Resonant Betatron Hard X-rays from Ionization Injected Electrons in a Laser Plasma Accelerator

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Abstracts: A new scheme for bright hard x-ray emission via controlled ionization injection is presented. A total photon yield 8×10^8/shot and 10^8 photons with energy over 110 keV are obtained. In particular, the yield is 10 times higher than the case of self-injection mode under similar laser parameters. Simulation suggests that ionization injected electrons are quickly accelerated to the driving laser region and subsequently driven into betatron resonance. The present scheme enable the single stage betatron radiation from LWFA to be extended to bright γ-ray radiation, which is beyond the capability of the 3rd generation of synchrotrons.

Ultrafast x-ray sources have tremendous applications in time resolved x-ray diffraction and x-ray absorption spectroscopy to study the transient properties of condensed matter and biological structures, which have been realized so far mainly by use of x-ray free electron lasers (XFELs) with high brightness. However, XFELs are huge facilities accessible to limited users. With the development of femtosecond high power lasers, laser plasma x-ray sources are becoming increasingly attractive due to their compactness and natural synchronization of drive lasers and produced x-ray sources. X-ray emission from laser plasma interactions, such as Kα x-ray emission, nonlinear Thomson scattering and betatron x-ray sources, have been intensively studied. In particular, the betatron x-ray emission from electron oscillations in the laser wakefield acceleration (LWFA) is a promising source for its high spatial coherence, sound photon yield ($>10^8$/shot) and high photon energy (up to MeV).

In this report, we show the first study of bright hard x-rays based upon ionization-injected electron beams accelerated in LWFA via betatron oscillations. Highly collimated hard x-rays with a photon flux of 8×10^8/shot and with 10^8 photons over 110 keV have been produced with a pure nitrogen gas jet irradiated with 100 TW laser pulses. This yield is about 10 times higher than that obtained with helium gas under similar laser conditions, and much higher than other experiment results reported working in the self-injection mode. Two-dimensional (2D) particle-in-cell (PIC) simulations suggest that the enhanced betatron photon energy and photon flux are due to ionized early injection and effective betatron resonant oscillation in the laser fields.

The experiment was carried out using the hundred TW laser system at the Key Laboratory for Laser Plasmas in Shanghai Jiao Tong University, which delivered 40fs pulses with energy up to 3J in this experiment. The pulses were focused by an f/20 off-axis-parabola onto a 1.2mm × 10mm supersonic gas jet. The focal spot has a $1/e^2$ radius of w_0=21μm containing 50% energy. The resultant laser peak intensity was up to 1.0×10^{19} W/cm^2, corresponding to normalized vector potential a_0=2.2. A top-view system was set to monitor Thomson-scattering. The electron beams emitted from the gas jet were dispersed by a 16cm-long dipole magnet with magnetic field strength 0.98T. A combo of 4 image plates (IP) (Fuji Film SR series) covered with 12μm Al foil was set behind the magnet to record the electron and x-ray signal simultaneously. For comparison, nitrogen and helium gases had been used in the same experiment. In the presentation, we will show the details of the comparison, and the physical mechanism, which plays a critical role but has not included so far.