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PICOSECOND PULSES FROM FUTURE SYNCHROTRON-RADIATION SOURCES

R.C. Sah, D.T. Attwood, and
A.P. Sabersky

July 1984

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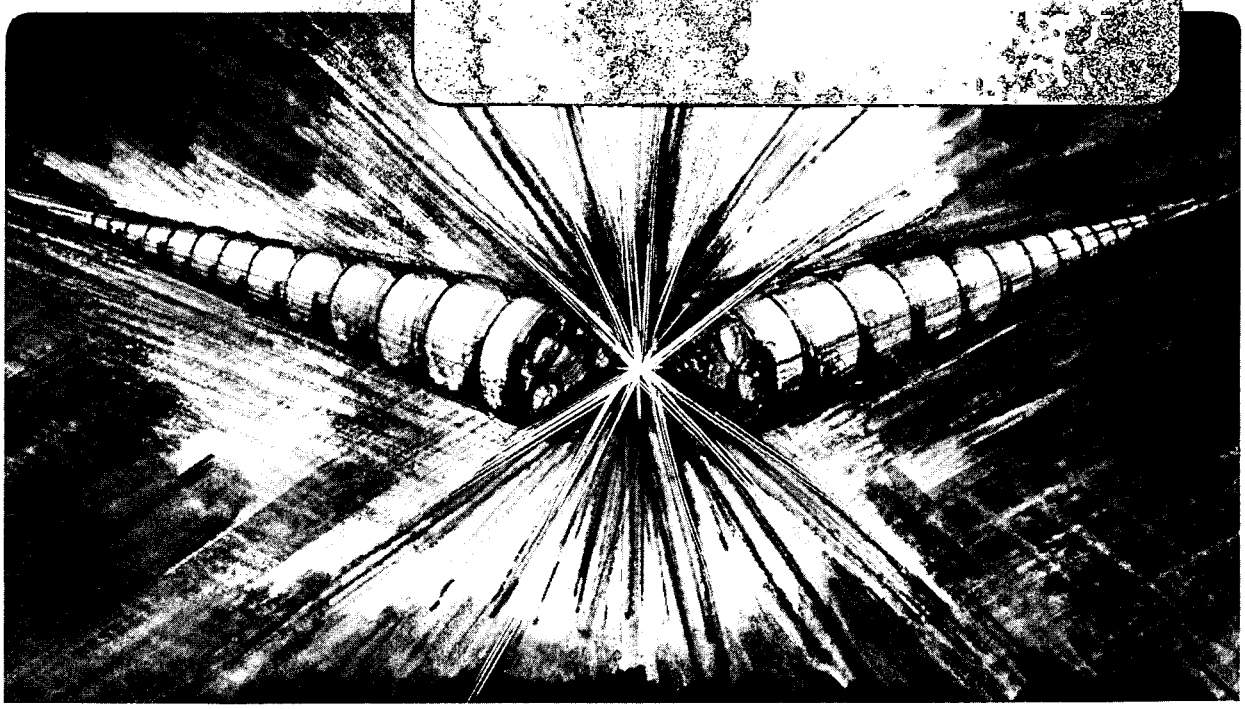

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Picosecond Pulses from Future Synchrotron-Radiation Sources*

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1 Summary

Intense, quasi-coherent photon pulses with pulse lengths on the order of 10 picoseconds will be available from future high-brilliance synchrotron-radiation sources. Photon energies will span the range from the VUV to soft x-rays.

2 Synchrotron-Radiation Sources

Existing synchrotron facilities, such as those at the Stanford Synchrotron Radiation Laboratory (SSRL) and at the National Synchrotron Light Source (NSLS), provide intense and tunable sources of electromagnetic radiation. In these facilities, short bunches of electrons circulate in electron storage rings and emit synchrotron radiation when they pass through the bending magnets of the storage rings. In a few instances, special magnetic insertion devices called "wigglers" and "undulators" [1] are used to provide even more intense photon beams. Wigglers and undulators are characterized by periodic spatial alternations in magnetic-field direction, and they produce no net deflections of the electron beam. Photon energies over a wide range, up to the x-ray region, are available from these machines. Typical photon pulse lengths are 100 to 400 picoseconds, and repetition rates can be as high as 10 MHz or more.

A new generation of high-brightness synchrotron-radiation facilities is now in the planning stages. In these new designs, most photon beams will originate from wiggler and undulator magnets rather than from storage-ring bending magnets. As an example of one of these new storage-ring designs, we shall consider the Advanced Light Source (ALS), which has been proposed by Lawrence Berkeley Laboratory [2]. The ALS has been designed to provide pulse lengths of 20-90 picoseconds at a repetition rate of up to 500 MHz. Extremely intense photon beams from the VUV to soft x-rays will be available from wiggler and undulator magnets. Interference effects in the undulators will produce quasi-monochromatic radiation (in the sense that the emitted radiation will be largely confined to a few sharp spectral lines), and undulators will provide extraordinarily high spectral brilliance, up to 10^{18} photons/(sec)(mm^2)(mr^2)(0.1 percent bandwidth). Because high-brilliance photon beams originate from a small

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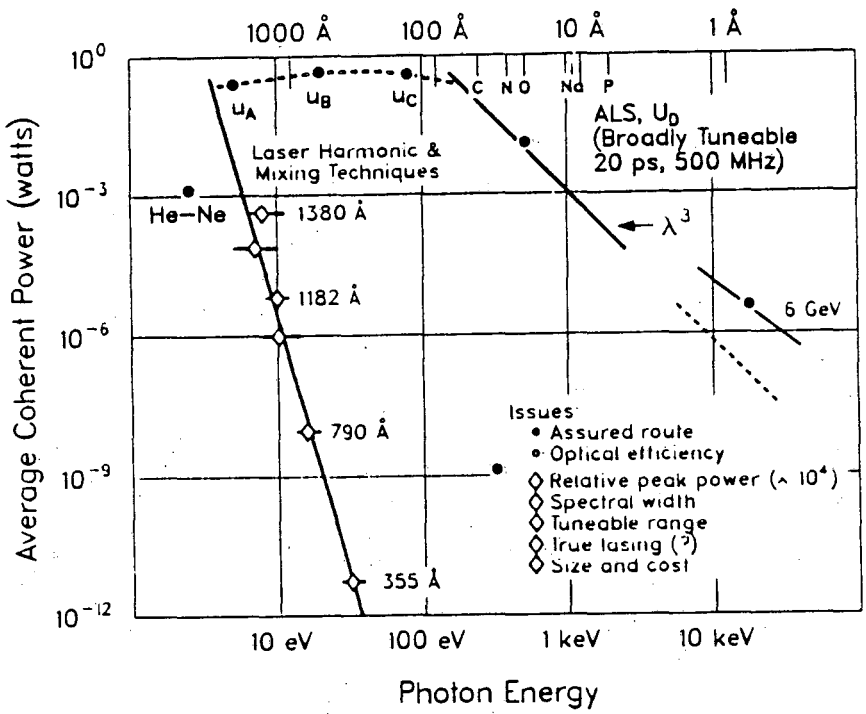
area and are emitted into a small solid angle, they have a substantial coherent power, as shown in Fig. 1. Figure 2 shows the spatial pattern of 500-eV radiation from a 5.7 kG (K = 1.87) ALS undulator, as seen on a screen located 10 meters from the source. The high-brilliance central spot provides 10^{16} photons per second in a 1-percent bandwidth.



*Full spatial coherence, longitudinal coherence ≥ 1μm

Fig. 1. Broadly tunable coherent power* will be available in an interesting spectral region

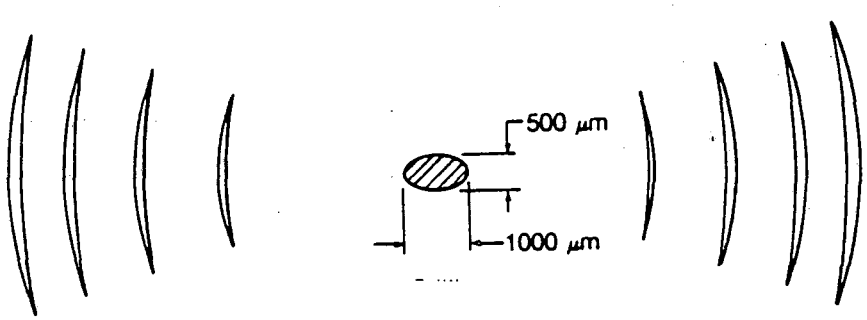


Fig. 2. Spatial distribution of 500 eV radiation from an ALS undulator

Special measures may produce photon pulses as short as 3 picoseconds at the ALS. First, the storage-ring magnets can be re-tuned for a low "momentum-compaction factor," in order to reduce the natural bunch length. Unfortunately, this re-tuning would have adverse consequences on the electron beam: larger emittance, non-zero momentum dispersion at the insertion devices, and reduced quantum lifetime. Furthermore, the ALS must be operated at greatly reduced beam currents to avoid the bunch-lengthening effects of the microwave instability. A second approach would be to use a high-frequency, high-power RF system to provide high-current, ultra-short-bunch operation. However, the higher impedance of this RF system may cause electron-beam instabilities.

3 Short-Pulse Diagnostic Instrumentation

Electron bunches in high-current storage rings are subject to many temporal instabilities. Pulse jitter (an instability in which an entire electron bunch oscillates as a whole) is best measured by spectral analysis of the signal from a beam pick-up electrode in the storage-ring vacuum chamber. Pulse-length and pulse-shape measurements are best studied using a streak camera [3], which can provide 3-picosecond time resolution and 10-picosecond stability. Visible-light intensities from synchrotron-radiation facilities are adequate for single-pulse measurements. The streak camera can be triggered with signals from beam pick-up electrodes. To make full use of the short pulse structure of synchrotron radiation, one must work below the instability threshold in beam current or use measurement methods [4] which are insensitive to instabilities.

4 New Applications

The short pulse lengths, high brilliance, and quasi-coherent nature of photon beams from modern x-ray synchrotron sources will permit new applications across the scientific spectrum. These include time-resolved absorption and fluorescence studies of chemical and material properties with small samples and improved spectroscopic resolution, studies of highly ionized plasmas whose lifetimes are measured in tens of picoseconds, as well as picosecond imaging and diffraction studies. Unique applications will certainly appear for coherent VUV and soft x-ray probing on these time scales, including off-axis x-ray holography of microscopic samples. Depending on system and pulse shape stability it may be possible to extend some of the fluorimetry techniques below one picosecond using frequency domain techniques.

5 References

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