Nano-focusing of soft x-ray free-electron laser with a hybrid two-stage reflective optics

Hiroto Motoyama[1], Shigeki Owada[2,3], Gota Yamaguchi[1], Takehiro Kume[1], Kensuke Tono[2,3], Yuichi Inubushi[2,3], Takahisa Koyama[2,3], Satoru Egawa[1], Haruhiko Ohashi[2,3], Makina Yabashi[2,3], and Hidekazu Mimura*[1]

[1]*The University of Tokyo, Japan*

[2]*Japan Synchrotron Radiation Research Institute (JASRI), Japan*

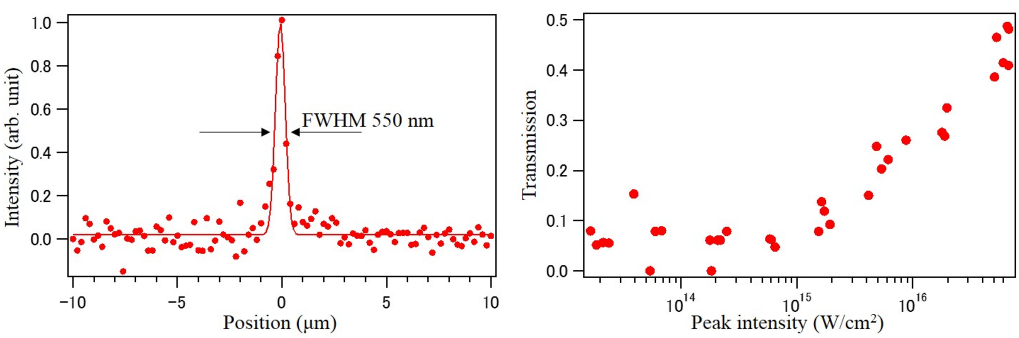
[3]*RIKEN SPring-8 Center, Japan*

**mimura@edm.t.u-tokyo.ac.jp*

Combination of X-ray free electron laser (XFEL) with reflective focusing optics has enabled to generate ultraintense X-ray beams, which is highly useful for exploring various scientific frontiers such as nonlinear X-ray optics. Although hard X-ray FEL can be focused down to a sub-micron region with a simple K-B mirror system, a typical spot size of soft X-ray FEL has been limited to be several microns with this geometry, mainly due to a geometrical constraint. In this presentation, we propose a novel scheme, a hybrid two-stage reflective optics, to generate a nano-focus of soft X-ray FEL with a high intensity above 10^{16}W/cm^2.

This scheme combines a standard K-B optics with a small numerical aperture (NA) and an ellipsoidal mirror with a large NA. The soft x-ray FEL beam is first focused with the K-B system that has a large spatial acceptance of 15 mm with a focal length of $\sim$ 2 m, and confined to a $\sim$10 μm focal spot. The ellipsoidal mirror with a short focal length of about 35 mm, located after the K-B focus, refocuses the beam to produce a sub-1-μm spot with a high efficiency.

We designed and constructed the focusing system, and tested it at BL1 of SACLA. Figure (a) shows an intensity profile at the focus, measured with a knife-edge scanning method, at a photon energy of 100 eV. We confirmed generation of a small focus with a size of 550 nm in FWHM. Next we used the focused beam to irradiate a Si_3N_4 membrane, and measured the transmission dependence on beam intensity at a photon energy of 120 eV, as shown in Figure (b). We found a drastic increase in transmission for higher intensity over 10^{15} W/cm^2; the transmission at an intensity of 5×10^{16} W/cm^2 reached to 50 %. This abrupt increase is explained by a saturable absorption effect at the Si L-edge with a binding energy of 99.8 eV. We will discuss various possible applications that are enabled by this small focused beam with an extreme intensity.



(a) Measured intensity profile at the focus

(b) Relative increase in transmission

(a)Intensity profile at the focus measured with knife-edge scanning method. (b) Dependence of transmission on intensity.