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An undulator based scanning microscope at the National Synchrotron Light Source

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Abstract

A second generation scanning soft x-ray microscope is under construction, designed to utilize the dramatic increase in source bightness available at the soft x-ray undulator. The new instrument is expected to reduce image acquisition time by a factor of about 100, and to improve resolution, stability, and reproducibility.

Introduction

In collaboration with our colleagues at IBM, Brookhaven, and King's College, London, we have developed a scanning soft x-ray microscope for imaging biological specimens. The microscope uses a Fresnel zone plate to form a microprobe, the size of which determines the resolution. The specimen is scanned across this focused spot under computer control, and the fraction of the incident x-rays that are transmitted and detected are used to form the image.

A first generation microscope has been in operation at the bending magnet beam line U15 at the National Synchrotron Light Source (NSLS), since 1983.[1-3] This instrument has demonstrated a resolution approaching 1000 Å (4), the ability to image wet, unstained biological specimens,[5] and to map the distribution of calcium in sections of bone.[6] Limitations on the available coherent flux from this beam line limit the rate of data collection to about an image per hour. For this reason we are constructing, in collaboration with the NSLS and the Lawrence Berkeley Laboratory, a beam line on the soft x-ray undulator X1. With the increased brightness of this new source, the limitation on imaging will shift to the data acquisition system. We are in the process of constructing a second generation instrument that will collect the data for a 256 x 256 pixel image in less than one minute. We expect this to be a practical instrument for biological imaging.

The undulator

The source for the new microscope is the soft x-ray undulator.[7] This magnet structure, when inserted into a straight section of an electron storage ring, forces the electron beam into gentle sinusoidal oscillations with a period determined by the distance between the alternations of the magnetic field. Radiation emitted from the device is highly collimated, and concentrated into narrow spectral peaks, whose wavelength is determined by the electron beam energy, the magnet period and the strength of the magnetic field. A similar structure has already been used for x-ray microscopy in Japan,[8] and another one is being commissioned in England.[9]

Our undulator is being built in two stages, as part of the Phase II construction project at the NSLS. The first stage has 10 magnetic periods. It is installed on the x-ray ring at the NSLS, and will be used for microscopy after commissioning during the second half of 1986. A more powerful 37 period structure will replace it during the first half of 1987. Both devices have an 8 cm period and the first order spectral peak is tunable between 17 Å and 73 Å (by changing the gap) when the X-ray ring is operating at 2.5 GeV. The brightness of these devices (the number of X-ray photons per second, per unit source area, solid angle, and bandwidth) is about three orders of magnitude larger than that of our bending magnet source, and is expected to be the brightest cw source in this wavelength range.

The beam line

To make use of the undulator source for the microscope, a spatially coherent and monochromatic portion of the beam must be isolated, and transported safely to the enclosure where the optics and the specimen are located in an atmospheric environment. This is the task of the beam line. Much of the equipment is there to protect personnel against accidental exposure to radiation, and to prevent the overheating of objects exposed to the full power of the radiation.[10] The principal components are shown in Figure 1.

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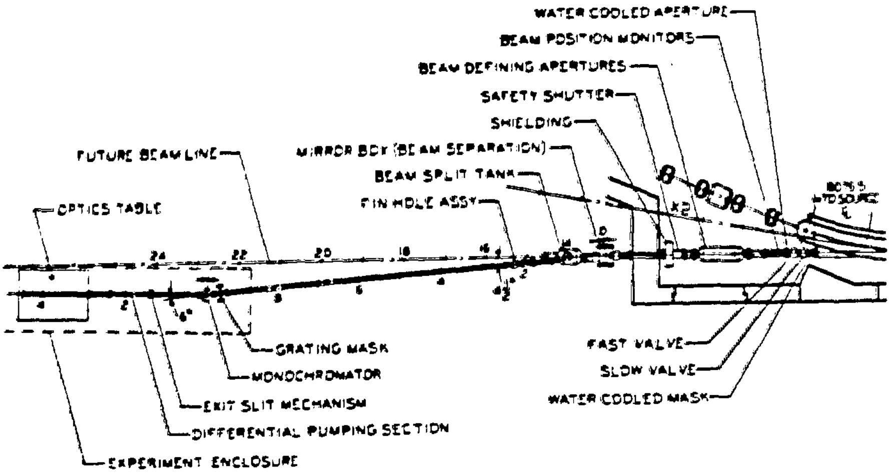

Figure 1. Beam Line Schematic (Plan View)

A spatially coherent portion of the beam is isolated with a pinhole, about 100 μm in diameter. This pinhole also serves as the entrance "slit" of the spherical grating monochromator, which will produce a resolving power of at least 1000 at 32 Å. A plane mirror upstream of the pinhole can be used to steer the beam and to eliminate higher energy x-rays thereby reducing higher order contamination in the output of the monochromator.

The monochromator forms a demagnified image of the pinhole at the exit slit, located 21 m from the source, and at the input-end of an optical table on which the microscope is located. The undulator output spectrum can be explored by scanning the grating through its angular range. Because the bandwidth of the source in first order is just the inverse of the number of magnetic periods, the monochromator can be used by itself to change the wavelength by a percent or two without much penalty in intensity. For larger changes in wavelength the undulator gap must be adjusted as well as the grating, to maximize the intensity.

The microscope

The monochromatized, spatially coherent radiation, (effectively a plane wave) is incident on a Fresnel zone plate. The first order focus of this optical element is the microprobe that we use to image the specimen. The zone plate and specimen are located in an enclosure filled with one atmosphere of helium. This environment is transparent to x-rays, yet it is compatible with wet biological specimens. To transport the beam from the ultrahigh vacuum of the storage ring to this atmospheric region, we use a thin aluminum contamination barrier and a silicon nitride window, as described in our previous work.[1] This arrangement will be modified next year, when a differential pumping system will replace the contamination barrier.

Zone plates have been made at IBM under a collaborative arrangement with the Center for X-Ray Optics, Lawrence Berkeley Laboratory,[11] and at King's College, London.[12] In both instances electron beam microfabrication is used, and the final zone plates are supported on thin silicon nitride windows. In tests carried out so far, on the order of 5% of the radiation incident on the zone plate is focused, a value that is within a factor of 2 of the theoretical maximum for these devices. Much of the rest of the radiation is absorbed in the zone plate, but the amount of unfocused radiation that is transmitted still outweighs the amount focused by a large factor. To eliminate these unwanted photons, the zone plates are fabricated with a central stop. A collimator is interposed between the zone plate and the focus, which is now within the clean shadow cast by the central stop and the collimator.

The specimen is mounted on a stage that performs the raster scan under computer control. A pair of piezoelectric elements generate the displacement, while a specially designed laser interferometer,[13] shown in Figure 2, monitors the position. To be able to make use of the greatly improved intensity in the microprobe, we must be able to scan and collect data more rapidly than we have done so far. The new microscope will feature a more powerful computer, a MicroVAX II with satellite PDP 11/73, and better stage control, including a large bandwidth high voltage operational amplifier to run the piezoelectric transducers. This apparatus is designed to collect the data at a rate in excess of 1000 pixels per second, or a 256 x 256 picture in a minute or less. The laser interferometer is designed not only to keep up with this speed, but also to improve the accuracy and reproducibility of the stage motion.

Discussion

This Conference finds the new microscope in transition from design to operation. The undulator has been installed, and is being characterized. The beam line is complete, and the monochromator is being aligned. The scanning stage is under construction, and the software to drive it is in progress.

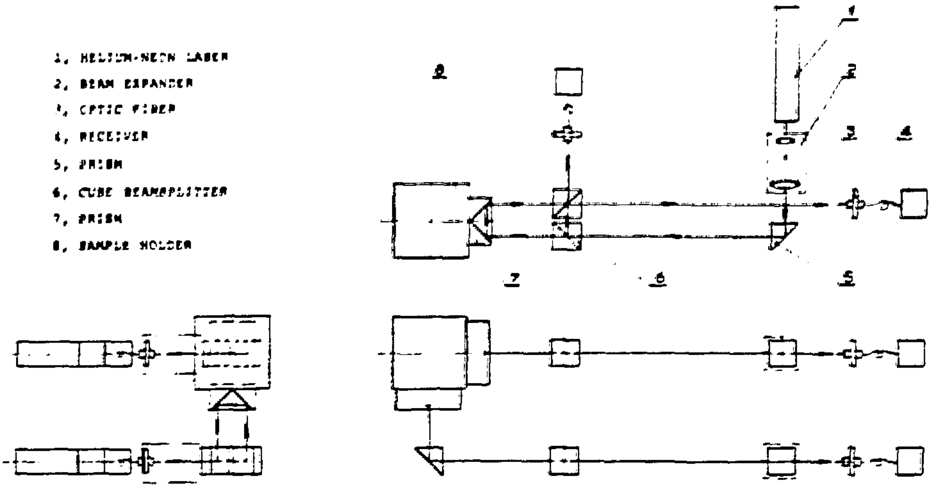

Figure 2. Two-dimensional laser interferometer (optical schematic)

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