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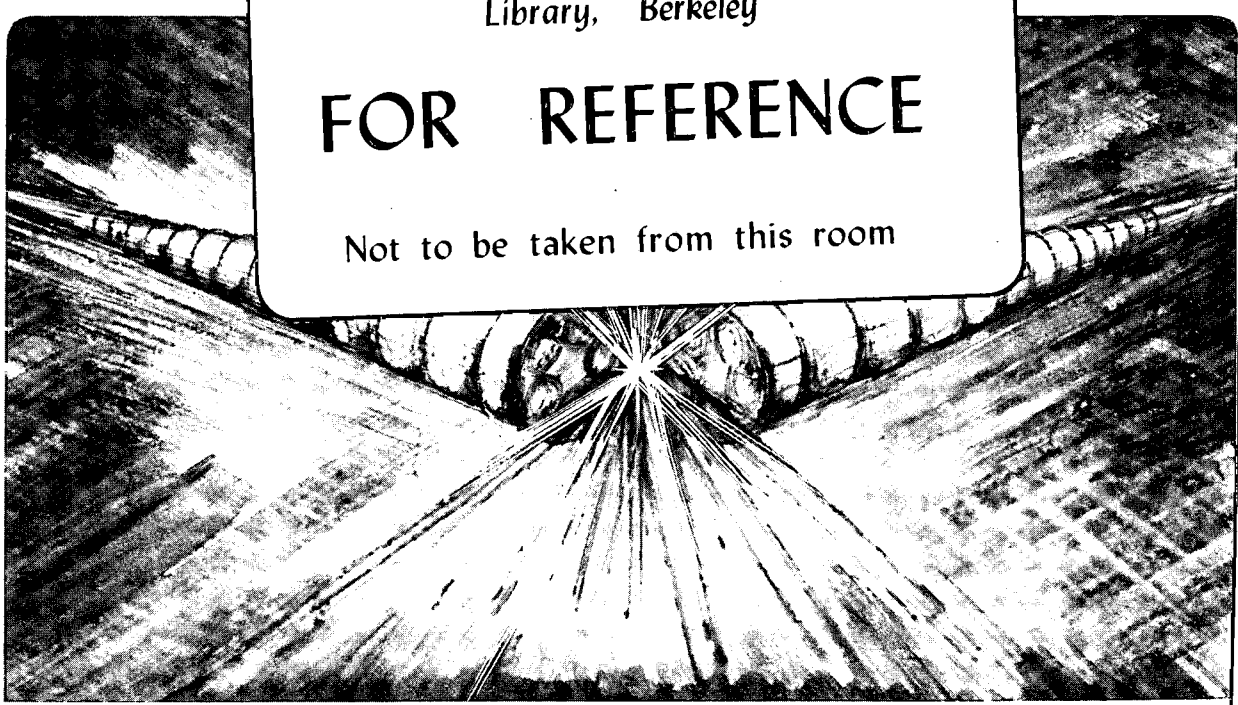

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Thermal Effects and Mirror Surface Figure Requirements for a Diagnostic Beamline at the Advanced Light Source*

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Abstract

An imaging beamline based on a Kirkpatrick–Baez mirror configuration has been designed to image the electron beam in the ALS storage ring, to measure its size and shape. The electron beam emittance will be small (ϵ_h=3.4 x 10^{-9} m rad) and the quality of the image is extremely sensitive to surface figure distortion of the mirrors. Thermal distortions and surface temperatures have been calculated for radiatively cooled mirrors of various materials in a search for a simple design which avoids water cooling. The choice of mirror material and the thermal and mechanical design is discussed.

1. Introduction

A Kirkpatrick–Baez [1] pair of mirrors, for precision imaging of the electron beam using synchrotron radiation, is planned as a means of measuring the transverse beam dimensions in the ALS storage ring. We plan an optical system with unity magnification, making use of photons in a selected range of wavelength.

The ALS has a natural r.m.s. horizontal emittance [2] of 3.4 x 10^{-9} m rad. Assuming 10% coupling into the vertical direction, the beam emittances are:

$$\varepsilon_h = 3.4 \times 10^{-9} \text{ m rad}$$

and

$$\varepsilon_v = 3.4 \times 10^{-10} \text{ m rad}$$

At the bend magnet where the diagnostic beamline will be installed, the horizontal and vertical beta functions (β_h and β_v) take the values 0.394 m and 20.3387 m respectively [2] and the horizontal dispersion is 0.0301. The relative momentum spread is 8 x 10^{-4}. Therefore, the r.m.s. beam sizes are:

$$\sigma_h = (\varepsilon_h\beta_h + (D_h \ \Delta p/p)^2)^{1/2} = 43.8 \ \mu m$$

and

$$\sigma_V = (\varepsilon_V \beta_V)^{1/2} = 83.2 \ \mu m$$

2. Optical tolerances for surface figure errors

The choice of photon wavelengths which avoid diffractive broadening and the required numerical aperture are discussed, and a ray–trace analysis of the optical system is presented, elsewhere [3]. Figure 1 shows the layout of the mirrors and the storage ring shield wall. In order to spread the power load on the first mirror the grazing angle is 1.5 degrees. The second mirror has a grazing angle of 2 degrees.

To match the tolerance for thermal distortion with the design image resolution of the optical system [3], we require the r.m.s. ray deviation due to figure errors to be less than $\sigma/4$.

Thus for the vertical mirror we need an r.m.s. ray deviation of less than 21 μm at the image 6.7 m downstream from the mirror, corresponding to an r.m.s. tangential slope error of 1.6 μrad.

For the horizontal mirror we need an r.m.s. ray deviation of less than 11 μm at the image 6.35 m downstream from the mirror, corresponding to an r.m.s. tangential slope error of 0.9 μrad.

3. Thermal load on mirrors

The first mirror, which is the vertical focussing mirror, imaging in the direction where the beam size is larger, absorbs more radiation power. Thermal distortions of this mirror are analyzed here.

Figure 2 shows the reflectance of a gold surface at 1.5 degrees grazing angle, the spectrum of absorbed power in the horizontal plane and the angular distribution of spectrally integrated power absorbed by the mirror. With the required numerical aperture [3], subtending 2 horizontal milliradians and collecting ±0.5mrad vertically, the mirror will absorb 6.4Watts from 400mA of electron current in the storage ring at 1.5GeV.

A substrate has been designed as a simple rectangular slab, 30cm x 5cm x 5cm. We have performed finite element analyses of thermal deformations and heating for radiatively cooled mirrors. We have considered ULE glass from Corning [4], Glidcop™ [5] with a polished nickel surface and α–sintered silicon carbide [6] with a polished CVD–silicon carbide surface.

The infra–red emissivity of clean, unpolished ULE, Glidcop and silicon carbide was measured (at 6 μm wavelength at about 80°C) and found to be about 0.8, 0.1 and 0.9 respectively. With an emissivity of 0.8 across the infra–red spectrum the mirrors will come to an elevated temperature of approximately 45°C, at which the unpolished surface area can radiate 6.4 Watts. If copper is to be used in this radiatively cooled configuration, the back, sides and ends must be coated

with a high emissivity material to prevent the temperature of the mirror from rising higher than is consistent with UHV requirements.

The calculated surface temperatures, the expansion normal to the optical surface and the tangential slope errors are shown in figure 3 for the three different mirror materials. Material properties are given in Table 1, an emissivity of 0.8 was assumed for the back, sides and ends in each case.

The ULE has a hot spot on the front surface, due to its poor conductivity. Because of the adverse temperature dependence of the expansion coefficient, the ULE distortions are only just within the tolerance. The Glidcop expansion is more, but the distortions are less, and there is no hot spot. The silicon carbide is better yet. The cost of the mirrors was found to increase with their increasing perfomance. We chose a Glidcop substrate for this mirror, to meet the slope error tolerance and in line with other mirrors being fabricated by the ALS at this time. Although Glidcop does not perform as well as silicon carbide, it is thoroughly annealed and believed to be more stable than the sintered material.

The second mirror absorbs little power, Glidcop was chosen here too, in order to minimize engineering effort.

5. Mounting and alignment tolerance

The mirrors will be mounted kinematically, from rods or balls screwed into the copper at three locations midway between the back surface and the reflecting surface, giving point supports. This gives minimal conductive cooling so that temperature gradients within the substrate are not substantially increased by the mounting. Some thermal drift of the mirror mount is to be expected on a time scale of one hour but temperatures of the support will rise by only one or two degrees. Slow motion of the image is tolerable in this system, up to about 100μm.

Glidcop mirrors are heavy (7kg). Gravity sag of the vertically deflecting mirror has been evaluated by means of a finite element calculation. With a three point support, slope errors are developed in the unsupported corners up to a maximum of 0.5μrad, which is acceptable.

An important feature of this optical system is that it be stigmatic. It is essential to form an image which is in focus from both mirrors simultaneously.
The tolerable error in focal length to ensure a stigmatic focus is 1.4% for the first mirror, 0.36% for the second. This error can arise from the measured radius, the installation angle of the mirrors or the position of the source with respect to the optical axis. When imaging the electron beam the horizontal focus will be found, and the pitch of the vertical mirror will be altered, if necessary, by tipping the mirror tank to bring the vertical focus to the same point. The image would move vertically through less than a millimeter during this procedure.

6. Summary

Radiatively cooled Glidcop mirrors will satisfy our requirements for the ALS diagnostic beamline. The extent to which thermal drift moves the image will be

evaluated when the system is operational at the ALS and the operating electron current and lifetime are known. This design is a candidate for generic first optics receiving ALS bend magnet radiation.

Table 1. Material Properties

	ULE	Glidcop	silicon-carbide
Thermal conductivity: ($W\ m^{-1}\ °K^{-1}$)	1.31	365	125
Thermal expansion: coefficient ($°K^{-1}$)	$4\ 10^{-8}$ (at 45°C)	$16.6\ 10^{-6}$	$4.02\ 10^{-6}$
Elastic modulus: ($N\ m^{-2}$)	$6.76\ 10^{10}$	$10.7\ 10^{10}$	$40.7\ 10^{10}$
Density: ($kg\ m^{-3}$)		$8.8\ 10^{3}$	

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2. ALS Handbook, Lawrence Berkeley Laboratory, Berkeley, CA. PUB-643 Rev.(1989).

3. Diagnostic Beam Line for a Third Generation Storage Ring, R.C.C. Perera, M.E.Melczer, A.Warwick, A.Jackson and B.M.Kincaid Proc. 4th Intl. Conf. Synchrotron Radiation Instrumentation, Chester, England, 15-19 July 1991.

4. Corning Advanced Products Dept., Corning Inc., Corning, NY 14831

5. SCM Metal Products Inc., 11000 Cedar Ave., Cleveland, Ohio 44106

6. Texas Instruments Inc.

FIGURE CAPTIONS

Figure 1. Layout of the diagnostic beamline.

Figure 2. Spectral and angular dependence of the power absorbed by the first mirror. Spectra are shown versus photon energy in eV, psi is the vertical angle in radians.

Figure 3. Results of finite element calculations of the thermal response of the first mirror, considering three different materials. The curves show the properties of the reflecting surface versus distance from the center of the illuminated area, in the tangential direction. 'Expansion' is the increase in the thickness of the substrate, in the direction normal to the reflecting surface

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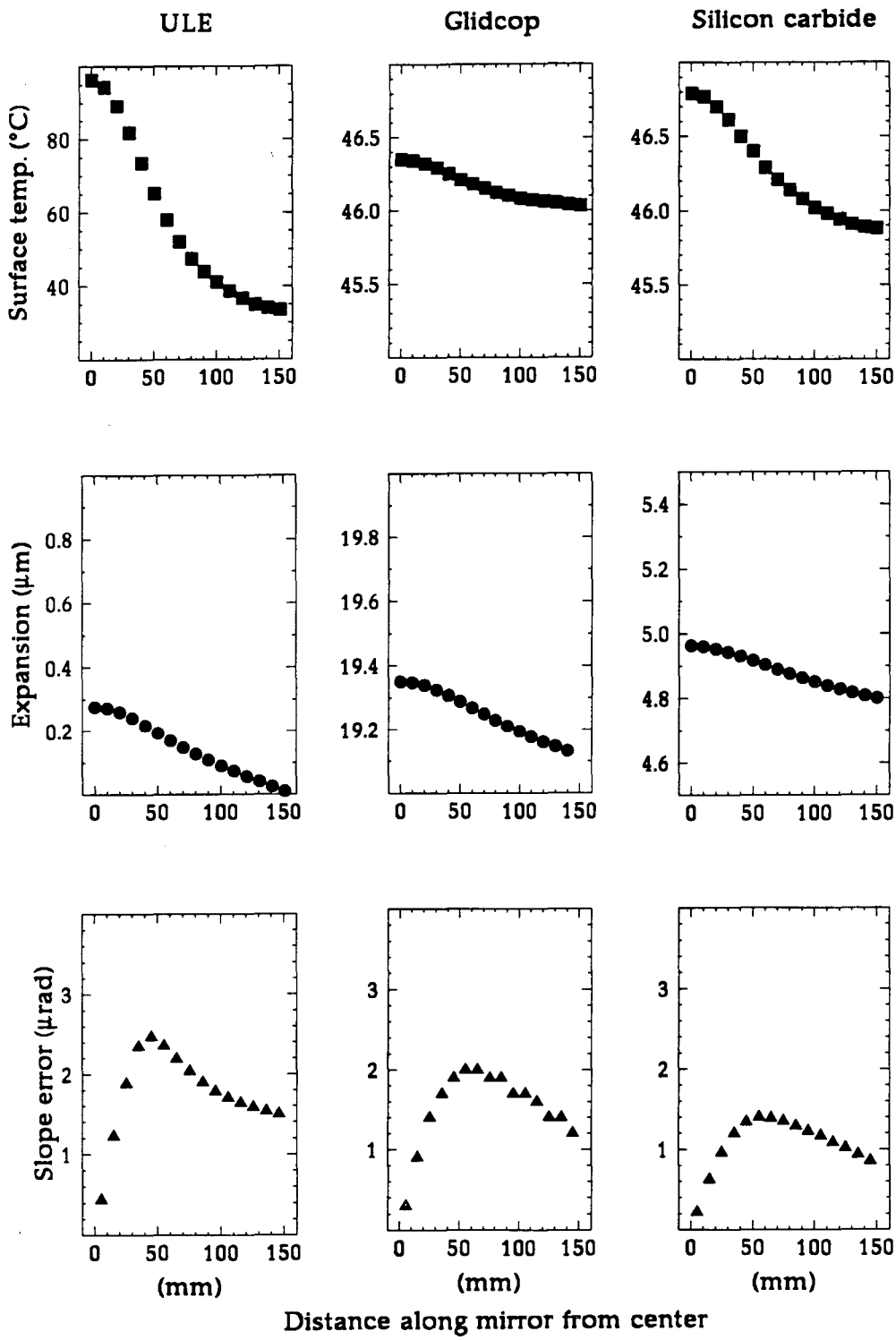

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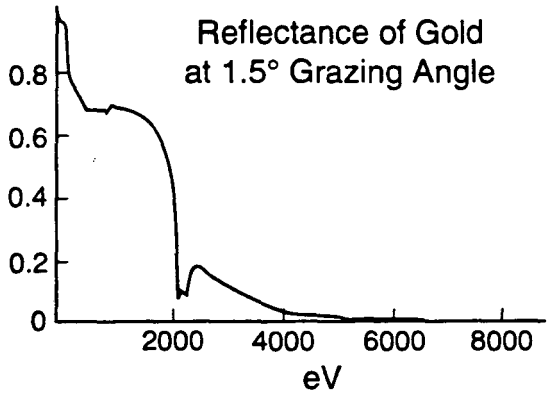

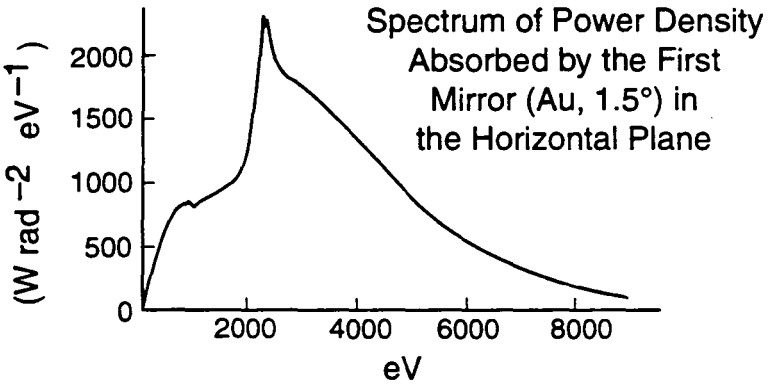

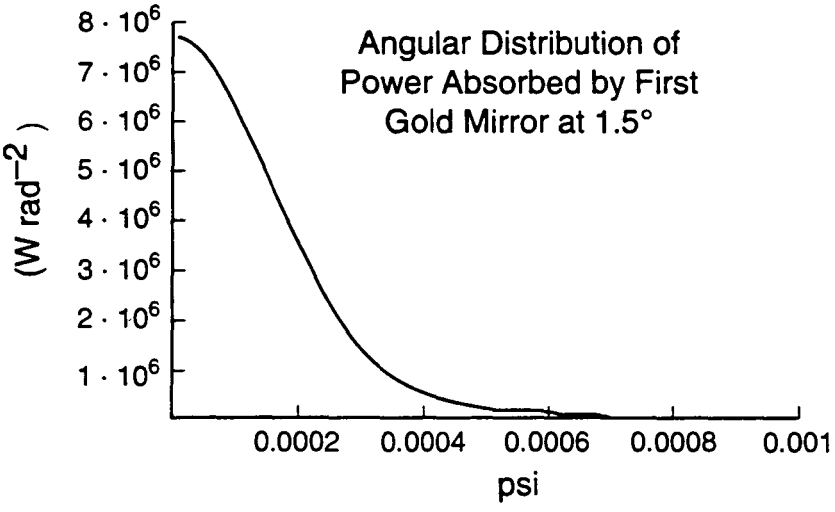

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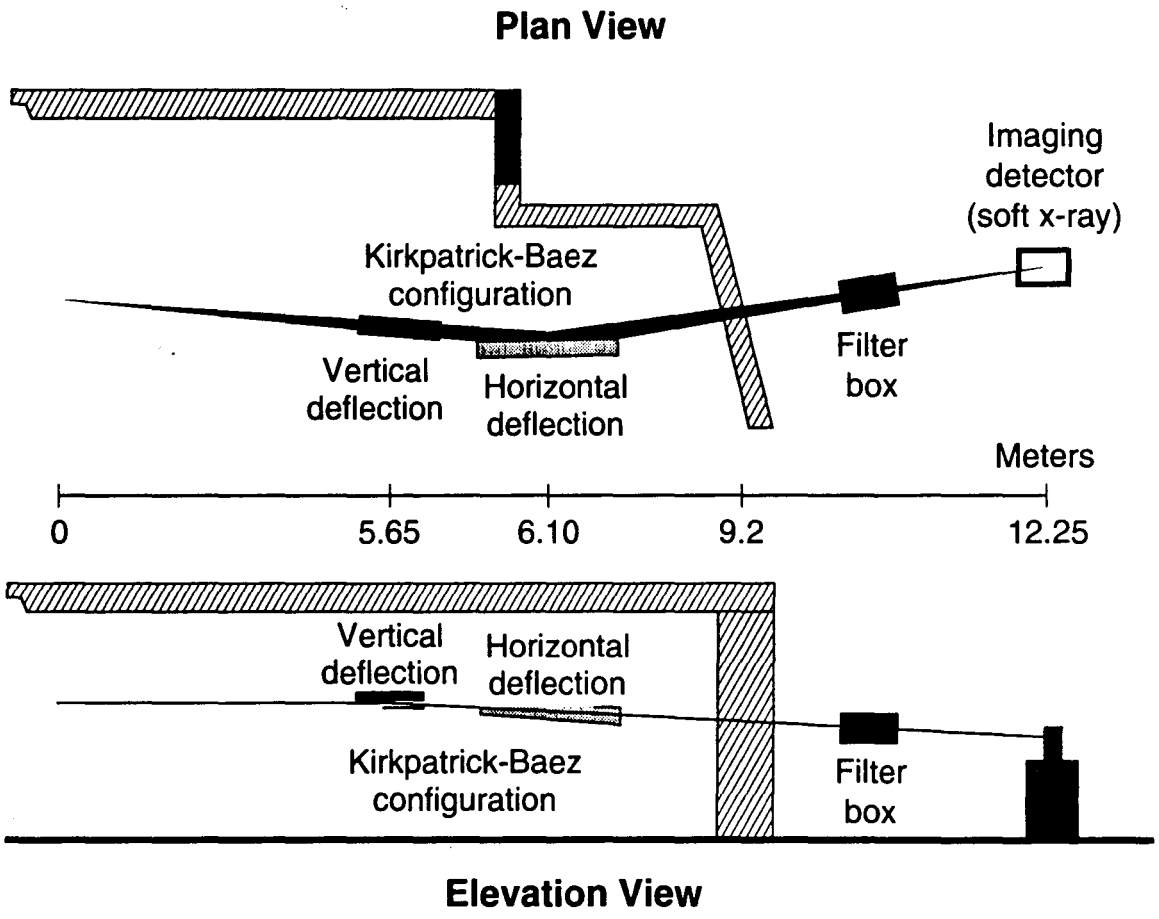
Diagnostic Bend Magnet Beamline



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