【Grant-in-Aid for Scientific Research(S)】
Science and Engineering (Engineering I)

Title of Project : Adaptively controlled multistage nanofocusing systemfor x-ray free electron laser

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Research Area : ultraprecision machining, optical fabrication and metrology, x-ray optics
Keyword : ultraprecision machining, optical sensing, x-ray optics

【Purpose and Background of the Research】

Third generation synchrotron radiation facilities are now producing high-quality light with wavelengths ranging from the infrared to hard-x-ray regions. The use of hard x-rays in conjunction with analysis methods such as x-ray diffraction, x-ray fluorescence, x-ray absorption, and x-ray photoelectron spectroscopy has unique advantages for investigating the structure, elemental distribution, and chemical bonding state of advanced materials and biological samples. In these analytical methods, the resolution, signal strength, and contrast must be as high as possible. In this regard, the development of a hard-x-ray focusing device is important to meet these requirements.

In the past decade, we have attempted to condense synchrotron radiation x-rays by using a mirror optical system, which has many advantages such as achromaticity, high focusing efficiency, and long working distance. In scanning microscopy, we broke the 10nm barrier in beam size by achieving 7nm×8nm spot size (Nat. Phys. (2010)). Moreover, in the diffraction microscopy, we achieved a 3nm resolution (Nano Lett. (2010)). In this study, we will attempt to realize high-precision multistage mirror optics for the single-nanometer focusing of next generation x-ray free electron lasers (XFELs).

【Research Methods】

The XFEL has very small source divergence, which is theoretically limited by a diffraction; thus, the beam size of the XFEL at the experimental hutch becomes very small, such as smaller than 200μm. To condense an x-ray with a wavelength shorter than 1Å into a single-nanometer spot size, the numerical aperture (NA) must be larger than 10^{-2}. In this study, we plan a multistage nanofocusing system to optimally control the NA at the final stage. Additionally, we will develop in situ wavefront measurement and correction methods to enable the construction of a novel adaptive optical system. Adaptive compensation may be a key technology that can be used to satisfy the Rayleigh quarter-wavelength rule and to overcome the unprecedented accuracy required in an ultimately high precision optical system. In this multistage focusing, we propose two-stage focusing as an intial trial. The mirror on the first stage will play the roles of changing the NA and prefocusing the XFEL down to micrometer size. The mirror on the second stage will be multlayer-coated and will have a large NA to focus the beam down to a single-nanometer size. The First mirror is planned to be controlled adaptively to enable the wavefront compensation.

【Expected Research Achievements and Scientific Significance】

The XFEL has a spatially fully coherent and ultrashort-pulse beam. The peak intensity is 10^9 times higher than that of the x-rays provided at SPring-8. Such x-rays will enable us to explore the forefront of x-ray science and technology such as x-ray nonlinear optics, high density-plasma physics, and single-molecule diffraction microscopy. In particular, the structural analysis of a single protein molecule will be possible by diffraction microscopy. In addition, the development of the high-precision optics will contribute to next-generation optical fabrication technology.

【Publications Relevant to the Project】

[1] H. Mimura, S. Handa, T. Kimura, H. Yumoto, D. Yamakawa, H. Yokoyama, S. Matsuyama, K. Inagaki, K. Yamamura, Y. Sano, K. Tamasaku, Y. Nishino, M. Yabashi, T. Ishikawa, and K. Yamauchi, "Breaking the 10 nm barrier in hard-X-ray focusing," Nature Physics, vol. 6, 2010, pp. 122-125.

[2] Y. Takahashi, N. Zettsu, Y. Nishino, R. Tsutsumi, E. Matsubara, T. Ishikawa, and K. Yamauchi, "Three-dimensional electron density mapping of shape-controlled nanoparticle by focused hard X-ray diffraction microscopy.," Nano letters, vol. 10, 2010, pp. 1922-6.

【Term of Project】 FY2011-2015

【Budget Allocation】 166,100 Thousand Yen

【Homepage Address and Other Contact Information】

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