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X-Ray Microscopy Resource Center at the Advanced Light Source

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Materials Sciences Division

Center for X-Ray Optics

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W. Meyer-Ilse, M. Koike, R. Beguiristain, J. Maser, and D. Attwood

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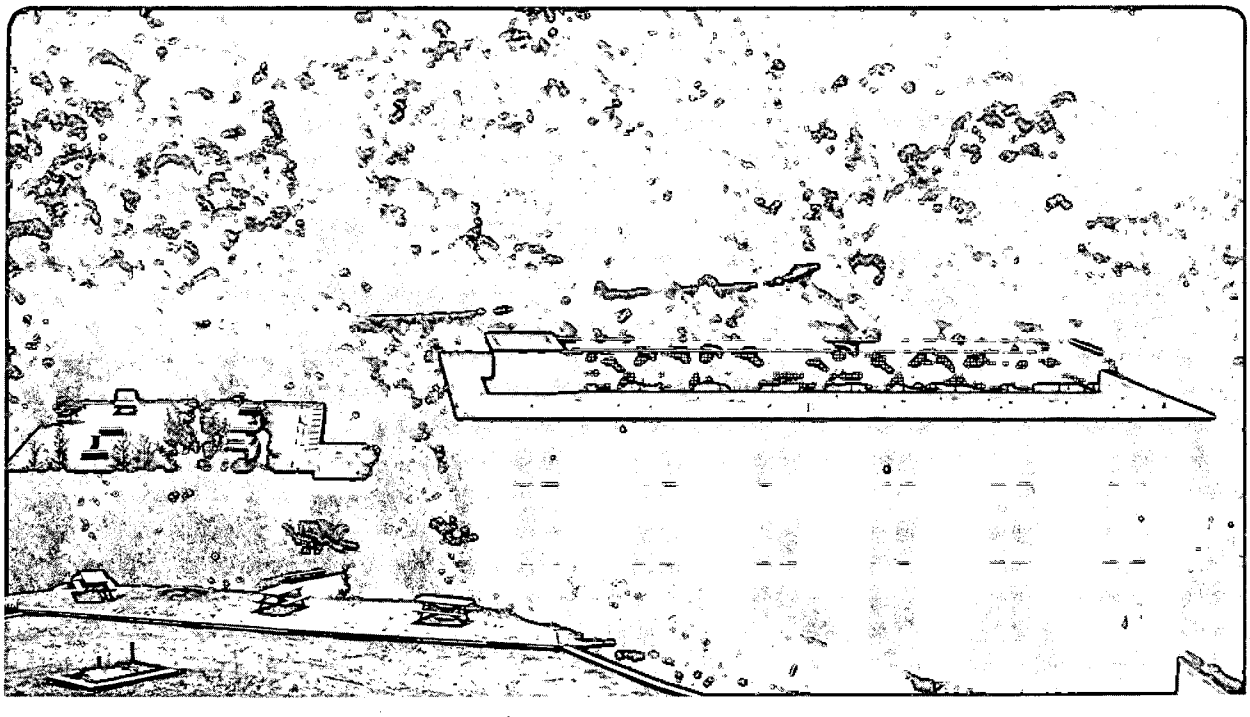

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X-ray Microscopy Resource Center at the Advanced Light Source

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1. Abstract

An x-ray microscopy resource center for biological x-ray imaging will be built at the Advanced Light Source (ALS) in Berkeley. The unique high brightness of the ALS allows short exposure times and high image quality.

Two microscopes, an x-ray microscope (XM) and a scanning x-ray microscope (SXM) are planned. These microscopes serve complementary needs. The XM gives images in parallel at comparable short exposure times, and the SXM is optimized for low radiation doses applied to the sample. The microscopes extend visible light microscopy towards significantly higher resolution and permit images of objects in an aqueous medium. High resolution is accomplished by the use of Fresnel zone plates. Design considerations to serve the needs of biological x-ray microscopy are given. Also the preliminary design of the microscopes is presented. Multiple wavelength and multiple view images will provide elemental contrast and some degree of 3D information.

2. Introduction

The high spectral brightness of undulator radiation from the Advanced Light Source (ALS) offers a great scientific opportunity for biological x-ray microscopy. X-ray microscopy extends visible light microscopy to higher resolution and makes use of unique contrast mechanisms. It does not compete with techniques such as electron microscopy in terms of resolution, but rather offers unique advantages, including the opportunity to take images of samples in a near-native state.

To exploit this opportunity, the construction of a Biological X-ray Microscopy Resource Center will begin soon. Two types of x-ray microscopes are to be built: an imaging type x-ray microscope (XM) and a scanning x-ray microscope (SXM). The SXM produces a diffraction-limited point which is scanned across the sample; therefore the SXM can use only the spatially coherent portion of the source radiation. Accordingly the SXM needs an undulator source with its small phase space for optimized performance. On the other hand, an XM can use the full brightness, including the incoherent fraction of the source. This means it can be operated with either a bending magnet or an undulator. Although exposure times are shorter with an undulator, the XM will be installed initially at a bending magnet which will be available at an earlier time. Later this XM will be either moved to an undulator or left at the bending magnet for developmental and less demanding experiments.

The anticipated working conditions of the undulator at the ALS are summarized in Table 1. The information has been compiled from data out of the ALS Handbook[1].

Table 1	
Electron beam energy	1.5 GeV
Beam current	400 mA
Undulator period	3.9 cm
Magnet periods, length of undulator	123 periods, 4.8 m
Peak spectral brightness	$1 \cdot 10^{18}$ Phot.@24Å/(s mm^2 mrad^2 0.1%BW)
Source size σ rms	64 µm (V), 331 µm (H) @24Å
Source divergence σ' rms	27 µrad (V), 37 µrad (H) @24Å

3. Floor space layout

The floor space layout of the beam lines dedicated for the Biological X-ray Microscopy Resource Center at the ALS is shown in Fig. 1. The undulator radiation is alternatively fed into an XM and an SXM branch line by the use of a pop-up mirror, as well as two additional branch lines, the so called white light station and a coherent optics station. A second XM is located at a bending magnet beam line.

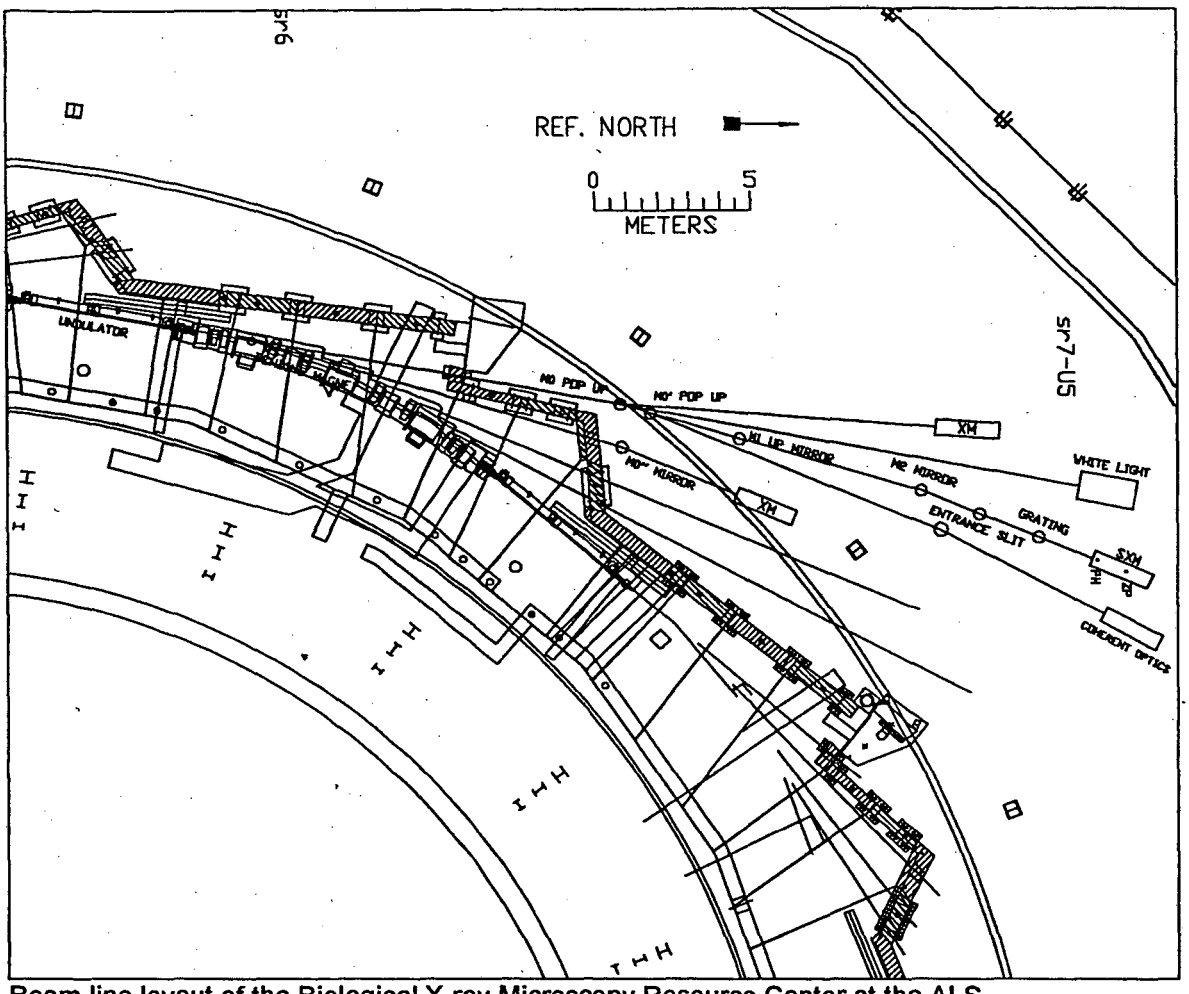

Fig. 1: Beam line layout of the Biological X-ray Microscopy Resource Center at the ALS.

4. Specification of the x-ray microscopes

The specifications of the microscopes are summarized in Table 2. The resolution of the microscope is limited by the fineness of the outermost zone width of the micro zone plate. It is expected that resolutions approaching 150Å will be eventually achieved at the X-ray Microscopy Resource Center. Preliminary estimates of exposure times expected at the ALS are given in Table 3.

Table 2. Specifications of the x-ray microscopes at the ALS:	
Resolution	down to 150 Å
Field of view	30 µm (requires effort at XM)
Wavelength	24 Å to 45 Å (extended range considered)
Position accuracy of scanning stage (SXM only)	50 Å
Spectral resolving power	XM: 1:300 SXM: adjustable from 1:100 to 1:3000
Counts per Pixel	100 to 100,000 (observe radiation damage)

Table 3. Exposure times preliminary estimate:		
300 Å Resolution	X-ray microscope (XM)	Scanning x-ray microscope (SXM)
1000 Counts 1000x1000 pixels 30 µm field	3 sec (B) 20 msec (U)	5 sec
Times for the XM are for a bending magnet (B) or for an undulator (U).		

5. X-ray Microscope (XM)

The optical setup of the XM is shown in Fig. 2. The specimen is illuminated from an illumination system and a high resolution zone plate is used to generate an enlarged image of the specimen on a detector. The complete image is formed simultaneously, just like in a visible light microscope. This allows high quality and high resolution imaging. The purpose of the illumination system is to illuminate the specimen but also to provide the monochromaticity necessary for the micro zone plate. At higher emittance sources like BESSY[2] a linear monochromator consisting out of a condenser zone plate and a pinhole is used as illumination system. A similar setup at the ALS will either reduce the size of the illumination or not match the numerical aperture of the illumination system to the numerical aperture of the micro zone plate. We have been examining several different illumination schemes for the XM at an ALS bending magnet and undulator.

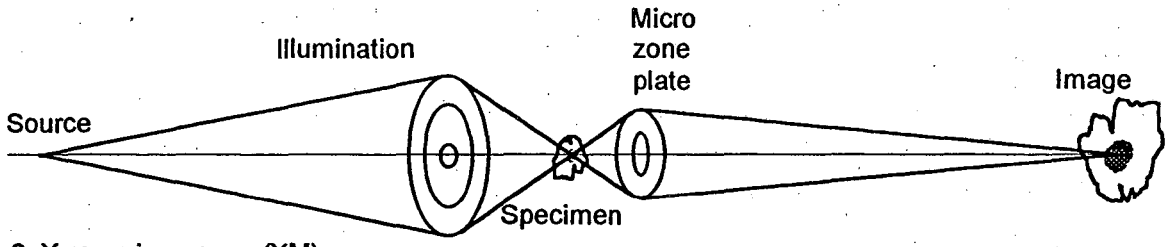

Figure 2: X-ray microscope (XM)

6. Scanning X-ray Microscope (SXM)

The purpose of the SXM illumination system is to provide a small scanning spot of monochromatic radiation, with a size limited by the numerical aperture of a high resolution micro zone plate. This implies that only the spatially coherent flux of the source is to be used. The spectral bandwidth is determined by the number of zones of the micro zone plate.

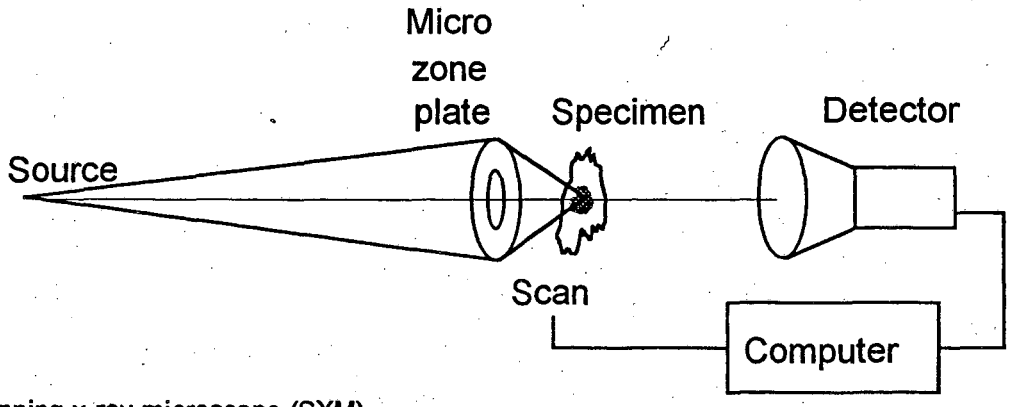

Figure 3: Scanning x-ray microscope (SXM)

Conceptional designs can be divided into two groups. The distinction between these groups is whether an intermediate pinhole is used or not. A design example of the first group is schematically shown in Figure 4. A

plane pop-up mirror feeds the undulator radiation into different branch lines for the XM and the SXM. A Kirkpatrick-Baez (KB) system then focuses the beam vertically onto an entrance slit to the grating monochromator and horizontally onto a pinhole, which also acts as an exit aperture of the monochromator. The monochromator uses a 38-m, 300-grooves/mm spherical grating with varied line space on a constant deviation of 174°. A resolving power of 500 - 1000 is expected at the pinhole having 30μm diameter in a wavelength range 20 - 50 Å

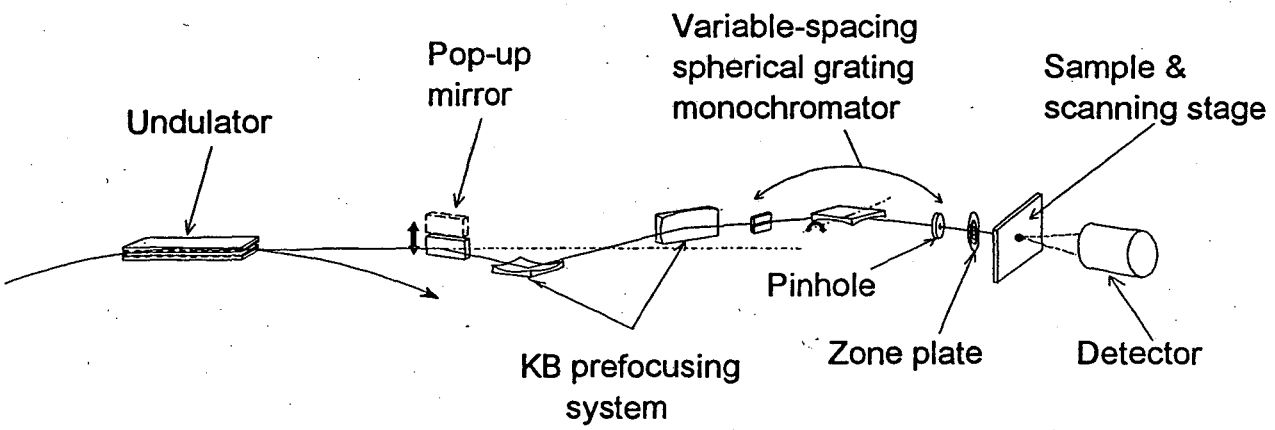

Figure 4: SXM beam line optics consisting of a pop-up mirror, a Kirkpatrick-Baez (KB) prefocusing system, a variable spacing spherical grating monochromator, and a scanning X-ray microscope.

The second group of designs do not use any intermediate pinholes. The source is directly demagnified to a diffraction limited point by use of a zone plate. The spatial coherence is chosen by the acceptance angle of the micro zone plate, but the temporal coherence must be provided by an additional optical element, for instance a varied line space grating.

7. Acknowledgments

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8. References

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2. A. G. Michette, G. R. Morrison and C. J. Buckley ,Eds., *X-Ray Microscopy III*, Springer Series in Optical Sciences, Vol. 67 (Springer - Verlag, Berlin, 1992).

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