MECHANICAL DESIGN OF MULTIPLE FRESNEL ZONE PLATES
PRECISION ALIGNMENT APPARATUS FOR HARD X-RAY FOCUSING
IN TWENTY-NANOMETER SCALE

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ABSTRACT

Fresnel-zone-plate-based optics is extensively applied for x-ray instruments. At the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), many synchrotron radiation beamlines are using Fresnel zone plates for hard x-ray focusing. However, the efficiency of Fresnel zone plates (FZPs) as focusing optics for x-rays depends on the height of the structures. In the hard x-ray regime, very high aspect ratios are required for maximum efficiency with focusing spot in few tens of nanometers, which is required for future hard x-ray nanoprobe beamlines planned as part of the APS Upgrade project [1,2].

To overcome the limitations of today's fabrication techniques for high-efficiency hard x-ray FZPs, a new approach of stacking FZPs at larger distances (in an intermediate-field) was published by Vila-Comamala et al. in 2012 [3]. According to this new approach, stacking zone plates with large separation distance is possible by adjusting the diameter of the downstream FZP so that its focal length is equal to the focal length of the upstream FZP minus the distance between both FZPs. Thus, the focal spots of both FZPs overlay when the separation of both FZPs is matching the difference in focal lengths. However, besides designing and fabricating of high quality FZPs for intermediate-field stacking, there are many mechanical design challenges to transfer the theory to a practical instrument. First of all, a precision alignment apparatus for multiple FZPs handling and aligning must be designed to meet the following challenging design requirements:

- Each of the stacking FZPs need to be manipulated in three dimensions with nanometer-scale resolution and several millimeters travel range.
- The relative three-dimensional stabilities between all of the stacking FZPs (especially in the x-ray beam transverse plane) are required to be kept within few nanometers for more than eight hours, the duration of the hard x-ray focusing for nanoprobe operation.
- Compatible with the operation of multiple optics configuration for the APS future x-ray nanoprobe design.

To meet the demanding mechanical requirement for the precision alignment apparatus system for the hard x-ray focusing in twenty-nanometer scale, several prototypes have been designed and tested at the APS.

Figure 1 shows a 3-D model of a prototype of Z2-33 alignment apparatus for two FZPs stacking [4]. It enabled the first experiment of stacking FZPs with adjusted diameter in the intermediate field, and the results prove the simulations by Vila-Comamala et al. [3]. It includes a pair of commercial Piezo-motor-driven linear stages (SmarAct™ SLC-1720S), which are mounted on the zone plate alignment base to provide 2-D alignment for the upstream zone plate in X-Y plane. The downstream zone plate holder is driven by a SmarAct™ SLC-1720S linear stage in Z-direction to adjust the gap distance between the upstream and downstream zone plates. All of the three piezo linear positioners are mounted on a zone plate alignment base frame, which is a part of the carriage of a 2D-tilting stage. Driven by a picomotor™ actuator, the V-axis tilting stage...
rotates around a vertical pin, which is fixed on the base of the 2D-tilting stage and sliding fitted with the base of the H-axis stage. The H-axis stage tilts around a pair of flexural pivot as shown in figure 1.

Figure 2 shows a 3-D model of a prototype of alignment apparatus for three FZPs stacking [4,5]. Its non-symmetric design is also compatible with mirror-based nanofocusing optics, such as Kirkpatrick-Baez (K-B) mirrors [6] for hard x-ray nanoprobe in switchable multi-optics operation modes. As shown in figure 2, the Z2-34 alignment apparatus has a non-symmetric invar base structure (1) and six commercial Piezo-motor-driven linear stages (SmarAct™ SLC-1720S). Three zone plates (2-4) are mounted on CVD-diamond holders (5-7). The CVD-diamond holder (5) for upstream zone plate (2) is driven by a stage (8) to adjust its position in Z direction with nanometer scale and stability. The second downstream zone plate (3) is driven by a pair of stages (9,10) to adjust its position in X and Y directions. The third downstream zone plate (4) is driven by a set of stages (11-13) to adjust its position in X, Y, and Z directions. Since the thermal expansion coefficient of CVD diamond is similar to the thermal expansion coefficient of invar, it can basically ensure thermal stability of the apparatus. To further compensate the thermal deformation from the stages (8), (9,10), and (11-13), the materials of the linkage components (14-16) between the stages and CVD-diamond holders are carefully chosen. If it is necessary, two or three materials may be combined to compensate the stages thermal deformation precisely. Figure 3 shows a photograph of the Z2-34 alignment apparatus for three FZPs stacking.

The precision mechanical design of the apparatus prototypes for two and three FZPs alignment in intermediate-field, as well as the test results of their hard x-ray focusing performances are presented in this paper. Design of the apparatus for six and more FZPs will also be presented in the paper.

Figure 3. A photograph of the Z2-34 alignment apparatus for three FZPs stacking test at the APS 2-ID-E hard x-ray experiment station.

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