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XFEL Sub-10 nm Focusing Mirror System at SACLA for Achieving 10^22 w/cm2 Intensity

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The XFELs with an anomalously high peak brilliance are opening the way to a number of novel X-ray photon research paths. At SPring-8 Angstrom Compact Free-Electron Laser (SACLA) [1], the XFEL pulses with high stability and short pulse duration (6-7 fs) have been regularly provided thanks to the unique electron gun, accelerator, and undulator systems [2]. By focusing these XFELs to 1um-100nm, the peak intensity has been dramatically increased and new phenomena in hard X-ray nonlinear optics have been explored, such as observation of saturable absorption [3], two-photon absorption [4], and the atomic inner-shell laser emission [5]. To further promote the study in the ultra-intense X-ray laser field, we have developed a focusing system that achieves sub-10nm spot size and 10²² W/cm² intensity.
For the sub-10 nm focusing optics, an advanced Kirkpatrick-Baez (AKB) mirror system based on Wolter-type III geometry [6] has been adopted. The AKB consisting of one-dimensional Wolter mirrors can satisfy Abbe' s sine condition, which leads to a reduced coma aberration and a high tolerance to the incident angle error. We have designed and developed the AKB mirror system for SACLA BL3-EH4c at a photon energy of 9.1 keV. One of the remarkable challenges for the development was the fabrication of the mirrors with 1-nm accuracy. We applied an X-ray wavefront correction scheme [7] for the precise fabrication, and achieved wavefront accuracy of λ/15 rms which satisfies Maréchal's criterion. Ptychographic probe measurements revealed the focusing spot size of 6.6 nm (horizontal) × 7.1 nm (vertical), indicating eventually attained focused intensity of 1.21 × 10²² W/cm².
References:
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