Generation and characterization of femtosecond x-ray pulses

R.W. Schoenlein,[2] T.E. Glover,[2] P.A. Heimann,[1] A.A. Zholents,[3] and M.S. Zolotorev[3]

[1]Advanced Light Source, Accelerator and Fusion Research Division, Lawrence Berkeley National
[2]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
[3]Center for Beam Physics, Accelerator and Fusion Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Applying powerful x-ray techniques such as EXAFS and XANES on a femtosecond time scale will enable one to directly probe the atomic motion associated with phase transitions, coherent vibrational motion and ultrafast chemical reactions. However, the current temporal resolution of synchrotron sources is several orders of magnitudes lower than the fundamental time scale for atomic motion, which is on the order of one vibrational period (~100 fs). We are developing a technique to generate ~200 fs x-ray pulses using synchrotron radiation from a bending magnet of the ALS.

The duration of ALS x-ray pulses (~30 ps) can be reduced by more than two orders of magnitude by selecting radiation which originates from only a thin (~100 fs) temporal slice of an electron bunch. [1] Such a slice can be created through the interaction of a femtosecond laser pulse co-propagating with an electron bunch in an appropriate wiggler (Figure 1a). The high electric field present in the femtosecond laser pulse produces an energy modulation in the electrons as they traverse the wiggler. The accelerated and decelerated electrons are then spatially separated from the rest of the electron bunch in a dispersive section (bend magnet) of the storage ring which follows the wiggler (Figure 1b). Finally, by imaging the displaced beam slice to the experimental area, and by placing an aperture radially offset from the focus of the beam core, we will be able to separate out the radiation from the offset electrons (Figure 1c). Since the spatially offset electrons result

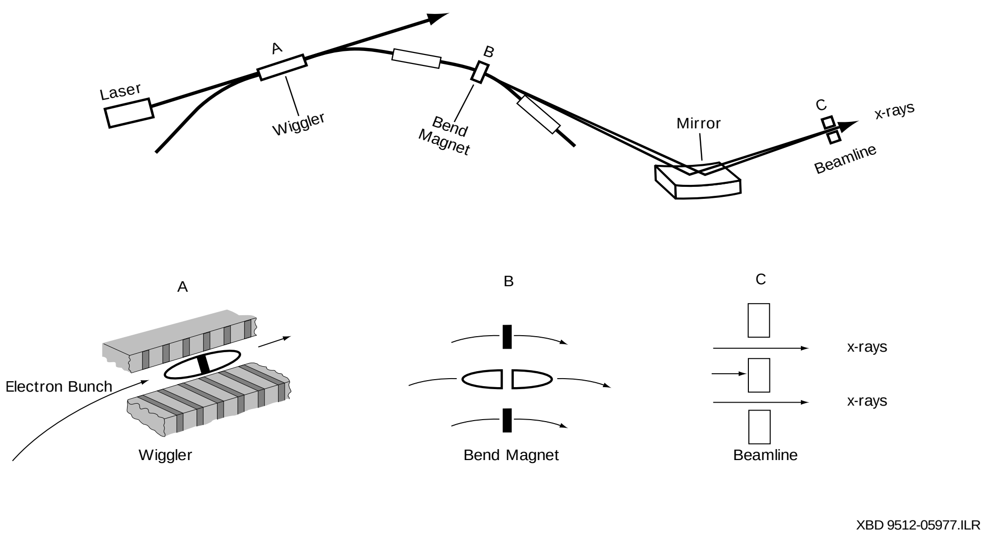

Figure 1. Schematic illustration of the technique for generating femtosecond pulses of synchrotron radiation.

from interaction with the laser pulse, the duration of the synchrotron radiation produced by these electrons will be approximately the same as the duration of the laser pulse, and will be absolutely synchronized.

The necessary components of the femtosecond x-ray source are installed at the ALS. A Ti : sapphire laser system generates 800 nm radiation with ~ 50 fs pulse duration and 2 kHz repetition rate. The femtosecond laser pulses co-propagate with electron bunches through the wiggler W16 in sector 5. The laser beam is injected into the ALS vacuum chamber through a window on the back-tangent port. After passing along the straight, the laser light (as well as the wiggler radiation) is deflected by water-cooled mirrors toward diagnostics, which monitor the spatial and temporal overlap of the laser and electron beams. X-rays are produced by bend magnet 6.3 and imaged by beamline 6.3.2.

The interaction of the laser field with the electrons can be observed in two ways. The electron bunch heated by the laser shows an increase in the spatial wings because of the increased energy spread. In the horizontal focus of the x-rays at beamline 6.3.2, a 10 % intensity increase was measured at a position 300 - 500 μm horizontally offset from the optical axis**.** The magnitude of this effect is less than the predictions of calculations and further improvement is required in matching the mode of the laser operating at a high average power and the spontaneous radiation from the electrons in the wiggler. Secondly, the laser field is amplified as a result of the free electron laser process in the wiggler. This gain was observed in a preliminary measurement at low laser power. The size of this effect was in a good agreement with predictions (see Figure 2).

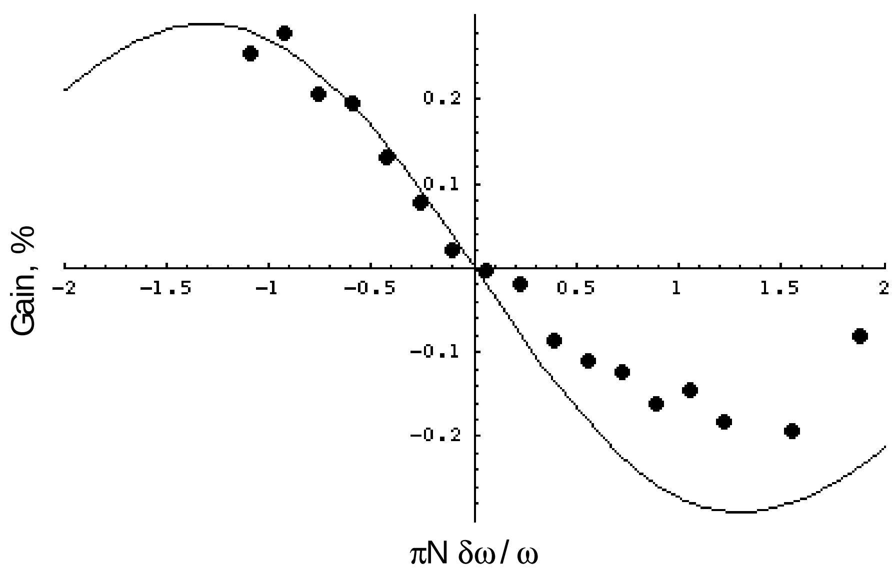

Figure 2. FEL gain measured at the beam line 5.0. Solid line is a theoretical prediction. Dots show data points. N=19 is the number of wiggler periods and δω/ω is wiggler detuning with respect to the laser frequency.

Methods are being developed to measure the duration of the femtosecond x-ray pulses created by slicing technique. Using the visible synchrotron radiation, a cross-correlation can be performed with 100 fs laser pulses in a non-linear crystal. To date, the synchrotron radiation pulse has been measured in the absence of laser-electron beam interaction. In addition, a gating detector is under construction to determine the duration of the x-ray pulse directly. This detector is based on laser-assisted photoemission, which has been demonstrated with high laser harmonics at 320 Å wavelength. [2]

REFERENCES

1. A. A. Zholents and M. S. Zolotorev, Phys. Rev. Lett. **76**, 916 (1996).
2. T. E. Glover, R. W. Schoenlein, A. H. Chin, and C.V. Shank, Phys. Rev. Lett. **76**, 2468 (1996).

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Science Division, of the Department of Energy under Contract No. DE-AC03-76SF00098.

Principal investigator: Robert Schoenlein, Lawrence Berkeley National Laboratory. Email: rwschoenlein@lbl.gov.