ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP024

DESIGN OF A HARD X-RAY NANOPROBE BASED ON FZP*

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Abstract

A high-resolution hard X-ray nanoprobe (HXNP) based on Fresnel Zone plate (FZP) was designed. The HXNP relies on a compact, high stiffness, low heat dissipation and low vibration design philosophy and utilizes FZP as nanofocusing optics. The optical layout and overall mechanical design of the HXNP were introduced. Several important modules, such as probe module, sample module, interferometer module and vacuum chambers were discussed in detail.

INTRODUCTION

In recent years, X-ray nanoprobe operating in the hard X-ray regime has achieved rapid improvements based on the development of a lot of advanced X-ray optics, such as Fresnel zone plate (FZP) [1], multilayer Laue lens (MLL) [2], nanofocuisng K-B mirror. With outstanding quantitative non-destructive three-dimensional (3D) imaging capabilities, the hard X-ray nanoprobe (HXNP) has attracted significant interest across many different disciplines. In previous work, a prototype of HXNP with about 70 nm spacial resolution was constructed and tested at Shanghai Synchrotron Radiation Facility (SSRF) [3]. Driven by the needs of observing and analyzing the internal fabrication defects of the chips with feature size smaller than 28 nm, this paper introduced the recent development of a new HXNP based on FZP.

INSTRUMENT DESIGN

Optical Layout

As depicted in Fig. 1(a), the FZP was chosen as the nanofocusing optics. In order to select the -1st diffraction order of the FZP, a central beamstop (BS) and an order sorting aperture (OSA) were also utilized. The BS, FZP, OSA and their corresponding adjustment components together constituted the probe module. The coherent X-ray from the upstream of the beamline could be focused by the above probe module to form an X-ray nanoprobe, which was also the illumination probe for the ptychographic imaging.

The sample was located near the focus of the FZP. With XY two-dimensional (2D) scan of the sample, a series of diffraction patterns could be acquired by the far-field detector. As the over-sampling condition is satisfied, the 2D electron density distribution of the sample over the fully scanning area could be reconstructed. Moreover, by combining with the CT technology, the 3D sample information could be revealed. An in-line visible light microscope (VLM) was placed behind the sample for coarse adjustment of the FZP and fast calibration of the sample.

According to the functional requirements of the instrument, the freedom of motion required by the HXNP was also shown in Fig. 1(b).

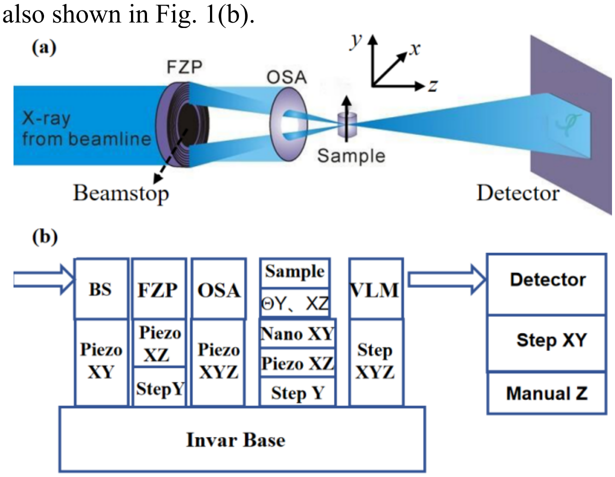

Figure 1: The optical layout of the HXNP.

Overall Scheme of the HXNP

The 3D mechanical design of the HXNP optimized for ptychographic imaging was shown in Fig. 2. The HXNP mainly consists of several important modules, including the welding supporting frame, the marble supporting base, the imaging module, the vacuum chamber and the detector module, which have been marked clearly in Fig. 2. The following was a further introduction.

First, a set of welding frame with high-rigidity was designed as the supporting base for the vacuum chamber. In order to decouple the vibration of the optical vacuum chamber from that of the imaging module, a more stable marble base was utilized for the supporting of the imaging module.

Second, the imaging module is composed of the probe module, the sample module, the interferometer module and

*Work supported by Jinan Haiyou Industry Leading Talent Project (2022), the National Natural Science Foundation of China (No.11505278, 11875315), the National Key R&D Program of China (2020YFA0405802), Innovation Promotion Project of SME in Shandong Province (No.2023TSGC0093).
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ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-WEPPP024

the VLM module, which were depicted in Fig. 3. The imaging module was designed in a compact style. As for the selection of motion stages, a combination of piezo stages with low heat dissipation and stepper stages with large stroke and high load capability was balanced.

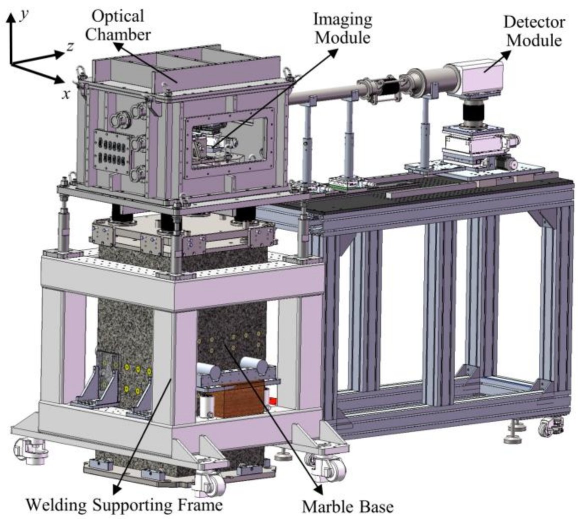

Figure 2: The overall scheme of the HXNP.

Third, the imaging module of the HXNP was installed on the Invar supporting base with a kinematic mounting design.

The design of all modules, including the selection of motion stages, the corresponding structural design and assembly design, was optimized by means of engineering analysis.

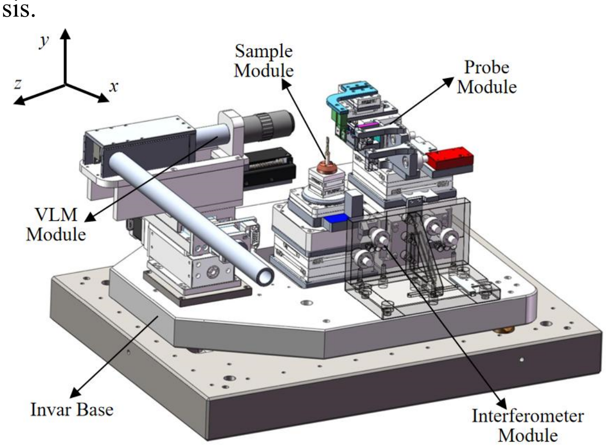

Figure 3: Mechanical model of the imaging module.

Probe Module

The probe module consists of FZP, OSA, BS and their adjustment components. As presented in Fig. 4, this module is quite compact with all components mounted on a high-load vertical stage ES10-Z12, which could handle up to a 5 kg load over 12 mm stroke. Two CLS9292 piezo stages were utilized for the movement of FZP in X and Z directions. The XY piezo stages for beamstop were mounted near the central part of the FZP assembly. As a comparison, the XYZ piezo stages for OSA was mounted on one side. The balancing of weight was also carefully considered.

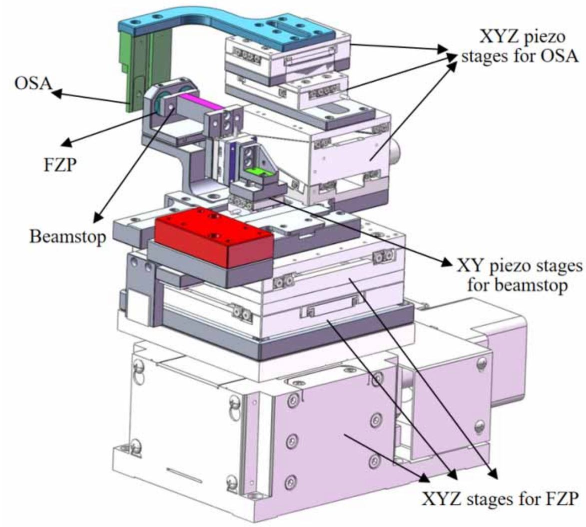

Figure 4: Details of the probe module.

Sample Module

A useful sample module was designed as shown in Fig. 5. The bottom was one stepper stage with high load capability in Y axis. Two piezo stages CLS9292 were used for the adjustment of sample in X and Z direction. The 2D ptychographic scan of the sample was realized through the flexure nano stage P-733.3DD. A piezo rotation stage SRM7012 was selected for the CT scan. Two piezo stages CLS3232 were used for the calibration of the rotation axis.

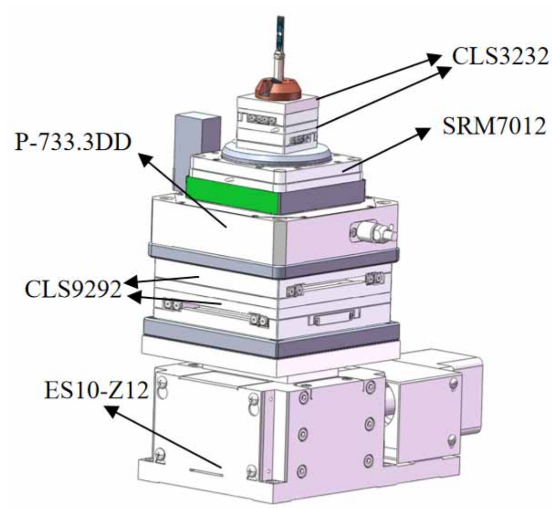

Figure 5: Details of the sample module.

Interferometer Module

The interferometer module is crucial for the HXNP especially when CT imaging is required. Two sets of IDS3010 interferometer with sub-nm accuracy from Attocube were utilized for the closed-loop control of both the probe module and the sample module. Totally 6-Axes closed-loop control were available by the above two sets of IDS3010. Figure 6 shows all the six optical paths of the interferometer, among which two absolute position loops were designed for FZP, another two absolute position loops were designed for sample, and the last two loops were prepared for the relative position control between FZP and sample. In Fig. 6, the red arrow and the yellow arrow represent the horizontal loop (X direction) and the vertical loop (Y direction) respectively.

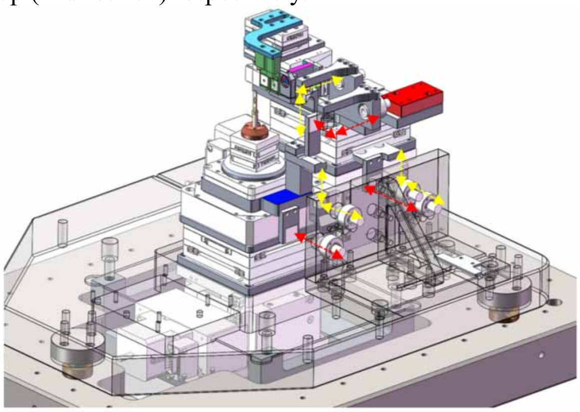

Figure 6: Schematic of the interferometer module.

Vacuum Chamber

A vacuum chamber was designed for the optical elements, shown in Fig. 7. The imaging module was mounted inside the optical chamber with the decoupling mechanism. This chamber could operate with HV pressures and at atmospheric pressure. The length of the vacuum pipe between the chamber and the detector was adjustable for different applications. A 3D manual adjustment assembly for the vacuum pipe was designed.

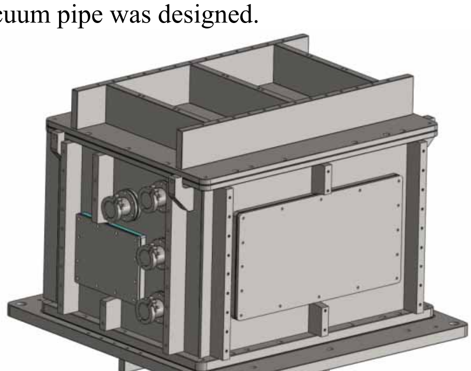

Figure 7: Schematic of the vacuum chamber.

The vacuum chamber was designed with various ports for SDD fluorescence detector, laser interferometers, and windows, which can be seen in Fig 7. The SDD fluorescence detector was mounted parallel to the horizontal X axis. A vacuum door was designed for the convenience of sample exchanging.

Control System

The control system for this HXNP is called HDC-Instrument, which is a distributed control system developed by C# programming language and based on the .NET 6 platform. The HDC-Instrument is configured with powerful functions, including motion control, environment parameter monitor, process control, log system, and imaging process.

CONCLUSION

Based on the prototype of HXNP, which has been constructed and verified at the beamline of SSRF [3], a new high-resolution HXNP utilizing FZP as nanofocusing optics was designed. In future work, further optimization and upgrade for this HXNP will be conducted.

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