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UCID- 17505

Lawrence Livermore Laboratory

Reflection Efficiencies of

X-ray Mirrors 1-10 KeV

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June 14, 1977

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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Abstract for UCID 17505

Measured reflectivity curves are given for several x-ray mirrors. Energy and angle ranges covered are 0.9 to 15 KeV and 0.5 to 2.0 degrees. Reflecting surfaces were Be, C, SiO₂, Ni, and Au. Measurements are complete for Ni and Au but only particular angles were measured for other mirrors.

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X-ray reflection coefficients for 12 mirrors were measured at angles of $1/2$, $3/4$, 1 and 2° . The purpose was to calibrate mirrors used in x-ray microscopes at LLL (Seward and Palmieri 1975), Seward et al, 1976). With these data, the energy response of the microscope lenses can be determined. Three mirror samples developed for x-ray astronomy instruments were also obtained from Smithsonian Astrophysical Observatory (SAO) for comparison.

A high intensity x-ray machine (Gaines 1972) and a Si (Li) detector were used to measure relative reflectivity as a function of energy. The absolute reflectivity was then measured at 1.5 KeV using the Al $K\alpha$ fluorescent line and all curves were normalized at this energy. A low energy x-ray machine was used to measure sub kilovolt reflectivity of one mirror.

Relative reflection efficiencies were measured with 15 KV bremsstrahlung x-rays from several anodes. A Cu anode was used most frequently because the .928 KeV characteristic line could be seen strongly (see Figure 1). Energies lower than this were not practical because of attenuation in a Be window in the x-ray tube. The Co line at .775 KeV was sometimes visible, but, not generally useful.

Mirrors and slits were aligned by removing the detector and sighting with a transit at a target placed just before the Be window. The layout is illustrated in Figure 2. The direct beam and reflected beam paths were defined by 2 slits: one just before the mirror, and one just in front of the detector. Because the anode was 1 cm in diameter, the detector also received scattered x-rays (as contrasted to specular reflection) from angles up to ± 7.5 arc min. A third slit could be placed between the anode and mirror to limit scattering to ± 1.3 arc min. The accuracy with which the reflection angle could be

measured was limited by the difficulty of seeing the optical target reflected in the small mirrors. The image was degraded by diffraction and mirror curvature.

The direct and reflected beams were each observed by blocking the undesired beam with a moveable shutter. A complete spectrum was measured in 400 sec with the x-ray tube anode current at 25 mamp. The spectra were recorded in a 1024 channel pulse height analyser and stored on magnetic tape. The LLL computer was used to set the energy scale correctly, to divide the reflected spectrum by the direct spectrum, and thus to obtain the relative reflection efficiency as a function of energy. Limitations of this technique are distortions produced by: 1) finite detector resolution and 2) escape peaks from characteristic lines just above the mirror cut off energy.

The detector resolution is indicated in Figure 5 and only distorts data in the vicinity of strong characteristic lines or when the reflection efficiency changes rapidly with energy. Each measurement was made with two or three different anodes to avoid the line problem. The 2° data may fall off sharply enough to be distorted by the detector resolution. Data at other angles probably do not need correction. In any case the curves presented here are not corrected for finite detector resolution.

The relative reflection efficiency curves were normalized by measuring the absolute reflection efficiency at 1.49 KeV. X-rays from an Al anode were filtered so only the Al characteristic line was transmitted. The beam was defined by 2 slits as shown in Figure 2. A small proportional counter was the detector and discriminator levels were set above and below the Al peak in the pulse height spectrum so only 1.5 KeV x-rays were counted. A third slit in front of the detector was wide enough so all reflected x-rays were clearly collected. The counter was rotated through the direct beam to define zero on the angle scale precisely and to measure the incident beam intensity. A mirror

was placed on the axis of rotation and the reflected beam intensity was measured at several angles of reflection. At each angle the counter was rotated completely through the reflected beam insuring that the angle of reflection was measured accurately. A counting rate versus angle curve with a flat maximum insured that all reflected x-rays were collected.

The thickness of the reflecting layers were measured by x-ray fluorescent analysis at LLL (R.Ryon and R. Gutmacher 1977). Mirror properties have been listed in Table 1. Thickness of plating was measured as an areal density (mg/cm^2). This has been converted to a thickness measured in Angstroms using the density of the normal material.

The carbon mirror at 2° reflects no x-rays above 1.5 KeV. A low energy Henke tube with Ti anode and a thin formvar exit window was used to measure its reflectivity. Geometry was different from that shown in Figure 2. Maximum angular divergence of the incident beam was $0.6'$. The detector, set at 2° , accepted scattered x-rays from angles up to $8'$.

SPECTRUM FROM COPPER ANODE

Fig. 1

RELATIVE REFLECTION EFFICIENCY

scale:

100 cm

1 cm

mirror

slit, 0.3 mm X 10 mm

moveable slit 1 mm X 10 mm

moveable beam stop

slit, 0.3 mm X 10 mm

target for alignment

Be window

anode, 10 mm dia

detector

aperture 0.35 mm dia

563 cm

237 cm

Fig. 2.

ABSOLUTE EFFICIENCY AT 1.5 KEV

Fig. 3

Angular Considerations

Measure relative reflection efficiency versus energy.

Max angular divergence of beam	0.40'
possible scattering contribution, no third slit	$\pm 7.5'$
possible scattering contribution with third slit	$\pm 1.3'$
accuracy of measuring angle of reflection	$\pm 2' = .03^\circ$

Measure absolute reflectivity at 1.5 KeV

max angular divergence of beam	0.30'
possible scattering contribution into counter	$\pm 2.4'$

Fig. 4

Fig. 5

Fig. 6

QUARTZ AND NICKEL, 0.75°, XRM (Boyle)

Fig. 7

Fig. 8

CHROMIUM AND BERYLLIUM, 0.95°, XRM (Seward)

Fig. 9

GLASS AND NICKEL, 0.95°, XRM#2 (Seward)

Fig. 10

Fig. 11

M I R R O R S

<u>MIRROR</u>	<u>AREA</u>	<u>SURFACE CURVATURE</u>	<u>COATING OR COMPOSITION</u>	<u>FRACTION OF REFLECTED BEAM BLOCKED BY THIRD SLIT</u>	<u>ANGLES MEASURED (deg)</u>			
Ni, HEAD B Sample	1" x 4"	optical flat	520 Å; 91%Ni,9%Cr	.025	.494	.752	1.095	1.90
Au, SAO #1	4" x 4"	flat-float glass	725 Å	.022		.752		
AU, SAO #2	3" x 3"	flat-float glass	680 Å	.032	.498	.755		1.86
Ni, XRM Boyle	1/4" x 1 3/8"	cyl R = 1310"	2600 Å	.027		.752		
SiO ₂ , XRM Boyle	1/4" x 1 3/8"	cyl R = 1310"	47%Si,53%O	.051		.752		
C, XRM Boyle	1/4" x 1 3/8"	cyl R = 490"	100%C	-				2.0
Au, XRM Boyle	1/4" x 1 3/8"	cyl R = 1310"	2230 Å	.306		.738		
Au, XRM Seward	1/2" x 1"	sph R = 1375"	2060 Å	-		.709	.950	
Ni, XRM #2	1/4" x 1 1/2"	sph R = 775"	2600 Å; 96%Ni,4%Cr	-			.948	
Glass, XRM #2	1/4" x 1 1/2"	sph R = 775"	30%Si,43%O,20%K,7%Ba	-			.948	
Cr, XRM Seward	1/4" x 1 1/2"	cyl R = 600"	760 Å; 85%Cr,15%Ni	.058			.939	
Be, XRM Seward	1/4" x 1 1/2"	cyl R = 600"	?, thin, Be is trans- parent to moderate light	.097			.951	

Comments on data shown in Figures 5-13

The data presented are in the form of smooth curves drawn through individual data points (57 points per KeV energy) obtained with x-rays from anodes with no characteristic line at these energies. Crosses indicate reflectivities obtained using characteristic lines. Since the crosses fall right on the smooth curves (obtained with a different anode) there is no distortion caused by detector resolution at these energies. The gap between the point at .93 KeV and the start of the curve at 1.2 KeV illustrates the range dominated by the detector response to the strong line at .93 KeV.

The major surprises in these data were resolved by fluorescent analysis of the mirror surfaces. It was found that a mirror we thought was nickel, was mostly chromium, and that a glass mirror contained large amounts of potassium. The potassium K absorption edge at 3.61 KeV accounts for the minimum in the reflectivity curve shown in Figure 10. The M edge of gold shows at 2.20 KeV at all angles. There is no sign of the K edge of Si at 1.84 KeV in the quartz or glass mirror reflectivities.

Figure 6 shows a dashed curve estimated for the SAO #2 mirror at an angle of 1.00° . This was done using data (shown in Figure 11) from another gold mirror. This was calculated in order to have a complete set of reflective efficiencies for this mirror.

Figure 13 and 14 compare Ni and Au mirrors measured at $\sim 3/4^\circ$. The shape of the Ni curves is about the same but the absolute intensity from different mirrors changes. Reflectivities of the various Au mirrors show both different shapes and intensities. This is also seen in the position of the "knee" as a function of angle. The energy of the "knee" in the reflectivity curve is defined as that point where an extension of the rapid fall off, on a log scale, intersects the flat low-energy part of the curve. This knee is illustrated in Figure 11 for a Au mirror at 0.71° . Since the fall off at high energies is rapid, the position is not too dependent on the extension of the low energy data. The knee is a measure of the "cut off" energy of a mirror and also an indicator of the "critical angle".

The SAO mirrors showed the highest reflectivities and highest energy cut offs of all samples. Certainly more care has been taken polishing the HEAO B mirror sample than the XRM mirrors. The thicker coating of the XRM mirrors probably also degrades the reflection properties. Gold XRM mirrors with 2000 Å coatings did not reflect as well as the x-ray astronomy samples with 500 Å coatings. One conclusion is that coatings should be as thin as possible.

The critical angle θ_c , is given by Compton and Allison (1935) as:

$$\theta_c = \text{constant} \times \sqrt{\frac{n}{E}}$$

where n is electron density, E is photon energy, and the expression does not apply close to an absorption edge. The straight lines in Figure 14 show $\sqrt{\frac{n}{E}}$. Normal material densities have been used to calculate n except as indicated.

These lines have been normalized to the Ni HEAO B data. The other Ni mirror points fall right on this line. The Au SAO #2 data fall above the Au line. SAO #1 and the Au mirrors with thick coatings all fall below the Au line. The three points for C, Be, and Cr mirrors are as expected.

Quartz is at too low an energy. Probably the "knee position is too close to the Si absorption edge at 1.84 KeV. Glass is high for reasons unknown.

Figure 14 then summarizes these results and shows generally that the measured "knee" follows the expected behavior of the calculated critical angle. The questions it poses are: Why is the reflectivity of SAO #2 better than the other 3 gold mirrors? Why is the "knee" of the glass reflectivity curve at so high an energy?

The last column in the table on page 15 lists the fraction of reflected intensity blocked when the third slit was inserted. This is a measure of x-rays scattered by mirror defects or by deviations of the mirror surface from a flat surface in the plane of reflection. Mirrors with spherical surfaces showed a 50% effect (because of the mirror curvature) and have not been listed. The other mirrors, all nominally planar in this dimension, showed decreases in intensity ranging from 2% to 10% except for a 30% decrease measured for the Au mirror XRM (Boyle). Addition of the third slit in this case both decreased the reflected beam intensity and changed the shape of the reflected spectrum. The lower energies were decreased more than the higher energies. The reflected beam without the third slit was used to derive the reflectivity curve given in Figure 8.

These numbers in the last column can be used as a measure of scattered intensity between 1.3' and 7.5' of arc. The energy range is that of the reflectivity curve. This number did not change much in those cases when a given mirror was measured at different angles. We cannot separate effects caused by surface defects from surface curvature.

TWO NICKEL MIRRORS, 0.75°

Fig. 12

SEVERAL GOLD MIRRORS, $\approx 3/4^\circ$

Fig. 13

KNEE POSITION VS. REFLECTION ANGLE

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Available from

National Technical Information Service

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