

# DEVELOPMENT OF MECHANISMS AND FRAME STRUCTURES FOR A LABORATORY-SCALE COMPACT SOFT X-RAY MICROSCOPY

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## INTRODUCTION

X-ray microscopy can fill the gap between optical microscopy (OM) and electron microscopy (EM). It uses the X-ray of which the wavelength lies from several nanometers to sub-nm. It makes the image resolution of X-ray microscopy much higher than OM. Recent research on micro-zoneplate for the objective of X-ray microscopy makes the X-ray image resolution even similar to that of EM[1]. X-ray microscopy can observe the samples thick up to 10um while EM can do for only 1um thick samples[2]. Especially, the interaction of soft X-ray is highly related to the atomic composition of samples therefore X-ray microscopy can be used widely from biology to industry[3].

Most of researches on X-ray microscopy used synchrotron as the X-ray source. Recently, however, rather compact X-ray sources are being used for X-ray microscopic imaging. Compact X-ray source usually has its X-ray intensity much weaker than synchrotron therefore the alignment and vibration of optical components should be one of the most important design criteria. In this paper, the mechanisms and frame structures for a laboratory-scale compact soft X-ray microscopy is presented.

## CONCEPT OF A LABORATORY-SCALE COMPACT SOFT X-RAY MICROSCOPY

Soft X-ray microscope researched for this paper is full-field type and, for a laboratory-scale one, X-ray source using liquid nitrogen and high power laser is used[4]. Double-ellipsoid condenser mirror is used to illuminate the specimen and micro-zoneplate is designed to focus the specimen image on X-ray CCD. Magnification ratio is from 300 to 1000 according to the position of CCD. Total system consists of source chamber, mirror chamber and other rather small chambers. In source chamber, the

components to make X-ray source as referred above, a tele-microscope to visualize the plasma and other required components is installed. Other main optical components for X-ray microscopy such as condenser mirror, specimen and Zoneplate are installed in mirror chamber.

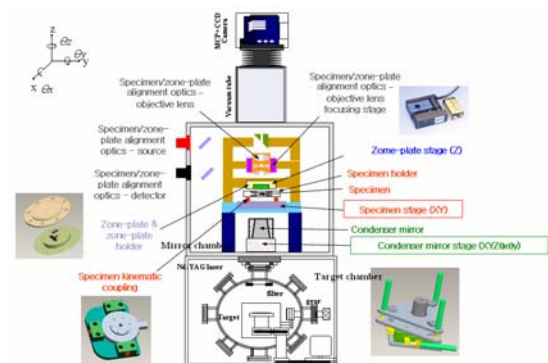


Figure 1: Conceptual design of mechanisms and frame structures of a laboratory-scale compact soft X-ray microscopy

As mentioned before, the alignment and vibration of optical components of a compact soft X-ray microscopy should be designed importantly. Due to the high magnification ratio, the misalignment of optics leads to the deterioration of X-ray image, or sometimes nothing can be detected from X-ray CCD. Vibration transmitted to optical components should blur the image therefore makes the image resolution bad.

The alignment capability of optical components is directly relate to the capability of mechanisms. Mechanisms also effect the vibration of optical components. Vibration is also influenced by the frame structure. Therefore, for the image quality of compact soft X-ray microscopy, the mechanisms for aligning optics and frame structures should be designed carefully.

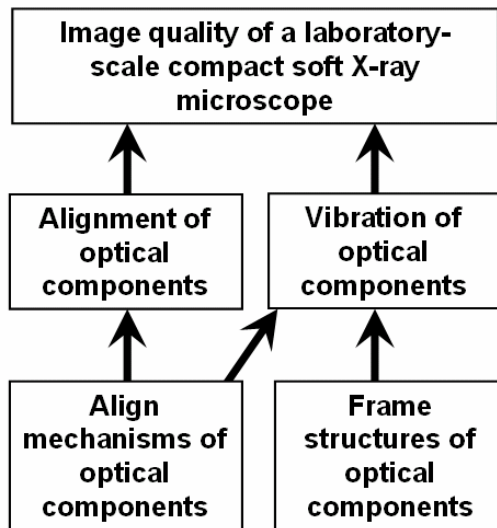


Figure 2: Effect of mechanisms and frame structures to X-ray image quality

### CONCEPTUAL DESIGN OF MECHANISMS AND FRAME STRUCTURES

In the compact soft X-ray microscope system, condenser mirror and zoneplate are most sensitive to alignment error and vibration. Because of the type of X-ray source, made by focusing the high power laser on nozzle jet of liquid nitrogen, it is desirable to correct the alignment error of condenser rather than X-ray source. Condenser mirror should have five degree of freedom from which the rotation about optic axis is excluded[4]. In addition, because the condenser mirror is 1:1 optics, Z error of condenser can be negligible to some extent. Then rest four DOF can be categorized by decenter alignment (XY) and tilt one ( $\theta_x \theta_y$ ), and each can be design separately.

Another sensitive optical component is zoneplate. Z error between sample and zoneplate changes the objective distance of zoneplate, and XY error the imaging area. Due to the high magnification ratio, XY motion of zoneplate causes also the error of CCD. In addition, the alignment of zoneplate is not so easy. Therefore, in this case, specimen is aligned in XY instead of zoneplate. Objective distance still can be aligned by Z stage of zoneplate.

Frame structure can be categorized into outer frame and inner frame. Outer frame supports the total chamber body while inner frame support the components inside the chamber. Figure 3

shows the concepts of outer and inner frame structures. Outer frame consists of three hollow posts connected to the extended flange between source chamber and mirror chamber. Additional support is plate under the source chamber to lower the maximum stress and strain of flange due to system mass. This support is shaped like a cylinder for the ease of assembly.

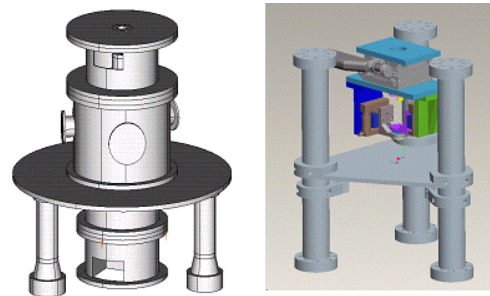


Figure 3 Concepts of outer and inner frame structures

Because of the type of X-ray source, the inner frame inside the source chamber is not easy to be installed. Therefore the inner frame in the mirror chamber only is described in this paper. As drawn in figure 3, inner frame consists of a middle plate supported by three hollow posts like outer frame. Sample is placed on the middle plate, and zoneplate and zoneplate Z stage is attached to the upper plate of mirror chamber. Specially, three posts is design to connect the lower and upper plate of mirror chamber to strengthen the stiffness of mirror chamber itself and the entire structure.

### DETAIL DESIGN OF MECHANISMS

As referred before, condenser mirror stage composed of decenter stage and tilt stage. This mechanism should have high motion resolution to align the condenser finely, and have high stiffness to maintain the position of condenser after the completion of alignment. For these purposes, the condenser stage shown in figure 4 is manufactured. In XY stage, two sets of cross-roller guides are used as guide mechanisms for high stiffness, and two sets of DC linear motor with PZT tip makes the fine XY motion by dual servo control. To stiffen in motion direction, coil springs are used to provide sufficient preload. Tilt stage uses three DC linear motors to make tilt motion. At the end of each linear motor, there is a ball-shaped tip and this makes a fully kinematic contact with a v-groove. Tilt stage also is stiffened by preloading with coil springs. Same concept of XY stage of condenser stage is

applied to the specimen stage. Figure 5 shows the manufactured specimen stage.

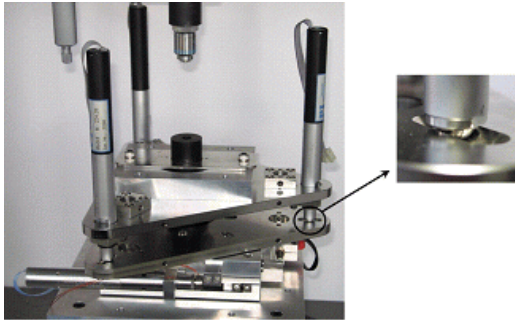


Figure 4 Manufactured condenser mirror stage

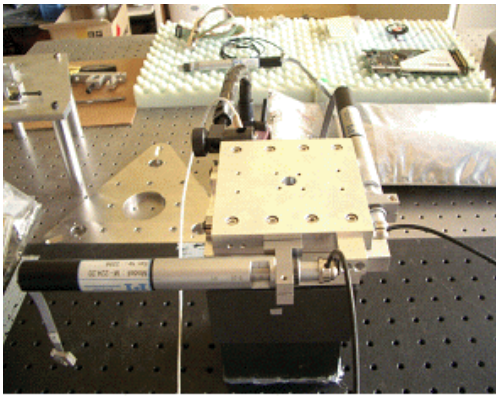


Figure 5 Manufactured specimen stage

Figure 6 and 7 shows the resolution test results of condenser and specimen stage. Condenser stage has 10nm resolution in XY, 0.08arcsec in  $\Theta_x$ , and 0.04arcsec in  $\Theta_y$  direction. Specimen stage has 10nm resolution in XY direction.

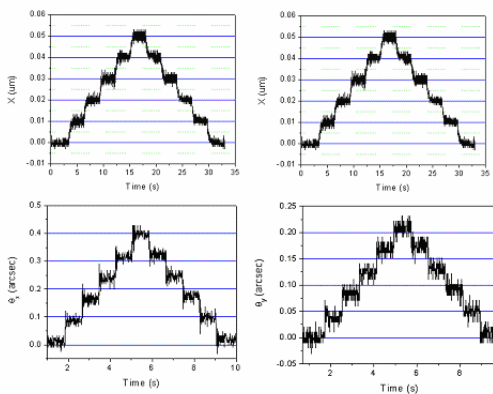


Figure 6 Resolution test result of condenser mirror stage

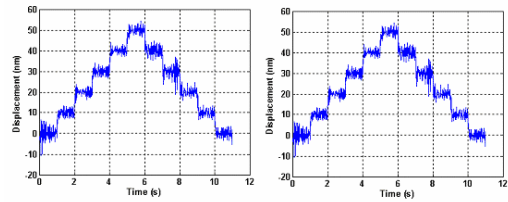


Figure 7 Resolution test result of specimen stage

### DETAIL DESIGN OF FRAME STRUCTURES

The objective of outer frame is set to the 1<sup>st</sup> natural frequency above 100Hz which can ensure the stability of general structures. Natural frequencies of outer frame and total structure are calculated by FEM simulation, and feasible solution is found by changing the important dimensions of outer frame. In statics, gravity and air pressure is considered. In dynamics, some parts difficult to design in FEM is simplified using lumped masses with same mass and inertia of original parts.

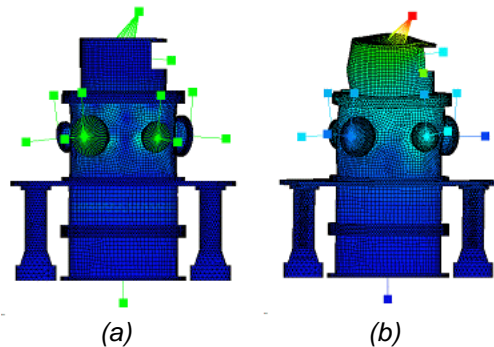


Figure 8 FEM result of outer frame (a) statics (b) modal shape of 1<sup>st</sup> natural frequency

The design results are shown in figure 8. Statics result shows that maximum displacement does not exceed 20um and maximum stress 50MPa. Dynamics shows that the 1<sup>st</sup> natural frequency is 103Hz.

The objective of inner frame is set to be reasonable numerical values of distance change between the optical components. First, the distance change due to vibration between specimen and zoneplate should not exceed 10nm considering that the objective image resolution is 50nm. Distance changes between other optical components should be less than 1um. Inner frame is also designed using FEM simulation. Distance change between components due to vibration is obtained from FRF simulation. FRF is calculated from modal

shapes of inner frame structures, and important dimensions are modified to find the feasible solution of inner frame. Vibration sources are the turbo pump attached under the source chamber, another turbo on the side of mirror chamber, and ground vibration.

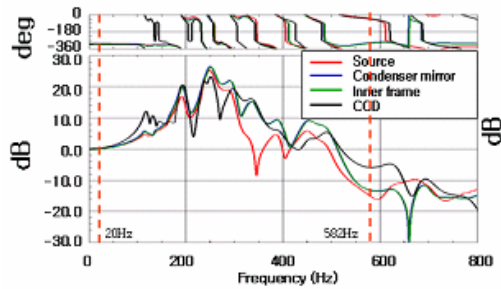
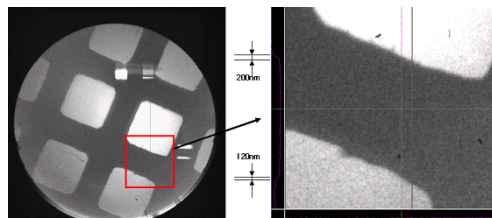


Figure 9 FRF result of inner frame

FRF graph in figure 9 is obtained in this manner, and this result shows that the objective of inner frame design is accomplished.

### IMAGE ACQUISITION RESULT

Using the mechanisms and frame structures designed in this paper, a gold mesh image shows in figure 10 is acquired. The magnification ratio is set to be 325 because of the difficulty of alignment. The edge profile of the image shows the image resolution is about 120nm. This can be improved by designing the vibration of optical components more specifically.



배율 325X

Figure 10 Image acquisition result of a gold mesh with 2000 pitches in 1" (X325)

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