Intense x-ray interaction experiments with SACLA x-ray free electron laser

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Abstract

The recently developed X-ray Free-Electron Laser, combined with high precision optics allow us to enter a new range of interaction parameters for X-ray interaction physics. Several symbolic experiments succeeded, such as inner-shell lasing of atoms pumped by the X-FEL, saturable absorption, and self-guiding of an X-ray laser pulse. In addition, through this research, we can obtain new knowledge about X-ray interactions. Typical experimental results are introduced in this paper. The physical models used to understand the interaction mechanisms are also described.

X-ray free electron laser

The first demonstration of an X-ray Free Electron Laser (X-FEL) occurred in 2009 at the SLAC Laboratory in US[1]. In Japan, we also developed a Japanese X-ray Free Electron Laser named SACLA[2] (SPring-8 Angstrom Compact free electron LAser), operating since 2011. Up to now, these two XFELs are being used for research on intense X-ray interactions with matter. After the success of intense X-ray laser pulse generation, many remarkable advances in X-ray science were achieved[3,4,5,6]. Especially, because of the short wavelength of X-FEL, 50nm focusing was achieved using high-precision optics for the X-rays [7]. By using this technology, a very intense field of more than 10^{20}W/cm^2 at 8~10 keV hard X-ray photon energy has been achieved. This intensity is high enough to open a new field of X-ray photon science.

Interaction experiments

At present, saturable absorption of 8 keV photons in Fe[5], X-ray laser guiding[5], and Kα laser generation[8] at 8 keV in Cu have been achieved. These are expected to improve coherence of X-ray laser light. In this research, details of the atomic physical situations are clarified. For example, the branching ratio between Kα1 and Kα2 can be changed due to strong induced emission process even in the hard X-ray region. We think this is the first observation of control of inner-shell atomic transitions by an applied X-ray field. Comparing the simulation results with the experimental intensity dependence, we find that even the branching ratio of Auger decay and fluorescence decay can be changed at the strong saturation condition of Kα lasing.

To analyse the detailed spectral shape of the Kα laser, we found that energies of inner-shell electrons are affected not only by increased binding of the remaining 1s electron due to the 1s vacancy, but also by electrons from neighboring atoms and ionization of 3d electrons. This means we have the possibility to control the X-ray laser wavelength by changing the condition of more weakly bound electrons (3d, 3p), which is a common technique to control laser wavelegth in solid state lasers.

Near future

In the Japanese SACLA facility, sub 10nm focusing optics are already prepared and tested now. By using these, we can reach more than 10^{21}W/cm^2 with a hard X-ray laser. We may expect other new phenomena such as strong nonlinear effects with x-ray lasers. In addition, we will design new type of x-ray laser, which includes gain, a saturable absorber, and gain guiding components. In near feature, a well organized and functional X-ray laser will be developed.

References

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