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Direct Measurement of Compressed Electron Pulse Duration through the Interaction with Terahertz Waves

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Keywords: Ultrafast time-resolved electron diffraction, Terahertz wave, Electron beam, Terahertz streaking, Pulse duration measurement.

Ultrafast time-resolved electron diffraction is one type of pump-probe measurement that uses an electron pulse as a probe. This methodology directly observes the structural dynamics of atomic and molecular rearrangements induced by photoexcitation on the femtosecond to the picosecond timescales [1]. Since the electrons are charged particles, they can be controlled with an external electrical field. Recently, the probe electron pulses for ultrafast time-resolved electron diffraction and electron microscopy have been controlled with the terahertz (THz) wave [2,3], where the THz wave can be used to accelerate or deflect the electron pulses and to measure the duration of the electron pulses. The THz wave has also been employed as a pump pulse [4]. Here, we are developing a time-resolved electron diffraction measurement setup with a radio-frequency cavity to compress the electron pulses [5]. To measure the compressed electron pulse, we conducted a THz streaking experiment. This experiment generates an instantaneous electric field by irradiating a metal resonator with a THz pulse. The electric field deflects the electron pulse as it passes through the metal resonator. According to the time evolution of the beam width or center position of the electron pulses, we can directly measure the pulse duration of the electron pulse.

The THz generation system is based on an organic BNA crystal. The THz wave is focused on the metal resonator using a lens with a focal length of 30 mm in the vacuum chamber. The polarization axis of the generated THz electric field is horizontal to the resonator; therefore, the electron pulse is horizontally deflected. Without compression by the RF cavity, the pulse duration was estimated to be 9.8 ps based on the spread of the electron beam width [Fig. 1(a)]. With the RF cavity activated, both the spread of the electron beam width and the oscillations in its center position were observed. Several Gaussian functions, synchronized with the oscillation of the center position of the electron beam and sharing the same full width at half maximum (FWHM), were fitted to the temporal profile of the electron beam width to determine the pulse duration [Fig. 1(b)]. Since the FWHM of the electron beam width was measured to be 2.3 ps, the compressed electron pulse duration was determined to be less than this value. Further improvements in the setup and additional analysis will enable more precise pulse duration measurement.

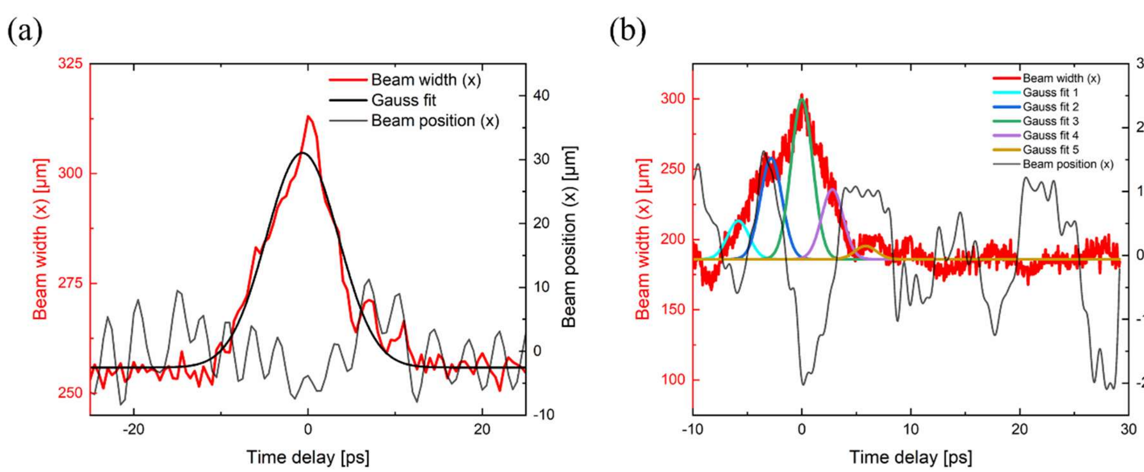

FIGURE 1. Time evolution of the beam width (red line) and center position (gray line) of the electron pulse. (a) Without electron pulse compression. The black line indicates the fitted Gaussian function, with the FWHM of the electron beam width being 9.8 ps. (b) With electron pulse compression. The colored lines (except for the red one) indicate the fitted Gaussian functions, synchronized with the oscillation of the center position of the electron beam and sharing the same FWHM (2.3 ps).

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