mold structures are shown in SEM images in Fig. 2. The outermost zones can easily obtain aspect ratios greater than 8 with good adhesion and mechanical stability. Au is deposited into the UNCD mold structures by electroplating from solution. The resulting gold structures (Fig. 3) demonstrate the ability to produce linear x-ray zone plates. Application of these structures to x-ray optics are discussed.

**References**

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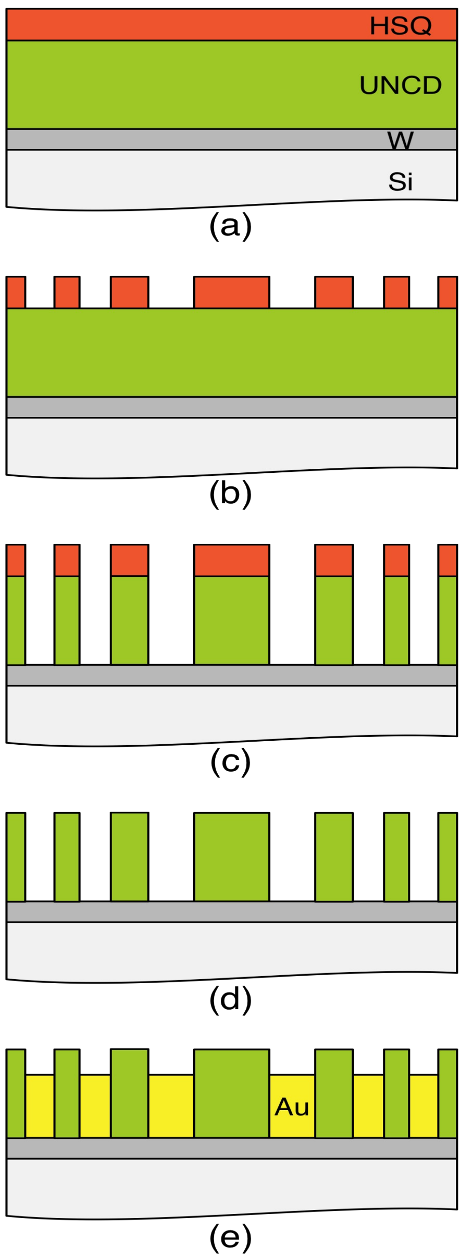


**Figure 1.** Steps for UNCD mold. (a) HSQ spin coat on UNCD coated Si wafer, (b) EBL expose resist and develop, (c) plasma etch to W layer, (d) strip remaining HSQ, and (e) electroform gold.

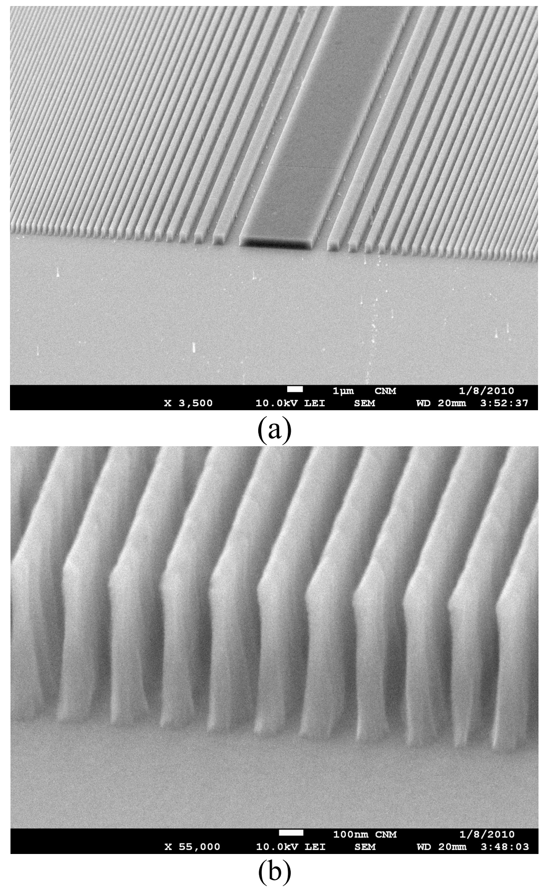


**Figure 2.** SEM micrograph of UNCD mold structures. (a) Low magnification, (b) high magnification.

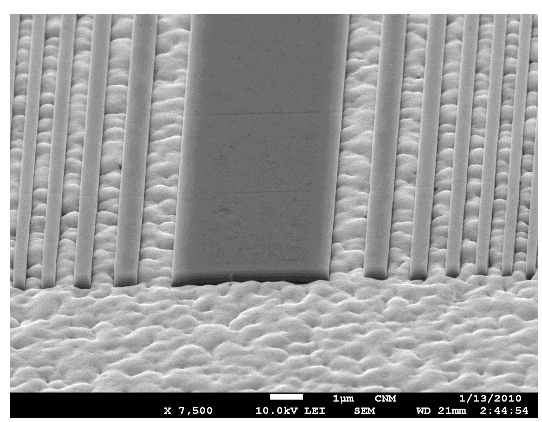

**Figure 3.** SEM micrograph of gold electroplated into UNCD mold structures to form a linear zone plate.