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Abstract

We describe the proceedings of the Workshop on the Uses and Generation of Femtosecond Radiation, held at the E.O. Lawrence Berkeley National Laboratory (LBNL), in February 1998, and some of the ideas that were generated subsequent to the workshop. The motivation for this workshop was to bring together accelerator physicists interested in the generation of ultra-short (< 200 fs) pulses of XUV and x-ray radiation, and scientists interested in using them. The primary purpose of the workshop was to educate the accelerator physicists about the source characteristics necessary to carry out specific experiments, and to inform the user community of ideas currently being explored by the accelerator community. A second objective was to develop a set of parameters and requirements that could form the basis for a broad-based femtoscience user facility. In this paper we describe some of the ideas and techniques that accelerator physicists are pursuing to fulfill the diverse requirements of this expanding community.

Introduction

The Workshop on the Uses and Generation of Femtosecond Radiation was held at LBNL on February 20, 1998. It was sponsored by the Director of LBNL, as part of a laboratory directed research and development (LDRD) project to investigate next-generation light sources. The program was a mix of scientific talks from the users of ultrafast pulses of radiation, and on ideas and techniques for generating fast pulses. Table 1 lists the speakers and presentation titles, in the order that the talks were given.

Table 1. Presentations at the Workshop

Charles Shank (LBNL):	Motivation for the Workshop
Roger Falcone (UCB):	Time Resolved Structural Changes in Materials
Ben Perman (U Chicago):	Nanosecond Time Resolved Macromolecular Crystallography, Early Structural Events in the Photocycle of a Xanthopsin
Swapan Chattopadhyay (LBNL):	Techniques for the Production of X-rays
Peilin Chen (UCI):	Ultrafast Time Resolved X-ray Diffraction
Alan Jackson (LBNL):	Linacs and Storage Rings as Sources of Femtosecond Radiation
Alan Chin (UCB):	Ultrafast X-ray Diffraction from InSb using the Thomson Scattering Femtosecond X-ray Source
Ernie Glover (LBNL):	Femtosecond X-ray Detectors
Sasha Zholents (LBNL):	Femtosecond Modulation of the ALS Energy Distribution to Produce Femtosecond X-ray Beams
Wim Leemans (LBNL):	Laser-Plasma Acceleration - A Route to fs Pulses of Electrons

The motivation for this workshop was to bring together accelerator physicists interested in the generation of ultra-short (< 200 fs) pulses of XUV and x-ray radiation, and scientists interested in using them. The primary purpose of the workshop was to educate the accelerator physicists about the source characteristics necessary to carry out specific experiments, and to inform the user community of ideas currently being explored by the accelerator community. A second objective was to develop a set of parameters and requirements that could form the basis for a broad-based femtoscience user facility. This second objective was actually achieved subsequent to the workshop as a result of numerous discussions. The consensus set of requirements is summarized in Table 2.

Table 2. Source Parameters for a Femtoscience User Facility

Energy range:	1 to > 10 keV
Flux:	10^9 photons/sec; in a Bandwidth ($\Delta\lambda/\lambda$): 10^{-3}
Pulse width:	< 200 fs FWHM
Acceptable repetition rate:	< 100 kHz, @ > 10^4 photons/pulse
Sample size:	≈ 100 microns to a side
Angular subtend:	< 1 mrad
Synchronization:	< 100 fs, with respect to a "pump" pulse

It is worth emphasizing that, almost uniformly, the user community was interested in x-rays, rather than VUV radiation. This might well reflect the fact that VUV experiments are intrinsically more difficult to perform (the experiments have to be carried out in ultra-high vacuum) than x-ray experiments, and the femtosecond experiments in and of themselves are already very exacting. Of course, optimum parameters will depend on specific experiments, and it was pointed out repeatedly that higher flux is always better!

We now explore accelerator based techniques that might fuel such a facility.

Accelerator Based Sources of Femtosecond X-Rays

Four ongoing programs on the generation of femtosecond radiation, being carried out at LBNL, were presented to the workshop; three associated with the Advanced Light Source, and one utilizing laser-based acceleration of electrons.

The ALS is a 3rd-generation synchrotron light source, designed to produce extremely high brightness beams of VUV and x-rays. The time structure of the pulses of radiation are Gaussian, with a pulse-width of ≈ 35 ps, FWHM. The three experiments being carried out at the ALS utilize different time-slicing techniques to deliver sub-picosecond pulses to the user community.

The first scheme utilizes the 50 MeV beam from the ALS linear accelerator (linac) to scatter a ≈ 100 fs laser pulse through 90° [1]. The Compton interaction boosts the 1.5 eV UV-laser photons to an energy ≈ 20 keV. In order to preserve the temporal characteristics of the laser pulse, the electron beam is focused to a transverse dimension less than the laser transit time across the pulse. Remember, 100 fs is equivalent to a distance of 30 μm.

The second scheme uses a 100 fs laser pulse to modulate the energy spread of part of the storage ring electron beam pulse. In order for the laser pulse to transfer energy to the electrons, the laser pulse must travel along with the electron beam as they pass through a wiggler magnet, whose magnetic field is tuned precisely to a resonance condition at which the fundamental of the radiation generated by the wiggler is the same as the wavelength of the laser light. This extremely demanding experiment is described elsewhere in this session [2].

The third technique involves time-slicing of the x-ray pulse itself, via laser manipulation of reflective/diffractive optics in the beamline that delivers the x-rays to the sample. Progress on this technique is also described elsewhere in this session [3].

Perhaps the most exciting talk at the workshop (author's opinion), was given by Leemans, who described an all optical technique to generate pulses of electrons with bunch lengths on the order of 1 fs! The electrons can be used in turn to produce fs pulses of x-rays, through synchrotron radiation, or thin target bremsstrahlung (as described below). The technique uses high power lasers to first create a guiding channel in a plasma, then to set up a wake-field in the plasma channel that can be used to accelerate electrons. A particularly elegant method of injecting electrons into the plasma accelerating structure is to use interfering laser pulses to kick electrons out of the plasma itself. A fraction of these electrons are then captured and accelerated in the potential well of the plasma wake-field [4]. Progress on this experiment is presented elsewhere in these proceedings [5].

Two talks at the workshop went back to the roots of x-ray generation, i.e., bremsstrahlung. Chen discussed ongoing experiments at UCI that used an x-ray tube whose gridded gun puts out pulses of a few picoseconds. Shorter pulses may be obtained by using a photo-cathode gun, however a limit will be reached because of thermal effects and space charge at the cathode. Jackson discussed the potential for thin-target bremsstrahlung, using highly relativistic electrons. The benefits of going to thin targets are: that the target thickness (≈ tens of μm) is consistent with fs pulses; that high energy electrons do not stop in the target (in thick target bremsstrahlung the slower electrons in the electromagnetic shower contribute to a tail in the time development of the x-ray beam); and that the x-rays are forward directed, and therefore easier to collect and focus. Subsequent studies indicate that atomic absorption and isotropic re-emission of x-rays might dwarf the advantages gained by the directed emission of the bremsstrahlung photons. This is under investigation. Because the electrons lose only a small fraction of their energy in the thin target (≈ 1%), the spent electrons can be bent away in an isochronous bend section (one that maintains the temporal characteristics of the electron beam), collimated, and used again in a second, and subsequent radiators. Thus several experimental beamlines could take advantage of the same electron pulse.

This idea of an isochronous bend can be taken to its logical limit to form an isochronous ring. In this case, a high energy electron beam, say 2 GeV, can generate x-rays through synchroton radiation from high field bend or wigglers, and the characteristics of the radiation can be tailored to the user. There can be many source points in the ring, and there is the advantage of a high (≈ 1 MHz) repetition rate of the pulse. The temporal characteristics of the electron pulse diminish with the number of turns around the ring, but a gain of 10 to 100 appears to be feasible. The injection rate to the ring could be enhanced through the use of a superconducting linac, where high pulse-repetition rate is not a limiting factor.

Another idea was generated at the meeting, then pursued later by Zholents and Heimann (LBNL). This involves taking a very low emittance beam (e.g., the vertical emittance in the ALS is $< 4 \times 10^{-11}$ m-rad) and inducing a localized betatron oscillation that varies linearly along the length of the bunch. This is achieved by a so-called "crab cavity" of the type that have been developed for high-energy physics colliding beam facilities. Transverse focusing elements (quadrupoles) allow the betatron oscillation to develop through one-quarter of a betatron period, at which point the instantaneous bunch-length is extremely short. After an integer number of half betatron periods the bunch rotation is canceled by a second crab cavity. If the angular kick between the front and back of the bunch is sufficiently large, the radiation generated in an extended device (like a wiggler) can be re-combined via different optical paths to form an x-ray pulse with a length of ≈ 200 fs.

Summary

This was a very interesting workshop. The primary goal - to bring together accelerator physicists interested in the generation of ultra-short (< 200 fs) pulses of XUV and x-ray radiation, and scientists interested in using them - was certainly met, as can be gathered by the quality and variety of the presentations, and the discussions that took place both within and subsequent to the meeting. In particular, the cross-discipline interactions were very successful. The secondary objective - to develop a set of parameters and requirements that could form the basis for a broad-based femtoscience user facility - resulted from discussions that took place directly as a result of the workshop. As we have shown above, there are several interesting avenues through which such a facility might be realized. The next step is to develop a plan, which identifies critical R&D and key decision points for each of the schemes, with the intent of turning one or more of these ideas into reality.

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