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Construction of a magnetic bottle electron spectrometer for electron energy measurement in BISER X-ray and Xe gas interaction

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The research on ultrafast phenomena in high-energy X-rays with matters has been conducted extensively. In particular, high-order harmonics has been expected as high-brightness coherent X-ray light sources having a pulse width of attosecond (10^{-18} s, as). Such a short X-ray pulse would enable us to understand electron behaviors within the atom in future. In fact, the shortest pulse duration realized has been 80 as[1], which is the similar time scale with that of electron to revolve the hydrogen classical orbit (150 as).

On the other hand, QST groups discovered the new harmonics radiation from the relativistic plasma[2]. This was called the Burst Intensification by Singularity Emitting Radiation (BISER). It produces the even as well as odd harmonics, in contrast to the conventional harmonics (just odd harmonics). The particle-in-cell (PIC) simulation showed that the X-ray pulse had attosecond coherent X-ray source extended to 10-keV energy range and clarified the X-ray radiation mechanism. Moreover, the X-ray pulse was predicted to be around 170 as[2]. Our final research goal is to develop a method to observe attosecond pulse width by means of a single shot measurement. In this study, we developed the electron spectrometer having high-energy resolution for measurement to examine the interaction of the BISER with Xe gas, where the innershell 4*d* electron can be photoionized, resulting in generating the photo- and Auger electrons. The electron to investigate is 8.26 eV Xe 4*d* Auger electron, because the BISER generates various photoelectrons due to 1.55-eV separated harmonics, resulting in difficult to resolve them precisely.

We constructed a magnetic bottle spectrometer, as shown in Fig. 1. The magnetic mirror field created by a permanent magnet (1.0 T) and solenoid coil (1.0 mT) collected the emitted electrons up to 50~100% efficiency. For designing, the mirror field was calculated using a finite-element method. Moreover, electron orbits in a magnetic field were investigated by the equation of motion in the field. It was composed the main chamber and 1.2-m time of flight tube. The BISER beam coming from down interacted with Xe gas targets introduced from a needle nozzle (0.2 mmϕ) through a variable leakvalve. The electron generated was guided to the TOF tube along the mirror field. The detector was a micro-channel plate (42 mmΦ). The permanent magnet (neodymium:30 mmΦ, *L*:30 mm, and a taper angle: 110°) and the needle nozzle, and 3.0 mmΦ aperture to improve energy resolution were installed inside the chamber. A 200-nm Zr thin foil was set to block unnecessary BISER radiations. The magnet, needle and aperture were aligned by a shadow graph.

The BISER generated by a fundamental Ti:S laser pulse of $\leq 5\times10^{19}$ W/cm^2 was focused onto 2.5 mm and it total energy of 6.2 pJ. The gas pressure in the interaction chamber was up to 1.0×10^{-3} Pa.

In order to characterize the spectrometer developed, the energy spectra were measured when Xe gas was irradiated with the BISER X-rays. Fig. 2(a) graphs the comparison between a relative Auger electron intensity. Fig. 2(b) shows the energy spectra calculated from the flight time. As shown in Fig. 2(b), the experiments show that energy spectra associated with Xe 4*p* electron is observed, although the signal-noise ratio is quite poor. In particular, a peak around 8.26 eV appears. For the next experiments, focusing mirror will be replaced to Mo/Si multilayer mirrors with a high reflectivity to increase electron number.

References

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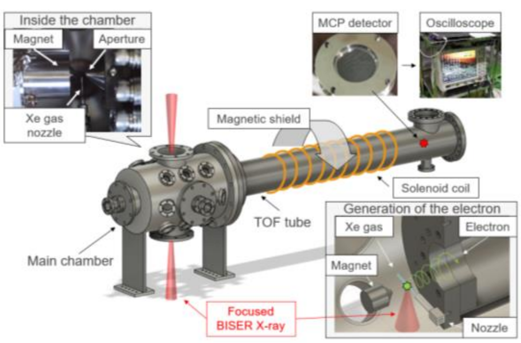

FIG. 1. Schematic diagram of the magnetic bottle electron spectrometer.

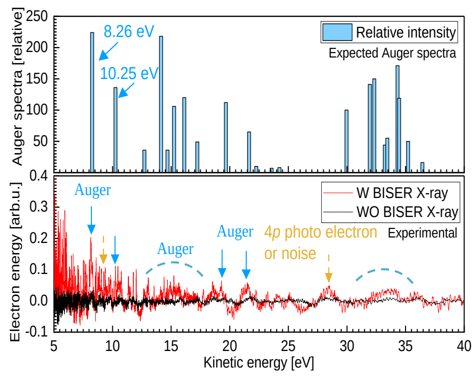

FIG. 2. (a) A relative Auger electron intensity. (b) Electron spectra generated in BISER and Xe interaction.