Ultrafast X-ray Science at the Advanced Light Source

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Abstract: The application of femtosecond x-ray pulses to probe structural dynamics is a rapidly emerging area of ultrafast research. Recent results and future plans for the development of femtosecond x-ray science at the Advanced Light Source are presented.

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1. Introduction

An important frontier in ultrafast research is the application of femtosecond x-ray pulses to investigate structural dynamics associated with phase transitions in solids, chemical reactions, and rapid biological processes. The fundamental time scale for such processes is an atomic vibrational period, ~100 fs. Since x-rays interact with core electronic levels they can provide direct information about atomic structure. X-ray diffraction, extended x-ray absorption fine structure (EXAFS), and related x-ray techniques are widely used at modern synchrotrons providing high-brightness x-ray beams. However, the time resolution available from synchrotrons is nearly three orders of magnitude too slow to probe atomic motion within a single vibrational period. We have recently generated femtosecond synchrotron pulses from the Advanced Light Source (ALS) using ultrashort laser pulses[1]. Future plans for developing femtosecond x-ray science at the ALS will be discussed.

2. Laser Modulation of Relativistic Electrons

The duration of synchrotron pulses is determined by the duration of each stored relativistic electron bunch (~30 ps or longer). However, a femtosecond laser pulse can be used to create femtosecond time structure on a long electron bunch via energy modulation and subsequent spatial separation of an ultrashort slice of electrons. Femtosecond x-rays are then generated from the ultrashort electron slice.

Modulation of the electron energy is accomplished by co-propagating a femtosecond laser pulse with the stored electron bunch through a wiggler (Fig 1a). The field of the laser pulse effectively accelerates the underlying electrons as they traverse the wiggler. The optimal interaction occurs when the central wavelength of the spontaneous emission from an electron passing through the wiggler, matches the laser wavelength (FEL resonance)[1].

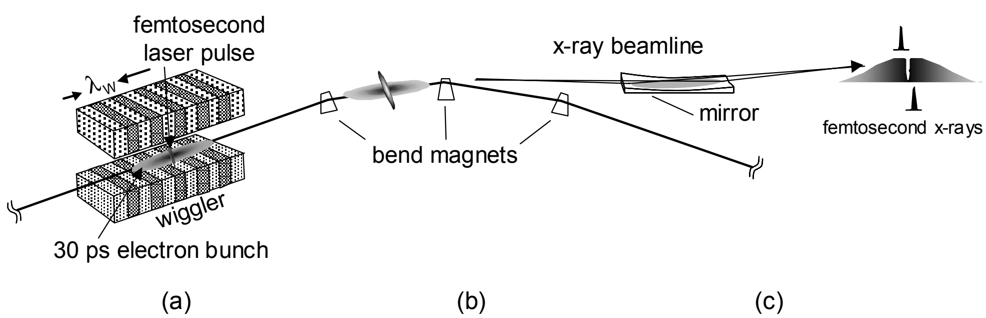

Fig. 1. Schematic of the laser-slicing method for generating femtosecond synchrotron pulses.

The laser-induced energy modulation is several times larger than the rms beam energy spread and is applied only to an ultrashort slice of the electron bunch. The modulated electrons are then spatially separated from the rest of the electron bunch (in a dispersive bend of the storage ring) by a transverse distance that is several times larger than the rms transverse size of the electron beam (Fig. 1b). Finally, by imaging the synchrotron x-rays from the displaced beam slice to the experimental area, we are able to separate out the radiation from the offset electrons (Fig. 1c).

3. Measurement of Femtosecond Synchrotron Pulses

Femtosecond synchrotron pulses are directly measured by cross-correlating the visible light from a bend-magnet beamline with the synchronized laser pulses. Figure 2a shows a correlation measurement of the femtosecond “dark” pulse that appears as a narrow hole in the main pulse, and originates from the central core of the sliced electron bunch. Figure 2b shows a measurement of the ~300 fs pulse originating from the spatial wings of the sliced electron bunch. The measured pulse duration is determined by the storage ring dispersion integrated from the wiggler to the radiation bend-magnet. A new beamline, dedicated to ultrafast x-ray spectroscopy is currently under construction at the ALS and will provide x-ray pulses of <100 fs duration. The femtosecond time structure is invariant over the entire spectral range of bend-magnet emission from the near infrared to the x-ray regime, making this a powerful tool for femtosecond x-ray spectroscopy.

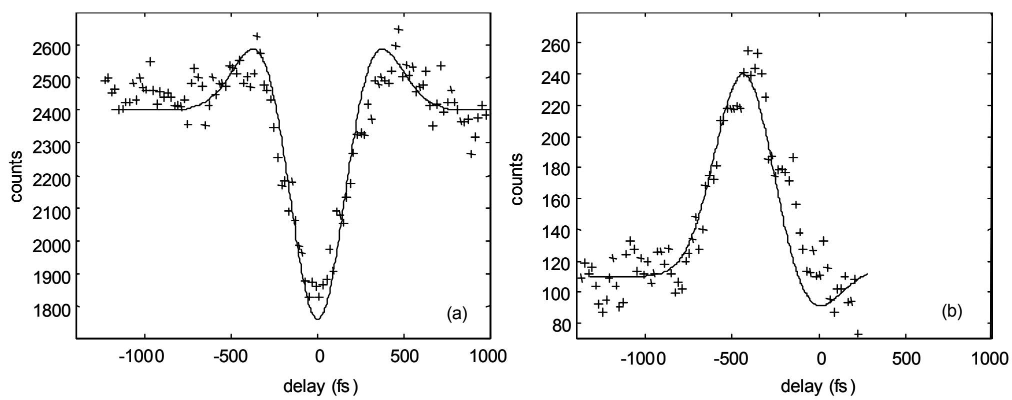

Fig. 2. Cross correlation of visible synchrotron pulse with femtosecond laser pulse: (a) femtosecond dark pulse from on-axis radiation, (b) femtosecond pulse from off-axis radiation. Solid lines are from a model calculation.

References

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