EXECUTIVE SUMMARY

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Third-generation synchrotron radiation facilities have been highly successful with respect to both machine operations and scientific output. Their success derives from the high brightness of the spontaneous emission from undulators in the straight sections of optimized electron storage rings. The brightness (in units of photons per second per mm^2 per $mrad^2$ per 0.1% relative bandwidth) is about 10^{20} in the wide spectral range from visible to hard x-ray wavelengths. Additional characteristics are tunability of the spectrum and adjustability of the polarization. The photon beams consist of bunches about 100 ps long. The peak brightness during the bunch duration is about 10^{23}.

Among the several possibilities for next-generation light sources, the most exciting is the one based on self-amplified spontaneous emission (SASE). SASE is intense, coherent radiation generated by amplifying the initial spontaneous emission via an extremely high gain free-electron laser (FEL) process. SASE in the x-ray region will be possible with a system composed of a photocathode rf gun, a bunch compressor, a high-energy linear accelerator (linac), and a long undulator. The Linac Coherent Light Source (LCLS) is a demonstration project for production and use of the SASE at 1 Angstrom using the Stanford Linear Accelerator Center linac [1]. The peak brightness of x-ray beam from LCLS is projected to be about 10^{33}, ten orders of magnitude larger than that of third-generation sources. The beam is completely transversely coherent, that is, diffraction-limited. The bunch length is about 100 femtoseconds, thus improving the time resolution by three orders of magnitude over that of third-generation sources. Given the positive experience from the LCLS, we may conceive of a "fourth-generation" user facility employing a superconducting linear accelerator, such as the one proposed by the DESY group [2]. The R&D preparing for the conceptual design of the LCLS was recently endorsed by the BESAC Committee on Novel Coherent Light Sources [3]. In view of these developments, a major part of this Workshop was devoted to issues related to SASE-based light sources in the hard x-ray region.

Working Group I (WG I) was concerned with the scientific opportunities of high brightness and short time resolution that will be possible with the LCLS type of next-generation light source. Further development of advanced experimental techniques (e.g., imaging, multiphoton methods, pump-probe methods, and correlation spectroscopy), now in various stages of development at current third-generation synchrotron radiation facilities, was considered. For a thorough discussion of these scientific opportunities, WG I was divided into separate subgroups for biology, condensed matter/materials science and technology, chemical science and technology, atomic and plasma physics, and fundamental physics. The subgroup reports may be found in these proceedings.
The high-gain FEL process that gives rise to SASE is well understood theoretically, thus establishing a set of criteria on electron beam and undulator qualities. These

criteria become progressively more stringent as the wavelength becomes shorter. A proof–of-principle high-gain experiment was carried out by the UCLA/Los Alamos National Laboratory collaboration achieving an FEL gain of 10^5 for 16 μm radiation. SASE experiments in the visible and ultraviolet wavelengths will be carried out in the near future by the Low-Energy Undulator Test Line (LEUTL) group at the APS, the TESLA Test Facility group at DESY, and the VISA collaboration at Brookhaven National Laboratory. Critical issues for accelerator development and possible new ideas were discussed by WG II.

It is generally accepted at present that the linac-based SASE will be the source of choice for the fourth-generation x-ray facility. However, storage ring-based sources will be at the forefront of photon beam research for at least another decade. The brightness of storage ring-based sources could be improved by employing a larger circumference, higher current, and damping wigglers. Such a ring could be operated in top-up mode to overcome lifetime reduction. It is possible that a brightness enhancement of two orders of magnitude or higher in the x-ray spectrum could be achieved in this way. However, the time resolution will, at best, remain about the same as that of current storage ring facilities. FEL oscillators in these rings could also provide intense, coherent radiation in the UV spectral range. These and other issues for the ring-based sources were discussed by WG III.

Undulators for hard x-ray SASE are long, typically about 100 m. For ease of construction, they can be assembled from 2- to 5-m-long segments. Several optimization issues arise, such as how to introduce focusing, the choice of magnetic design (pure permanent magnet, hybrid, superconducting device, ...), etc. The tolerance on the straightness of the electron trajectory is extremely tight, which can only be met with beam-based techniques. WG IV discussed these issues as well as other more general topics of undulator development, such as circularly polarizing devices and the in-vacuum devices for producing hard x-rays from moderate energy rings.

Development of optical elements and detectors matched to the unique properties of the fourth-generation sources is crucial. Possible damage of samples due to the intense beam is another critical issue that requires extensive R&D. WG V deliberated these problems.

High-power lasers have been important in the context of fourth-generation light source development in several ways—as a driver of the low-emittance photocathode gun, as a possible seed laser for the high-gain harmonic generation scheme (an alternative to the SASE), and for providing a scientific model for ultrafast or nonlinear phenomena at optical wavelengths. High-power lasers have also been used to develop compact radiation sources based on either electron-laser interaction or plasma-laser interaction. These issues were discussed in WG VI.

Adequate diagnostics for electron beams and x-ray beams are vitally important for developing and operating fourth-generation light sources. The resolution requirements for LCLS are very tight in view of the small emittance and short bunch length. The diagnostics in some cases are sufficiently developed for application to 1-Angstrom SASE. However, significant R&D will be necessary in key areas such as nonintercepting techniques and temporal diagnostics. These issues were investigated by WG VII.

The availability of a source of x-rays having several orders of magnitude increases in quantities such as peak brightness, photon degeneracy, and transverse coherence, and delivered in pulses of the order of 100 femtoseconds in duration would lead to revolutionary breakthroughs in many areas of science in ways that are at present only dimly evident. However, the impressive science currently being carried out with high-powered and short-pulse lasers in the visible region in many laboratories around the world, as well as innovative experiments in the x-ray region being carried out at the boundaries of what are possible with third-generation light sources, gives one confidence that the fourth-generation sources discussed in this workshop would open up new areas of research in physics, chemistry, biology, and materials science. Some of this research is discussed in the workshop group reports. The workshop thus represents a continuation of the accelerator, x-ray, and laser communities' scientific and technical planning for the "ultimate" x-ray source.

[1] LCLS Design Study Report, SLAC-R-51 (April 1998).
[2] Conceptual Design of a 500 GeV e+e- Linear Collider With Integrated X-Ray Facility, DESY 1997-048 (May 1997).
[3] Report of Panel on Novel Coherent Light Sources for DOE, Basic Energy Sciences Advisory Committee (February 1999).