Progress in electron-beam-lithography-fabricated Fresnel zone plates on diamond membranes for hard X-ray focusing

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Fresnel zone plates (FZPs) for high photon energy X-ray focusing are in high demand, but also difficult to fabricate. To achieve a relative phase shift of π, the rings of the zone plates have to be in the few micrometer thickness range, while the zone widths of interest should be in the few tens of nm range. Here is reported for the first time the fabrication of such zone plates on 4" wafer scale by electron beam lithography, reactive ion etching (RIE), back etching the Si for membranes formation, and atomic layer deposition (ALD) of Iridium as absorption/phase shifting material. 81 membrane chips with five zone plates each of 60 nm minimum zone width were obtained per wafer, with high wafer-scale uniformity. Another novelty is the design of the FZP structures, encompassing a composite zone plate[1] layout and branching buttresses (Fig. 1, 2), to avoid tearing of the zones in the buttress-anchoring points. This is a first stage in wafer-scale production of FZPs on diamond substrates, which is anticipated to receive a subsequent upgrade by a thickness enhancing method, during a second development stage.

The electron beam exposure was done with a JEOL JBX-9300FS electron beam lithography system working at 100 keV electron energy, in hydrogen silsesquioxane (HSQ) resist. The FZP pattern was then transferred into an engineered diamond layer to a depth of ~ 2 μm by oxygen reactive ion etching (RIE). The role of diamond is multiple: It provides a slightly electrical conductive substrate to prevent buildup of charges during the e-beam exposure, leads to membranes of low X-ray absorption, is a good thermal dissipation material, provides a mechanically resistant 3D pattern after deep etching to prevent collapsing of the structures, and allows deep, high aspect ratio etching and application of subsequent methods to enhance the thickness/ aspect ratio of the phase shifting metal layer. The diamond utilized was engineered to form a slightly tensile stack of non-conductive /conductive/ non-conductive (600 nm /2.2 μm /1.2 μm) ultra-nanocrystalline diamond (UNCD), with/without boron doping at deposition. The FZPs structures obtained in HSQ resist were deep etched using an optimized RIE recipe, to end in the middle boron-doped diamond layer. The conductive mid-layer of diamond will be used in the second stage development as plating base, to electroform a temporary metal (gold) directly into the diamond mold, to be transferred by self-aligned X-ray lithography into the back side of the diamond membrane, then removed and replaced with an ALD Ir, for thickness enhancement.

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[1] A.G.Michette, Optical Systems for Soft X Rays, Plenum, New York, London, 1986

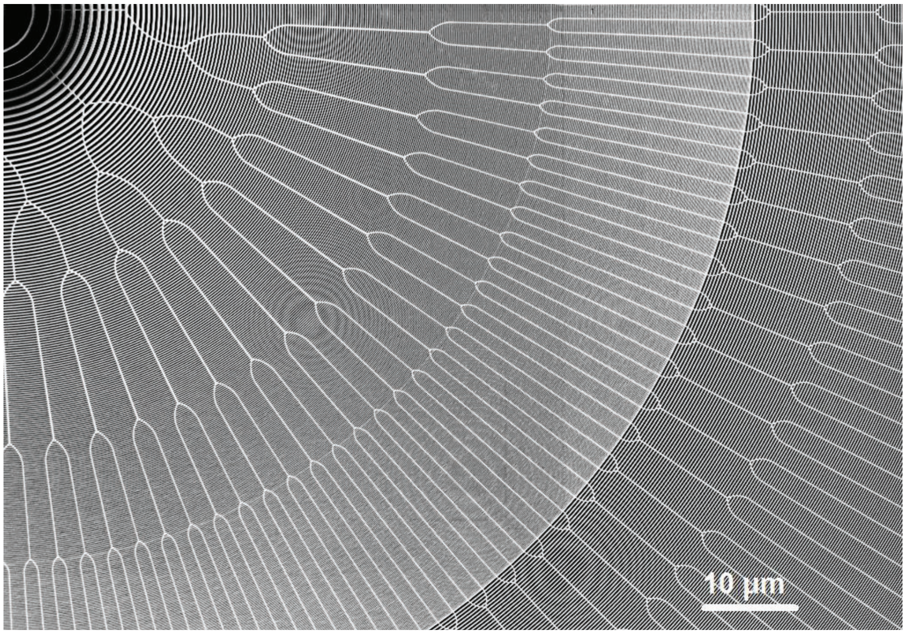

Figure 1. Composite FZP structure with 60 nm-wide outermost zone and branching buttresses as exposed in 500-nm-thick HSQ resist with an optimized lithographic process. (SEM image)

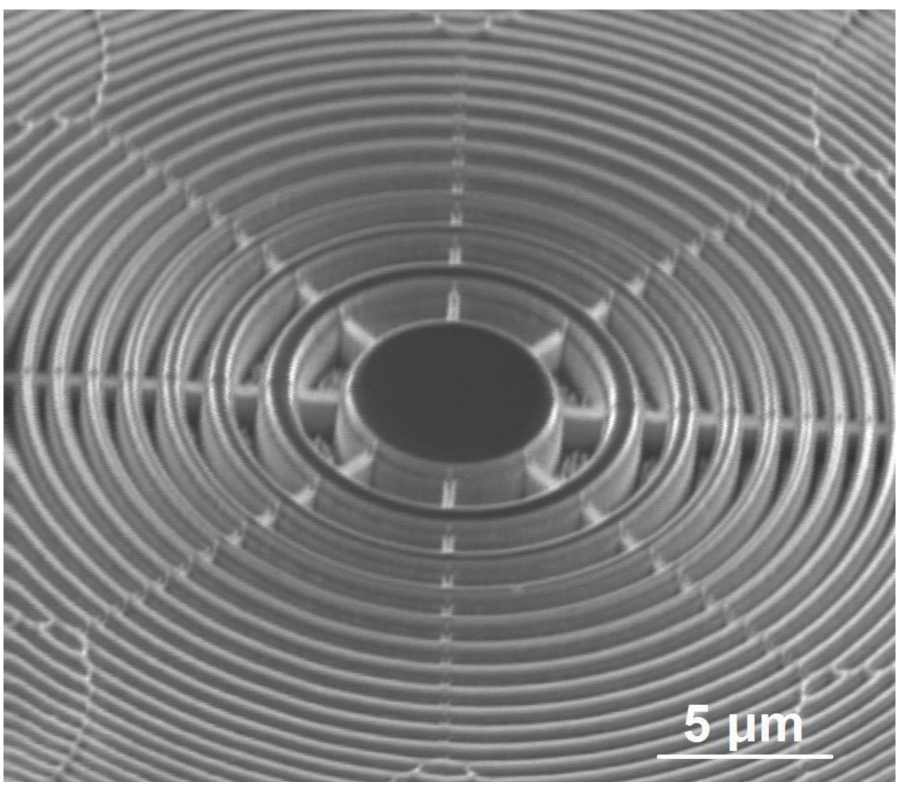

Figure 2. An example of deep etched FZP structures into diamond, to a depth of ~ 2 μm. (SEM image)