D D

INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 93-129

A.Braem[1], M.E.Kostrikov[2]

RADIATION TRANSPARENT MIRRORS FOR RICH

Submitted to *NIM*

---

[1] CERN, Geneve, ANDRE_BRAEM@MACMAIL.CERN.CH.
[2] Institute for High Energy Physics, Protvino, KOSTRIKOV@MX.IHEP.SU.

Protvino 1993

UDK 539.1.074 M–24

Abstract

Braem A., Kostrikov M.E. Radiation Transparent Mirrors for RICH Detectors: IHEP Preprint 93-129. – Protvino, 1993. – p. 8, figs. 3, table. 1, refs.: 15.

The possibility of obtaining beryllium substrates suitable for mirrors with average thickness of less than 1% of radiation length is demonstrated.

Аннотация

Брэм А., Костриков М.Е. Радиационно прозрачные зеркала для RICH: Препринт ИФВЭ 93-129. – Протвино, 1993. – 8 с., 3 рис., 1 табл., библиогр.: 15.

Показана возможность получения подложек из бериллия,подходящих для изготовления зеркал RICH со средней толщиной менее 1% радиационной длины.

INTRODUCTION

Ring-Imaging Cherenkov counters (RICH), considered in detail in [1], are widely used in high-energy physics. The mirror is an essential component of the RICH, reflecting photons radiated by the particle onto photodetectors. To reduce particle interactions with the detector material, the mirror thickness has to be reduced to minimum. In the first large RICH detector the glass substrates of the mirrors were 22 mm thick [2]. In subsequent RICHs 6 mm thick glass mirrors were used (5% of radiation length) [3,4,5,6]. Some detectors require mirrors with a thickness not exceeding 1% of radiation length [7,8].

In the light of foregoing, the work was started on the development of mirror substrates made of beryllium, since it is known for its high radiation length (36 cm). The high Young modulus of beryllium makes it possible to envisage the production of mirrors with a thickness of not more than 3 mm.

1. LIGHT REFLECTION FROM ROUGH SURFACE

The photodetectors used in RICH counters are sensitive to photons with a wavelength λ =140-220 nm and one of the basic parameters, defining the appropriateness of the substrates for the production of the mirrors is their smoothness. The rough surface is defined by the profile function [10]:

$$Z = z(x,y) = z(r),$$

where r is the radius-vector of the surface point, and z is the ordinate measured with respect to the ideal smooth reference plane. The value of roughness is characterized by the r.m.s. deviation, σ, from the centre plane. For RICH mirrors σ has to be 3 nm or less.

The fundamental characteristic of the surface profile describing the spatial correlation between the height of the relief at points $z(r)$ and $z(r')$ is the autocorrelation function

$$K(r-r') =< z(r)z(r') >,$$

which, apart from σ, has one more parameter, i.e., the autocorrelation length **a** ("« »" denotes space averaging). The autocorrelation length has several definitions, the most obvious being the mean step of roughness between peaks [9]. The Gaussian function of the correlation is often used [10,11,12]:

$$K(\tau) = \sigma exp(-\tau/\mathbf{a}).$$

The scalar theory of light scattering on the rough surface interprets the formation of a diffusely scattered component as reflection from the micro irregularities (facets) on the optical surface. In the first approximation the intensity of diffusely scattered light corresponds to the decrease of the mirror-reflected beam, i.e., the roughness does not lead to the appearance of additional absorption. With normal incidence, the specular factor x, defined as the ratio of the observed specular reflectance R of the surface to R_0 of the perfectly smooth surface of the same material, depends only on the wavelength λ and σ :

$$x = R/R_0 = exp(-(4\pi\sigma/\lambda)).$$

The aforementioned is applicable for a surface formed by a Gaussian process with parameters σ and **a**. The correlation functions of the majority of the polished surfaces are non-Gaussian. Thus, for a correct description of the angular distribution of scattered light a suitable approximation has to be selected for the autocorrelation function, or the autocorrelation function has to be represented as a sum of several Gaussians [11,12].

2. SAMPLES

Some 3 mm thick and 40 mm diameter samples of beryllium were polished. The samples were polished using two different technologies: one for samples 1 and 2, the other for samples 3 – 5. The reflecting coatings was deposited at CERN using the method described in [13]. At the same time as the beryllium was being coated, test samples cut out of the glass used for the DELPHI RICH were also coated. Sample No. 5 was not covered with a reflecting surface.

After coating, measurements were taken of the mirror specular reflectivity. Figure 1 shows the wavelength dependence of the specular reflectivity for four beryllium mirrors and a test glass mirror. The effect of heating on the mirror quality was investigated. One beryllium and one glass mirror were heated in the air for 6 hours up to 100 degrees. While the reflectivity of the glass mirror dropped within the range of 160-220 nm by an average of 6%, that of the beryllium mirror decreased by 3.5%.

3. ROUGHNESS MEASUREMENTS

Measurements of the samples roughness were taken using several methods.

4.1 Using an integrating sphere (the diameter of the sphere D=100 mm, the beam diameter 1.5 mm, the aperture diameter in the integrating sphere d=10 mm), the total integrated scattering (TIS) was measured at a wavelength of 337 nm. The accuracy of measurement was 0.01% at a scattering value up to 0.1% and 0.1% at a scattering value above 0.1%.

The surface roughness is often determined from the value of the total integrated scattering (TIS):

$$\sigma = -\lambda\sqrt{ln(1-TIS)}/4\pi \approx \lambda\sqrt{TIS}/4\pi. \qquad (1)$$

However, when diffusely scattered radiation is measured using an integrating sphere, the mirror-reflected beam must not be detected and must exit through the corresponding aperture. Since the maximum angular density of the diffusely reflected flux centered about the specular beam, part of the diffusely scattered light is lost through this exit hole. If the apparatus detects the light scattered between minimum angle ϑ_{min} and maximum angle ϑ_{max}, the rms roughness may be calculated using formula [10]:

Table 1 gives values of σ_{f1} and σ_{f2} calculated with formulae (1) and (2), where it is assumed that correlation length a=3 μm, ϑ_{min}=d/2D , $\vartheta_{max}=\pi\ /2$.

$$\sigma = \lambda\sqrt{(TIS)}/(4\pi\sqrt{F(\mathrm{a})}), \qquad (2)$$

where $F(a) = exp[-(\pi \mathrm{a}\vartheta_{min}/\lambda)^2] - exp[-(\pi \mathrm{a}\vartheta_{max}/\lambda)^2]$.

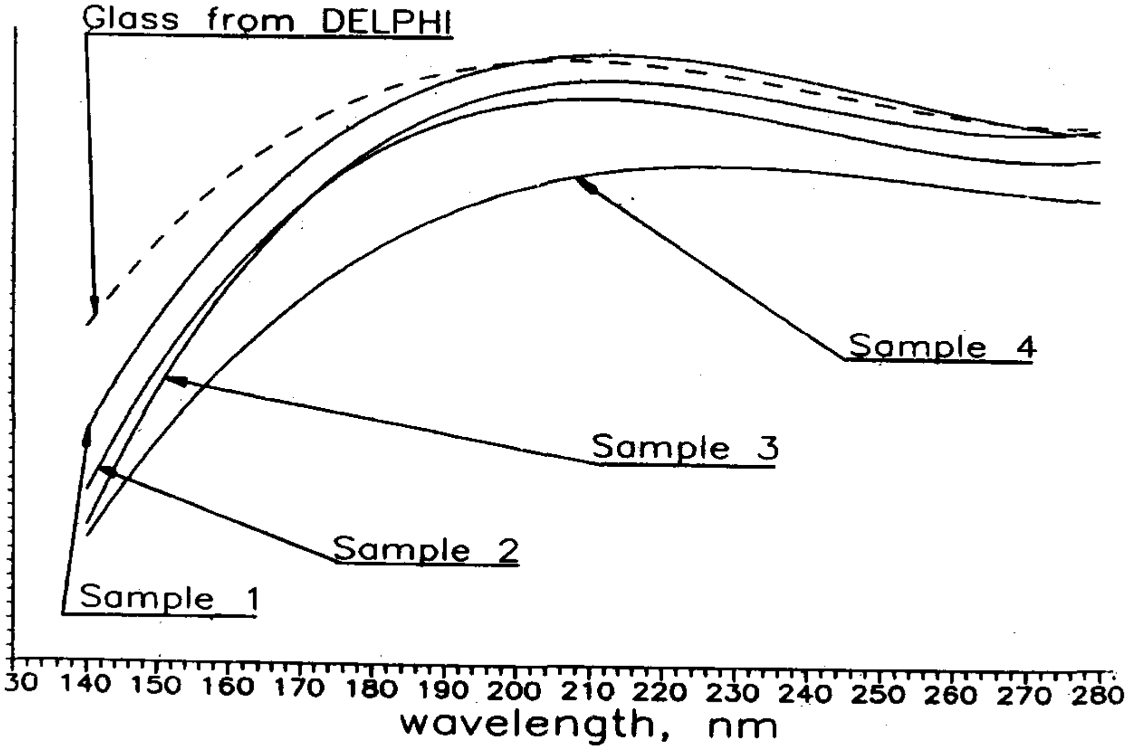


Figure 1. Wavelength dependence of reflectivity. Dashed line – glass mirror; solid lines – polished beryllium.

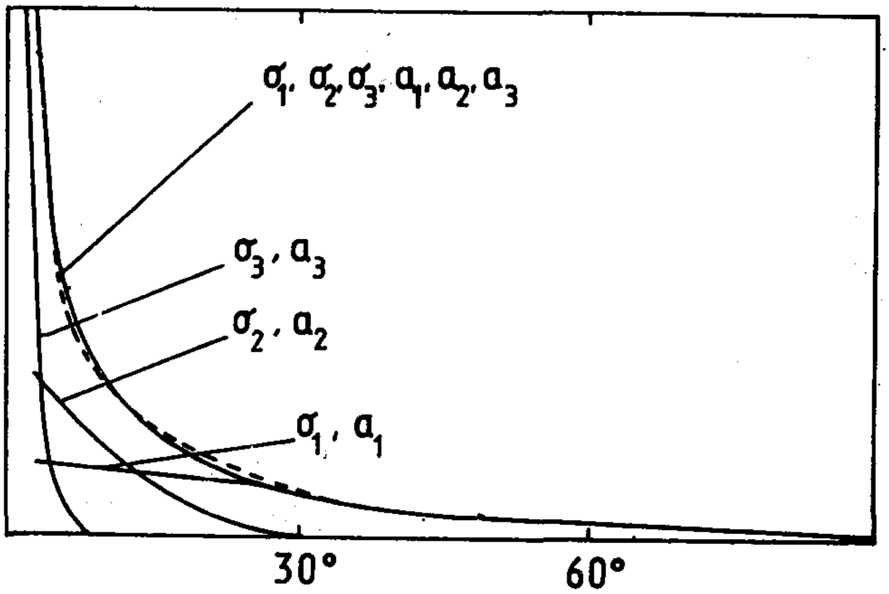


Figure 2. The angular dependence of diffusely scattered light: dashed line - measured dependence; σ_1, σ_2, σ_3, a_1, a_2, a_3 – surface is described by the sum of three gaussians; σ_i, a_i – surface is described by only one gaussian.

Table 1.

	TIS %	σ_{f1}	σ_{f2}	σ_1 ($\mathbf{a}_1$)	σ_2 ($\mathbf{a}_2$)	σ_3 ($\mathbf{a}_3$)	σ_{tot}	σ_{Taly}
Sample 1	0.2	1.2	3.2	1.2	1.3	1.6	2.4	0.8
				<(0.1)	(0.6)	(3.3)		
Sample 3	0.68	2.2	5.8	1.4	2.2	2.9	3.9	3.6
				(0.3)	(0.7)	(3.2)		
Sample 5	-	-	-	3.7	3.0	3.0	5.6	5.0
				(0.2)	(0.6)	(3.0)		

σ_{f1} ,σ_{f2} is the rms roughness according to formulae 1 and 2 (measured in nm);

σ_1, σ_2, σ_3, (measured in nm), a_1, a_2, a_3 (measured in μm) are calculated on the basis of the assumption that the surface may be described by the sum of three independent Gaussian correlation function, σ_{tot} is root mean square from σ_i;

σ_{Taly}, nm – measured by Talystep.

4.2. The angular dependence of scattered light was measured at a wavelength of λ =632 nm. Figure 2 gives the measured angular dependence and that calculated on the basis of the assumption that the surface may be described by the sum of three independent Gaussian correlation functions with parameters σ_1, σ_2, σ_3, $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$. The parameters of the functions are defined by fitting the reference curve to the measured one and are also shown in Table 1. Figure 2 also gives the angular dependence that the scattered light would have if the surface be described only by one of the three Gaussian functions.

4.3. Figure 3a-3c shows the surface scans of the test samples obtained using the Talystep profilograph with a stylus radius $r = 1$ μm. These surface profiles were used to measure the surface roughness (the basic measurement length is 50 μm). A surface scan was also made on a sample glass mirror used in the DELPHI RICH. The surface roughness values obtained from this scan coincide with those given in [13].

Roughness was measured by different methods and compared more than once [11,12]. Results on measuring are often sufficiently different.

We have to remember that the problem of measuring roughness is equivalent to the electrical engineers dilemma in measuring rms noise in a circuit. He must specify the bandwidth of the noise power spectrum for his measurements to have meaning [14]. With optical measurements the minimum space of surface structure equals λ [10]. With Talystep measurements the minimum spacing that can be resolved [12] as:

$$L > 2\pi\sqrt{hr},$$

where $h = 2\sqrt{2}\sigma$ is the amplitude of the roughness. For $\sigma = 2 - 3$ nm $L \simeq 400$ nm, i.e. the same minimal spacing as for optical measurement.

Our results using optical methods with appropriate treatments are found to coincide. Difference exist between optical measurements and stylus- type measurement of sample No 1. We suppose that optical measurements were spoiled by the presence of dust , micro-sleek or polishing pits distributed over surface. Although these small polishing artifacts may cover only a small fraction of the surface area they would cause a significant increase in the scattered light [15].

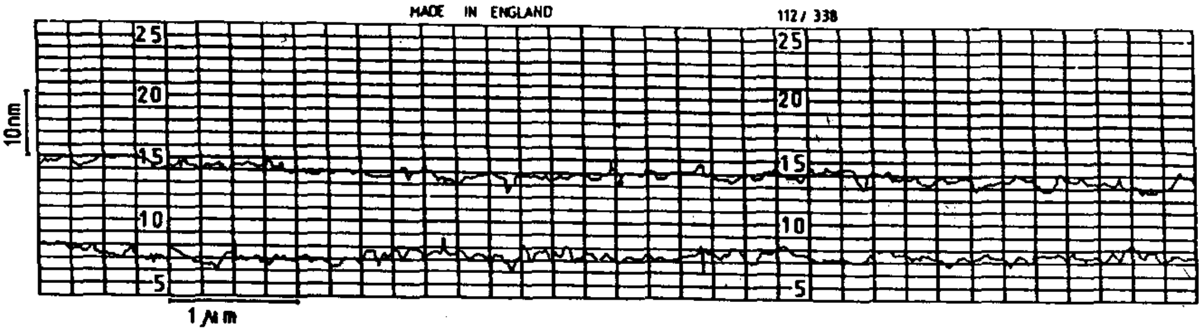
CONCLUSION

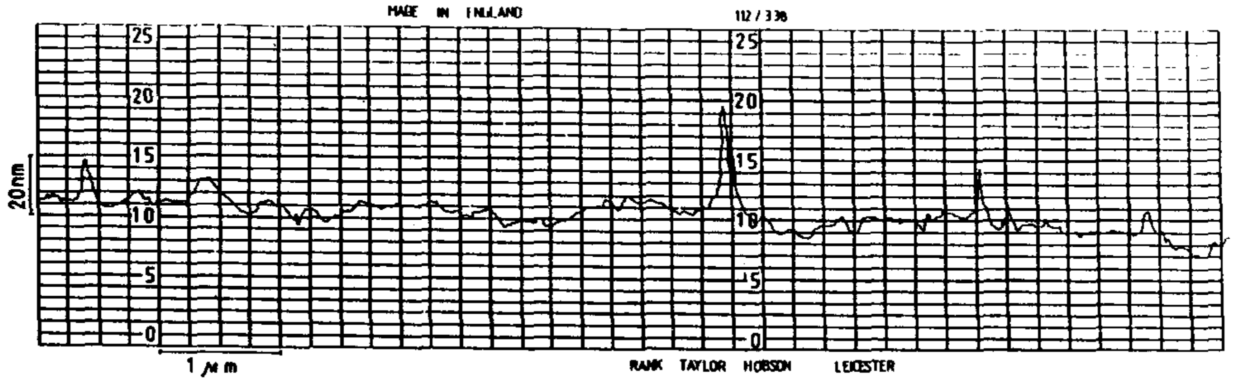
Samples of beryllium were obtained with sufficiently small roughness (at least σ=3 nm) to be used for mirrors reflecting vacuum ultraviolet.

The 3 mm thick mirror with diameter 250 mm and good reflectivity in vacuum ultraviolet is ready now, substrate was polished at NPO "Kompozit" (Kaliningrad, Russia).

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to A.Zaitsev for formulating the problem and for constant support of the work, to T.Ypsilantis and M. Price for their interest and support, to A.A.Semenov (NPO "Luch", Podolsk) for polishing the samples, D.Carminati for his help with the deposition of the reflecting films, V.Luk'yanov (All-Union Institute of Metrology, Moscow), A.Babin and A.Anoshin (NPO "Kompozit", Moscow) for their help in measurements and useful discussions.





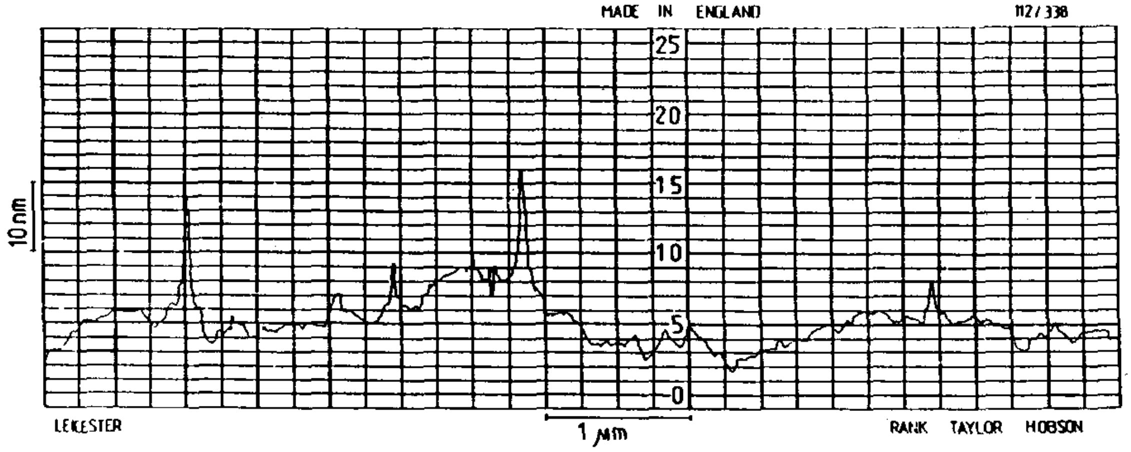


Fig 3a. Surface scan of sample №1.
Fig 3b. Surface scan of sample №3.
Fig 3c. Surface scan of sample №5.

References

[1] Ekelof T., Sequinot J., Tocqueville J., Ypsiylantis T. Physica Scripta **23**, (1981), 371; Sequinot J., Ypsilantis T. CERN-LAA/PI/91-004, (1991).

[2] McCarthy R., Adams M., Brown C. et al. NIM **248** (1986), 69.

[3] Apsimon R.J., Flower P.S., Hallewell G.D. et al. IEEE Trans. on Nuclear Science **NS34**, (1987), 504.

[4] Arnold R., Baillon P., Besch H.J. et al. NIM **A270**, (1988), 255.

[5] Aston D., Bean A., Bienz T. et al. NIM **A283**, (1989), 582.

[6] Courtracon G.B., Dhawan S., Shuler P. IEEE Trans. on Nuclear Science **NS35**, (1988), 470.

[7] Zaitsev A.M. et al. Workshop "Physical research at UNK", Serpukhov, (1988), 253.

[8] Faschingbauer U., Trauth M.G., Wurm J.P. et al. CERN/SPSC 88-25,SPSC/P237, (1988); Schukraft J., Faschingbauer U., Trauth M.G. et al. CERN/SPSC 88-40,SPSC/P237 Add1, (1988).

[9] Cesnec L.S., Sorokin O.V., Zolotukhin A.A. Metallicheskie Zerkala, M., Machinostroenie, 1983.

[10] Trofimov V.I., Osadchenko V.A. Poverchnoct: Fizika, khimiya, mekhanika (1987), N9, 5.

[11] Porteus J.O. Journal of Optical Society of America **53**, (1963), 1394.

[12] Elson J.M., Bennett J.M. Journal of Optical Society of America **69**, (1979),31.

[13] Baillon P. et al. CERN/EP 88-169,(1988).

[14] Noll R.J., Glenn P. Applied optics **21**, (1982), 1824.

[15] Edwin R.P. J. Phys. E: Scient. Instr. **6**, (1973), 55.

Received October **29**, *1993*

А.Брэм и др.
Радиационно прозрачные зеркала для RICH.

Оригинал-макет подготовлен с помощью системы LaTeX.
Редактор А.А.Антипова.
Корректор Е.Н.Горина.

Подписано к печати 1.11. 1993 г. Формат 60 × 90/16.
Офсетная печать. Печ.л. 0,50. Уч.-изд.л. 0,66. Тираж 260. Заказ 946.
Индекс 3649. Цена 100 руб.

Институт физики высоких энергий, 142284, Протвино Московской обл.

100 руб.

Индекс 3649

ПРЕПРИНТ 93-129, ИФВЭ, 1993