ULTRA-INTENSE X-RAY LASER MATTER INTERACTION WITH HARD X-RAY FREE ELECTRON LASER

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Recently, we have succeeded to produce extremely high intensity of hard x-rays with the Japanese free electron laser facility (SACLA)[1]. A hundred micro joule, 5~10keV, 7fs X-ray pulse can be generated with Self Amplified Spontaneous Emission (SASE) mode. In addition, two-stage focusing system can generate an ultrasmall spot on a target can be focused to 50nm diameter[2]. The nominal focal intensity exceeds 10^{20}W/cm^2. Using such an extreme high intensity x-ray pulse, it is possible to observe several nonlinear optics and quantum optics phenomena which are new for the hard x-ray region. In this talk, our recent experiments will be reviewed. Those include nonlinear transmission, phase front reshaping, saturable absorption, and laser-pumped inner-shell lasers.

The common interaction scheme is followed. When a x-ray pulse whose photon energy is tuned to be just above the K-edge of the target atom, many atoms inside solid target are ionized with inner-shell ionization. It is well known that this "hole" of the inner K-shell orbit is quickly reoccupied with the outer-shell electron. However, with well-tuned x-ray and high enough intensity ($>10^{19}$W/cm^2), we can make a high density single K-shell vacancy atoms with the solid density. This condition shifts the K-shell absorption edge toward higher energy direction and that results in the nonlinear transmission phenomena in hard x-ray[3]. Similar to the optical science, due to Kramers- Kronig relation, real part of optical constant is also changed along to the path of incident x-ray. It means we expect light guiding mode in x-ray region[3].

These media are also suitable for extremely large gain for Kalpha laser[4]. With this conversion scheme, it is expected a large improvement of coherency for SASE x-ray lasers. Here, we also report on a successful achievement of a hard x-ray inner-shell atomic laser operating at a wavelength of 1.5 angstrom. XFEL pulses with an intensity of $\sim10^{19}$ W/cm^2 tuned to the copper K-absorption edge ($h\nu_p$=9.0 keV) were used to efficiently pump the K-shell electrons of copper. The resulting population inversion generated strong amplified spontaneous emission on the Cu Kα lines ($h\nu_s$=8.0 keV). Furthermore, we operated the XFEL source in a two-color mode[5]: one color tuned for pumping and the other for seeding. We found significant improvement of temporal coherence in the pumped copper medium with the XFEL seeding method. For the hard x-ray atomic laser, both narrow bandwidth and excellent longitudinal coherence are very important for ultrafast X-ray spectroscopy, X-ray quantum optics, and fundamental physics applications.

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