Magnetic-bottle electron energy spectrometer for measuring 25 as pulses

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Synopsis: Non-uniform field in a magnetic-bottle electron energy spectrometer (MBEES) was simulated with finite-element software. The result showed that a field close to 1T may be obtained at the interaction region with a carefully designed NdFeB permanent magnet and soft iron pole piece. This field meets the requirement for 25as pulse duration measurement.

The duration of attosecond pulses is usually retrieved from streaked photoelectron energy spectra produced by XUV attosecond pulses [1]. A time-of-flight (TOF) spectrometer is the most widely used device for electron energy spectrum measurement. Among a variety of different TOF designs, a magnetic-bottle electron energy spectrometer (MBEES) with a non-uniform magnetic field is more preferable due to its large acceptance angle - at least 2π steradian [2]. It is critical to detect as many electrons as possible in attosecond photo-electron measurements because of the low XUV photon flux and low XUV to electron conversion efficiency.

A 25 as pulse corresponds to a spectrum of 75 eV FWHM, which requires the spectrometer to cover a 0~150 eV range. To resolve pre- or post-pulses one laser cycle away from the main attosecond pulse, the resolution of the spectrometer should be better than 0.4 eV [3].

Typically, the field in MBEES consists of a strong field at the interaction region (B_i), produced by a permanent magnet and a pole piece, and a weak field in the drifting tube (B_f) created by a solenoid. The non-uniformity of the field parallelizes the electron trajectories from the interaction region without changing the energy or flying time significantly.

There are three key requirements that affect the energy resolution [2]. First, the ratio of the weak and strong fields should be $B_f/B_i \approx \Delta E/E \approx 0.1\%$. Second, the adiabaticity parameter $\chi_1 = \frac{2\pi m_e v}{eB_z}\left|\frac{dB_z}{dz}\right|$ is smaller than unity. Third, the transition region (the region where the field drops from about 1 T to 100 G) should be small. However, this requirement contradicts the adiabatic requirement. Therefore, a carefully formulated simulation of the magnetic field is required for the design of MBEES.

The field of an NdFeB magnet with a soft iron pole piece was simulated. A cylindrical magnet and a properly shaped pole piece give one of the best results. This field, combined with the solenoid field, is shown in Fig. 1. At the interaction region (0.5 mm from the pole face), B_i is more than 0.8 T while B_f = 10 G in the drifting tube. For 1 eV electrons, χ_1<0.15. Simulations also showed that the field at the interaction region may be further increased if the soft iron pole piece is replaced by a cone-shaped permanent magnet while χ_1 is kept the same.

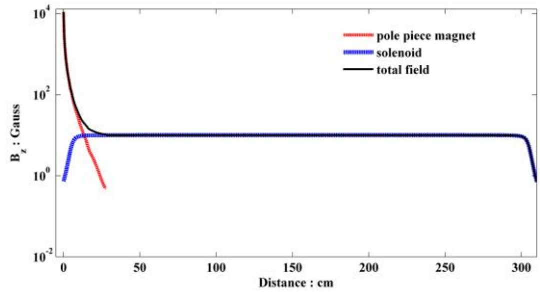

Fig. 1. Calculated magnetic field along z-axis (B_z).

In conclusion, we have designed a magnet and a pole piece to produce a non-uniform magnetic field with $B_f/B_i \approx 0.1\%$ and χ_1<0.15. The MBEES based on this field will be able to measure 0~150 eV electrons with 0.1% energy resolution and 2π-steradian acceptance angle, which guarantees a successful measurement for 25 as pulses. This material is supported by the U. S. Army Research Office under Grant No. W911NF-07-1-0475, and by the Chemical Sciences, Geosciences, and Biosciences Division, U.S. Department of Energy.

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