Title of Project : Development of X-ray nanobeam optics by precision wavefront control

YAMAUCHI Kazuto
(Osaka University, Graduate School of Engineering, Professor)

Research Project Number : 21H05004 Researcher Number : 10174575
Term of Project : FY2021-2024 Budget Allocation : 118,600 Thousand Yen
Keyword : X-ray optics, compensation optics, precision machining, precision metrology

【Purpose and Background of the Research】

In a continuous progress of synchrotron radiation (SR) X-ray sources, 3rd generation ring sources and X-ray free electron lasers (XFEL) have been realized, and the pace of the development is still accelerated. The electron beam convergence in the upgrading 3rd generation sources is enhanced to the limit, and "perfect coherent X-rays" are expected to be used. In XFELs, the power and quality of the beam are still being improved. These light sources can drastically raise the theoretical limit of the focusing performance and open up unexplored X-ray sciences such as ultra-strong photon field physics and ultrahigh resolution X-ray microscopy by forming nanobeams. In this research, we propose a new condenser system that can suppress the coma aberration and precisely control the wavefront as adaptive optics (FIG 1). This is an optical system with robustness that can provide sub-10nm beam into practical usage. In collaboration with researchers in the fields of nonlinear optics, we conduct demonstrational experiments of higher-order nonlinear optical, and so on.

【Research Methods】

In this research, we propose the world's first attempt at an optical system in which focusing is performed by two mirrors (convex hyperbola (upstream) and concave ellipse (downstream)). We have already found that the coma aberration can be greatly reduced in this optics. Whereas the allowable incident angle error of X-rays is 10^{-7} rad level in the conventional KB (Kirkpatrick-Baez) mirrors, it is expanded to more than 10^{-3} rad in this optics, which can actualize significantly robust. In addition to this, since the principal plane moves to the focus due to the introduction of the convex mirror, a large working distance becomes possible even in the ultimate focusing.

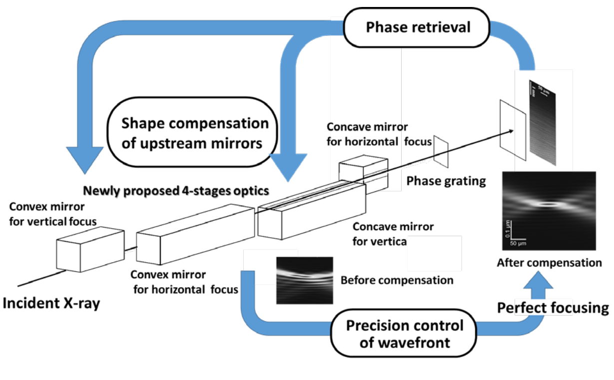

FIG 1 Optical configuration and wavefront control system

From a viewpoint of mirror precision, the shape accuracy higher than 1nm (PV) is required for sub-10nm focusing. It is impossible to prepare offline so that adaptive optical system based on waveoptics is planned in this research, in which the wavefront error is measured in-situ and the wavefront form is precisely controlled simultaneously by a deformable phase compensator mirror. Research items to be carried out for this purpose are shown below.

(1) Detailed understanding of the characteristics of the concave / convex combination optics and implementation of optical system design.
(2) Realization of a high-precision multilayer mirror that can preserve the coherence of X-ray beams.
(3) Establishments of wavefront measurement method and alignment error evaluation method using synchrotron radiation X-ray itself.
(4) Development of shape-variable phase correction mirror and realization of in-situ wavefront compensation.

【Expected Research Achievements and Scientific Significance】

From the current situation where X-rays acquire perfect coherence at the latest SR sources, the full applications of Fourier optics both to in-situ measurement and in-situ compensation of X-ray wavefront truly contribute to the academic progress of coherent X-ray science. Realizing a mirror optical system that can have a high robustness against disturbance, it is expected that X-ray microscopy science will significantly evolve. In addition, this optical system can provide an ultra-strong photon field that far exceeds the conventional intensity and greatly contribute to the evolution of X-ray nonlinear optics.

【Publications Relevant to the Project】

・ S. Matsuyama, T. Inoue, J. Yamada et al., and K. Yamauchi, Nanofocusing of X-ray free-electron laser using wavefront-corrected multilayer focusing mirrors, Scientific Reports 8, 17440, 2018.
・ T. Goto, S. Matsuyama et al., and K. Yamauchi, Nearly diffraction-limited hard X-ray line focusing with hybrid adaptive X-ray mirror based on mechanical and piezo-driven deformation, Optics Express 26, 17477, 2018.
・ H. Mimura et al., and, K. Yamauchi, Breaking the 10nm barrier in hard-X-ray focusing, Nature Phys. 6, 122, 2010.

【Homepage Address and Other Contact Information】

http://www-up.prec.eng.osaka-u.ac.jp/