Title
ALS: ADVANCED LIGHT SOURCE

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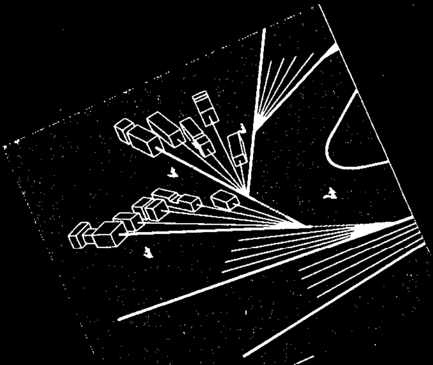
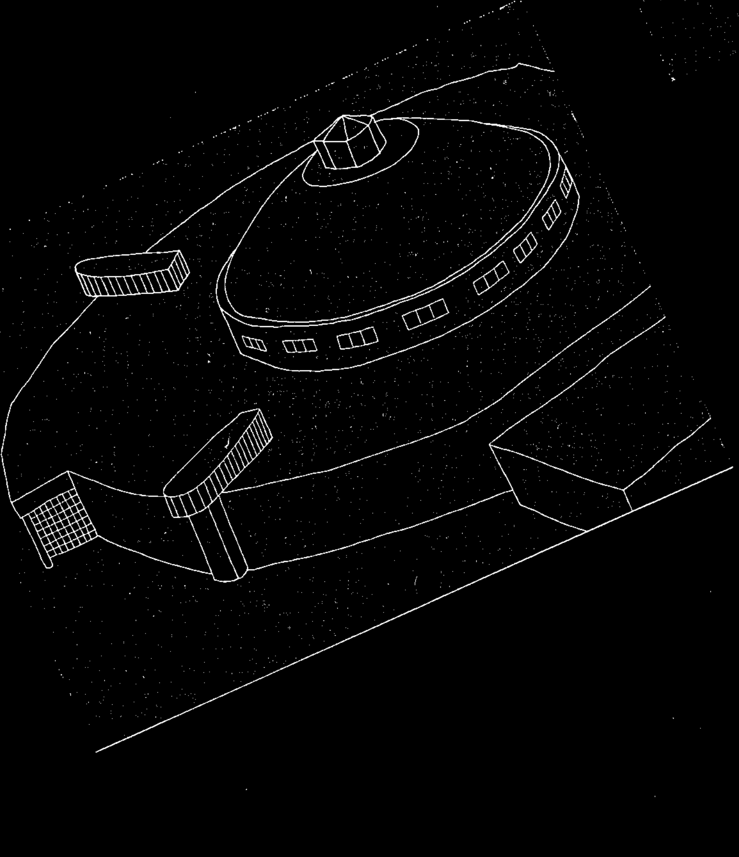
DISCLAIMER

ALS Advanced Light Source





LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA

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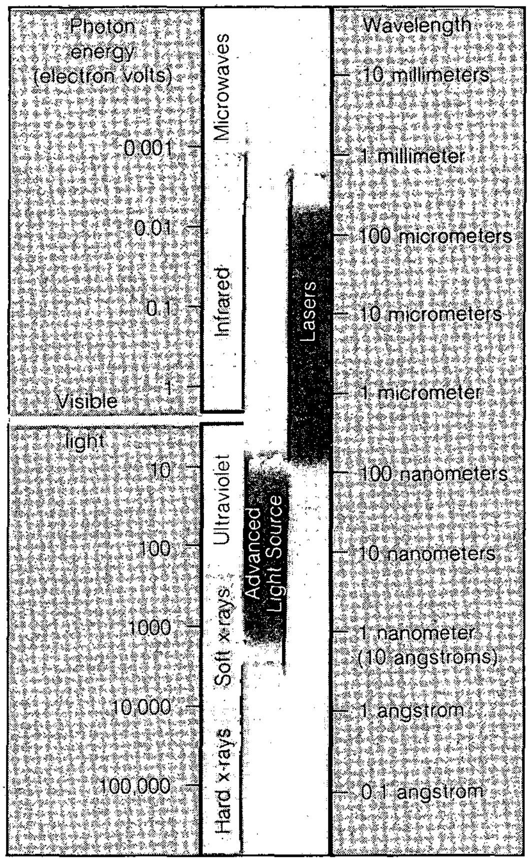
The electromagnetic spectrum



IT CAN BE ARGUED that light is the fundamental tool of science. Optical microscopy, astronomy, the spectroscopies of the physicist and chemist all depend on it. In some instances, the object of study—a distant galaxy, for example—produces its own light. More often, the probing sources of light, whether microwaves, visible light, or x-rays, are artificial—manmade implements of laboratory science. For more than two decades, lasers have dominated the visible and infrared regions of the electromagnetic spectrum. During this same period, the most powerful sources of x-rays and ultraviolet radiation—essential probes of atomic and molecular structure—have been particle accelerators, where circulating electrons emit light as a by-product of their motion. Missing so far at these shorter wavelengths has been light with many of the useful properties we associate with lasers.

In essence, the Advanced Light Source will provide such light to the experimental scientist. Though not a laser, the ALS will offer researchers laserlike radiation of unprecedented brightness, at ultraviolet and soft x-ray wavelengths. With it materials scientists will tackle questions that can lead to new generations of semiconductor devices, chemists will be able to study chemical reactivity at a new level of precision, and biologists can hope to watch processes unfold in living cells.

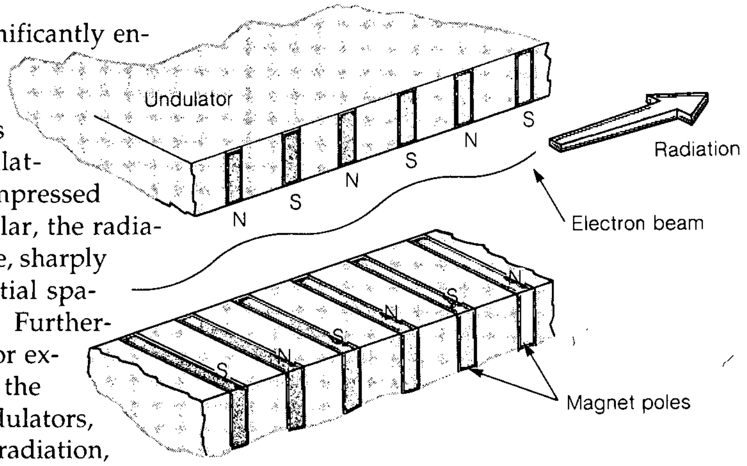
The laserlike virtues that will open the way to these opportunities require a brief explanation. Unlike ordinary light, which consists of many wavelengths, or colors, a laser produces light of a single color, its waves locked in step as they move in a common direction. A laser is thus said to produce light that is *monochromatic* and *spatially coherent.* In addition, in some lasers, the wavelength of this pure light can be varied, that is, the laser is *tunable.* For science—indeed, for society as a whole—the implications of these qualities have been profound.

In a few pages, this brochure aims to address three fundamental questions: How is such light to be generated at the ALS? What will this unique light source look like? And what new science will it make possible?

Electrons forced to follow a curved trajectory emit light—so-called *synchrotron radiation*—whose characteristics depend on the energy of the electrons and the radius of their curved path. In an electron *storage ring*, therefore, where electrons circulate for many hours at a constant energy and where magnets constrain the particles to nearly circular orbits, the electrons emit sweeping beams of light—like the headlight of a train on a circular track. It is this mechanism that produces most of the synchrotron radiation at present-day facilities. The promise of the ALS, however, derives from a more purposeful manipulation of the electrons' trajectory.

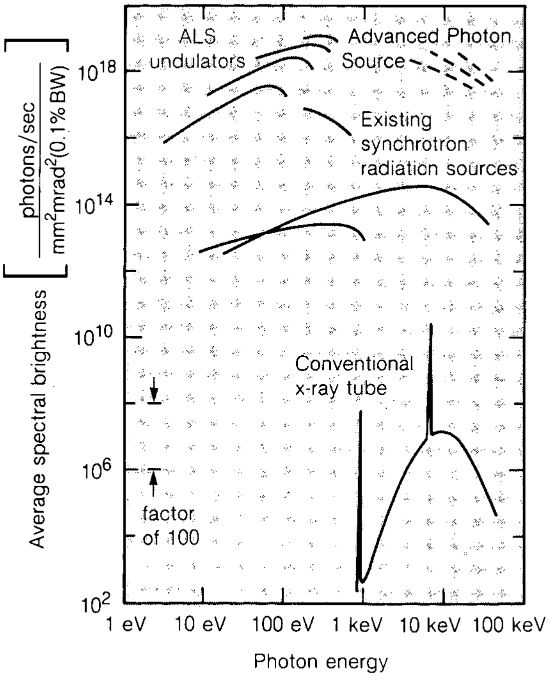
The quality of synchrotron radiation can be significantly enhanced by inserting *undulators* or *wigglers* in the straight sections of an electron storage ring. These periodic magnetic structures, collectively known as *insertion devices*, bend the electrons along an undulating path, whereby the emitted light is greatly compressed along the axis of the electrons' motion. In particular, the radiation from undulators emerges in a very narrow cone, sharply peaked at discrete wavelengths and with substantial spatial coherence. Hence the description "laserlike." Furthermore, the wavelength of the light can be tuned—for example, simply by mechanically opening or closing the gap between the undulator faces. In contrast to undulators, wigglers produce a broad spectrum of synchrotron radiation, shifted to higher photon energies, where the light can be used to probe heavier elements.

Radiation from an undulator



A special quality of the light produced by undulators is its high *spectral brightness*, a composite measure of several laserlike virtues: the intensity of the light, the narrowness of its spectral distribution, and the ease with which it can be focused to a small spot. Light from the ALS undulators will be a hundred million times as "bright" as light from the most powerful x-ray tubes. Indeed, because undulators are unique in producing such light, plans are afoot around the world to build several facilities similar to the ALS; in the U.S., the Advanced Photon Source, a complementary facility for generating intense x-rays at still higher energies, has been proposed for construction at the Argonne National Laboratory.

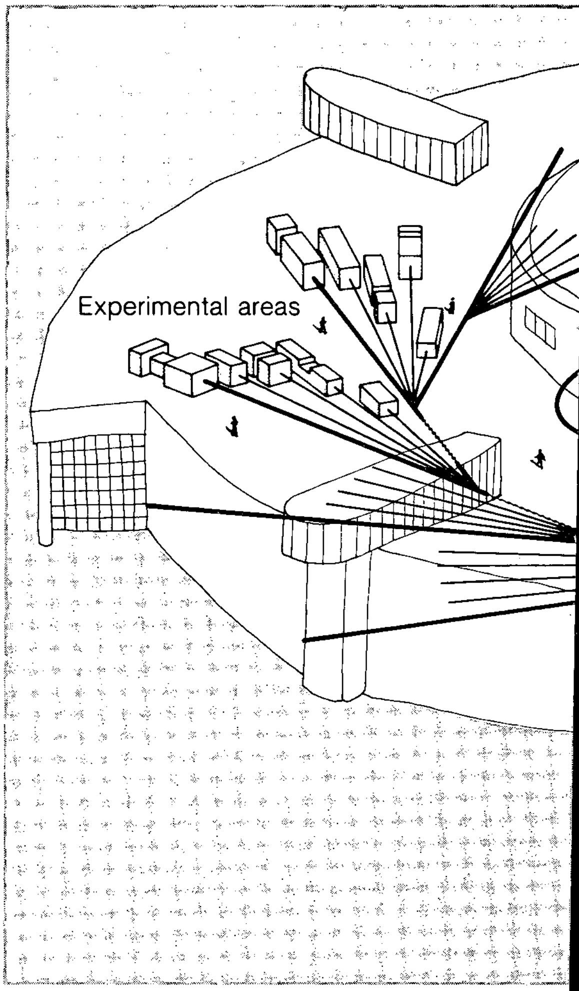
Brightness: an important measure of quality

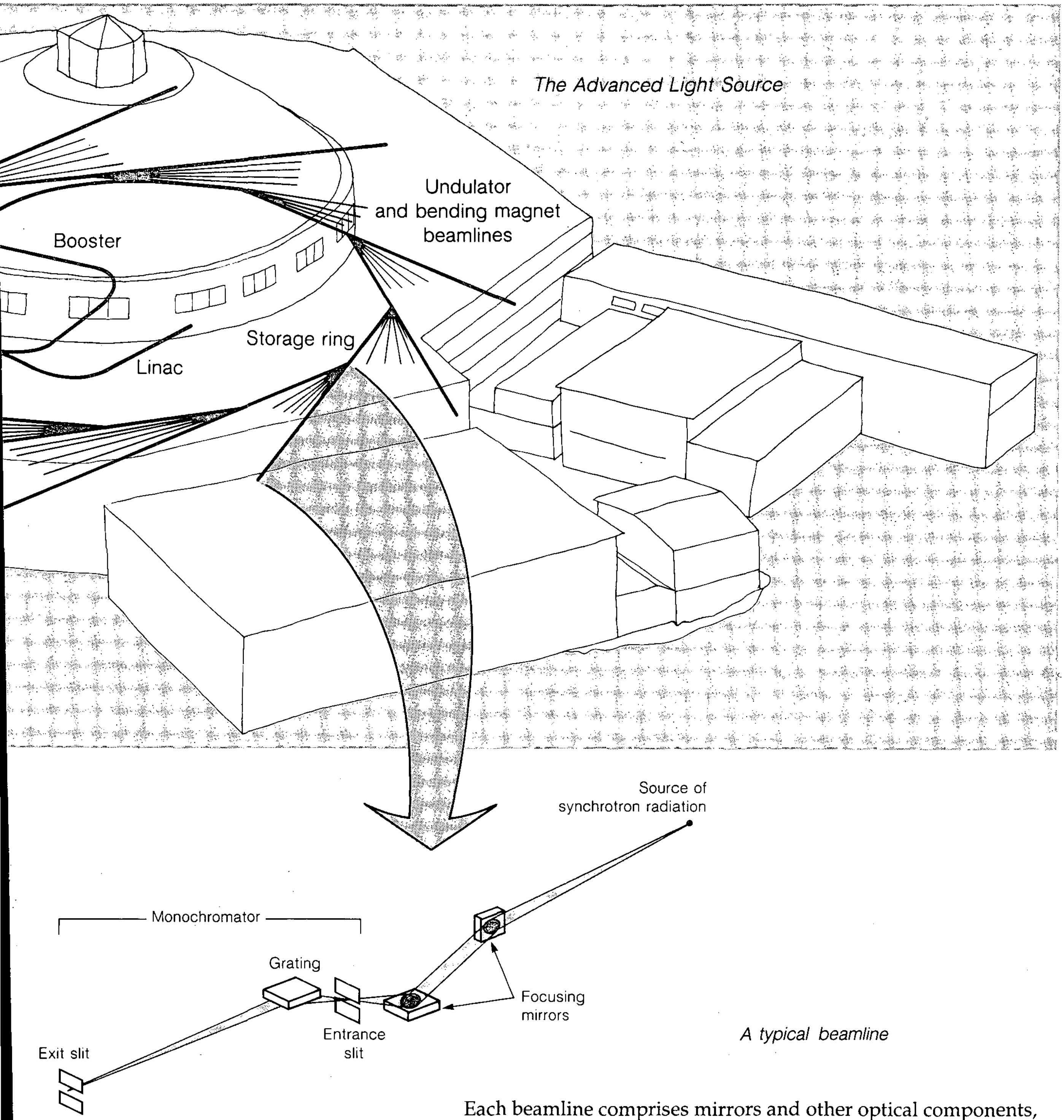


n the simplest terms, the ALS consists of a system for accelerating and storing bunches of electrons, a number of insertion devices for "extracting" light from these electrons, and provisions for up to 60 *beamlines* for transporting the light to experimental areas. Once accelerated by a linear accelerator and a small booster synchrotron, the electrons are injected into the storage ring, where they circulate for several hours at near the speed of light, at any chosen energy between about 1 and 1.9 billion electron volts. The energy the electrons lose by way of synchrotron radiation is replenished by the constant infusion of radio-frequency power. The uniqueness of the ALS rests with its long undulators, together with the quality of the stored electron beam. The key features of this stored beam are its small cross-sectional area and its small divergence (that is, it tends not to spread out). Such a beam is a prerequisite for undulator radiation of high brightness.

Ultimately, the ALS will include 11 insertion devices—both undulators and wigglers—and their associated beamlines, as well as up to 48 beamlines from the more "traditional" sources of synchrotron radiation, the bending magnets. More than 250 users may be present simultaneously.

Efforts are already well under way to define the program of scientific research to be conducted with the available light. For example, a Users' Executive Committee, representing a broad scientific and geographical spectrum of researchers from industrial, university, and government laboratories, has been meeting regularly since 1984. In collaboration with LBL, the Committee has sponsored a series of workshops aimed at delineating the types of experiments that can best exploit the opportunities the ALS will offer. When it first becomes operational in 1992, the ALS will include an initial complement of insertion devices and beamlines, funded as part of the construction project. Additional insertion devices (and their beamlines) and bending magnet beamlines will be developed and used by teams of researchers from across the country. The ALS will be open to all interested users (at no cost, except for proprietary research), and access will be based on the careful review of all submitted proposals.





The Advanced Light Source

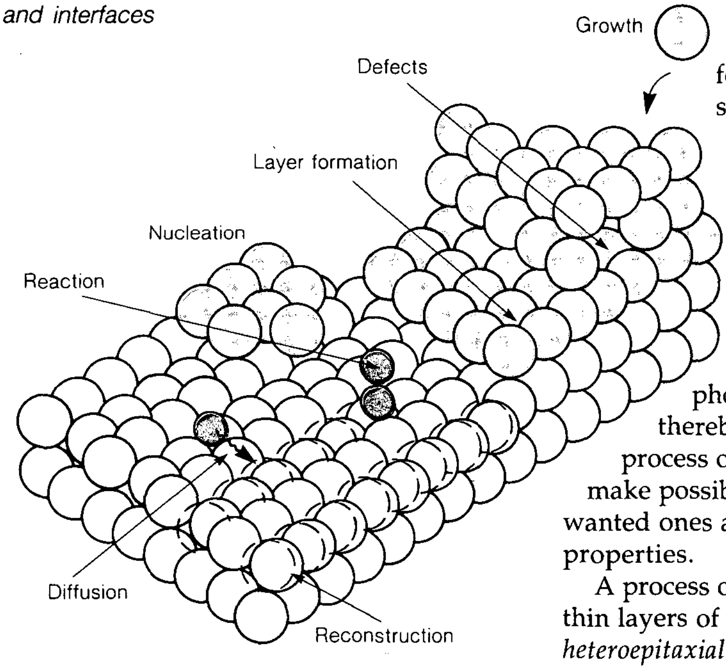
A typical beamline

Each beamline comprises mirrors and other optical components, whose purpose is to guide the synchrotron radiation from its source, the electron beam in the storage ring, to an experimental station. For a fixed electron beam energy, the magnetic field of the undulator determines the spectrum of wavelengths it generates. A *monochromator* in the beamline further narrows the range of wavelengths reaching the experimenter.

Largely because of its intensity and tunability, synchrotron radiation has already proved its value in many fields of basic and applied scientific research. By adding to these properties the quality of high brightness, the ALS will open even more doors to advanced research and will thus play a significant role in maintaining U.S. leadership in science and high technology. Examples of research the ALS will make possible in the fields of *materials and surface science, biology,* and *chemistry* are merely suggestive of this facility's exciting future.

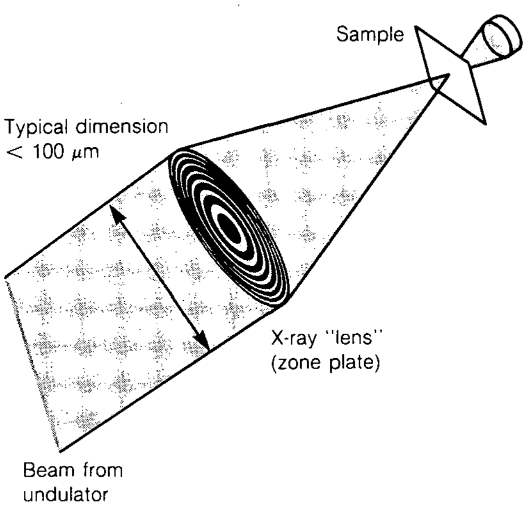
Solid surfaces and the interfaces between different materials often control physical, chemical, and biological processes in such wide-ranging instances as transistors in computer memory chips, catalysts for petrochemical synthesis, and membranes in cells of the human body. *Photoelectron spectroscopy* is one of several well-developed tools for probing surfaces and interfaces. For example, analysis of the energy and direction of motion of electrons ejected from a solid surface following the absorption of ultraviolet radiation or soft x-rays can provide information about several processes that often take place there, such as the rearrangement of atoms (*reconstruction*), chemical reactions, and the growth of new material layer by layer. The exceptional brightness of the light from the ALS undulators will allow useful photoelectron signals to be generated from areas only 500 atoms in diameter. By scanning a focused beam across the surface, spatially resolved photoelectron spectroscopy will become possible, thereby revealing the location, as well as the type, of process occurring there. The high brightness will also make possible the detection of dilute impurities, both unwanted ones and those implanted for their desirable electronic properties.

Processes at surfaces and interfaces



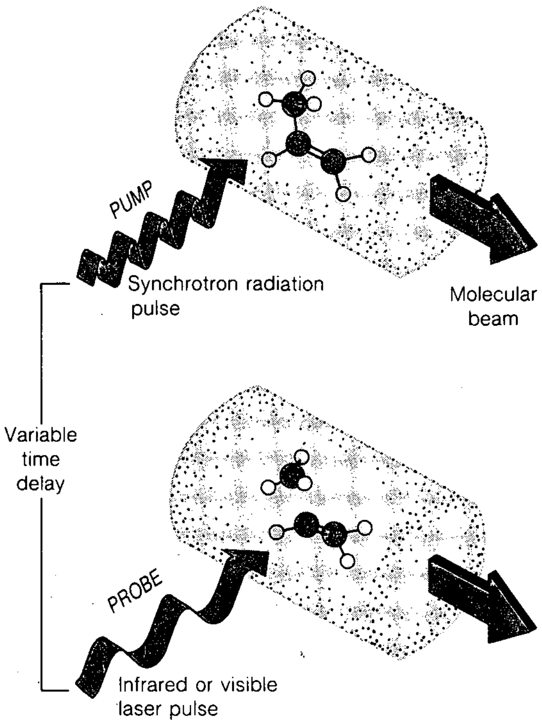
A process of great technological importance is the growth of thin layers of one kind of material on top of another—so-called *heteroepitaxial growth.* The effects of defects, such as missing or misplaced atoms, that originate at the interface between two semiconductors can propagate into the heteroepitaxial layer during the growth process, resulting in the degradation of the electrical or optical properties of devices made from these materials. With spatially resolved photoelectron microscopy and other techniques, it will be possible to investigate the origin of many such defects. With a special growth chamber, it may also be possible to monitor the process of *nucleation,* which produces nuggets of heteroepitaxial semiconductor on a surface, growing in turn into islands that eventually coalesce into a continuous layer.

An x-ray microscope for high-resolution imaging



Focusing light to the smallest possible spot requires spatially coherent radiation. The light from an undulator is thus uniquely useful for spatially resolved spectroscopy and for imaging such diverse structures as biological cells and microelectronic devices. The bright beam of an undulator can be focused to a spot by a zone plate lens, while the sample is moved past. The transmitted intensity at each point is recorded and stored in a computer, which then reconstructs the image point by point. This technique has already been demonstrated at an existing synchrotron radiation facility, Brookhaven's National Synchrotron Light Source, with a subcellular structure known as a zymogen granule. The diameter of the focused beam was about 750 angstroms (less than one ten-thousandth of a millimeter). High contrast in the biological image was obtained by using an x-ray wavelength absorbed by the protein in the granule but not by the water. At the ALS, where it will be possible to focus far more light on such small samples, the use of a similar scanning x-ray microscope may allow us to record images of processes within cells as they occur in their natural environment.

A two-color experiment for studying chemical reactions



Many important processes, such as the rupturing of chemical bonds in a reaction, occur in less than a *nanosecond* (a nanosecond is a billionth of a second). One way of studying fleeting processes of this type is by means of light pulses having a shorter duration than the process under investigation. Such light pulses can both set the process in motion and track its progress. Lasers have been built that flash on and off in about a hundredth of a *picosecond* (a picosecond is a thousandth of a nanosecond), but these do not yet operate in the ultraviolet or x-ray regions of the electromagnetic spectrum. Because the stored electron beam in the ALS is not continuous, but rather consists of discrete bunches, the synchrotron radiation is naturally pulsed, with on-off times that can be as short as 30 or 40 picoseconds. The additional ability to tune the bright synchrotron light makes it possible not only to probe short-lived processes requiring ultraviolet radiation or soft x-rays, but also to do time-resolved spectroscopy. One illustrative type of experiment is a *pump-probe* (or two-color) experiment in which a beam of molecules is excited by an ultraviolet beam from the ALS, then probed by a synchronized subpicosecond laser.

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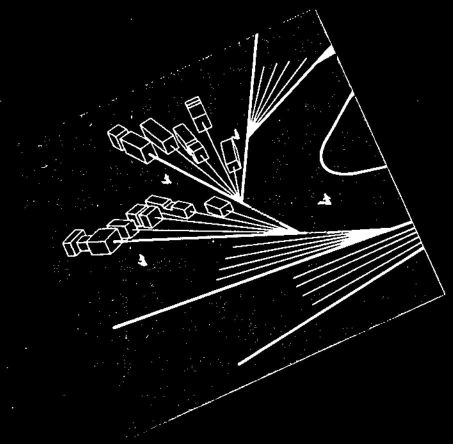

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