



HAL
open science

ADVANCES IN X-RAY OPTICS AT THE NATIONAL PHYSICAL LABORATORY

A. Franks

► **To cite this version:**

A. Franks. ADVANCES IN X-RAY OPTICS AT THE NATIONAL PHYSICAL LABORATORY. Journal de Physique Colloques, 1984, 45 (C2), pp.C2-69-C2-72. 10.1051/jphyscol:1984217 . jpa-00223843

HAL Id: jpa-00223843

<https://hal.science/jpa-00223843>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ADVANCES IN X-RAY OPTICS AT THE NATIONAL PHYSICAL LABORATORY

A. Franks

Division of Mechanical and Optical Metrology, National Physical Laboratory, Teddington, Middlesex TW11 0LW, U.K.

Résumé - Les progrès de la technologie de fabrication aussi bien que de la métrologie donnent la possibilité de développer des composants optiques à rayons X de haute qualité pour l'usage de l'astronomie, des recherches en radiation synchrotronique, et de la microscopie.

Abstract - Advances in manufacturing technology and metrology have made possible the development of high quality X-ray optical components for use in astronomy, synchrotron radiation research and microscopy.

I - INTRODUCTION

Renewed interest in X-ray reflection optics in the early 1950s came about as the result of the pioneering efforts of, for example Ehrenberg [1], Kirkpatrick and Baez [2] and Wolter [3,4]. Efforts were first directed towards X-ray microscopy, but the initial enthusiasm faded after it became evident that the achievement of high resolution would require a precision of surface figure and finish of the mirror surfaces which was beyond current capabilities. X-ray astronomy provided a new stimulus in the 1960s to develop grazing incidence mirrors. Synchrotron radiation research provided the next application and this was followed by the development of X-ray microscopes for laser fusion research [5]. The technology to produce reflection X-ray microscopes to complement optical and electron microscopes only now appears to be within our grasp.

II - SPECIFICATION FOR X-RAY OPTICAL COMPONENTS

It is not possible to make generalized statements about the specifications for optical components except to state that the trend is towards achieving arc second or better resolution in X-ray telescopes and to sub-micrometre resolution in microscopes, which translates to sub-arc second resolution in angular terms. The implications in terms of manufacturing tolerances to meet these requirements have previously been discussed [6] and may be summarized as follows.

The most demanding tolerances are those associated with axial slope and surface roughness. It is convenient and revealing to state the slope error in terms of the permitted amplitude variations of the surface for the range of surface wavelengths (waviness) which may result from the manufacturing processes. For the X-ray telescope quoted in [6], the tolerances on surface amplitude corresponding to the required 0.05 arc sec slope tolerance are 0.12 μm , 0.012 μm , and 2.5 nm for surface wavelengths of 500 mm, 50 mm, and 10 mm respectively. The tolerances for surface finish are equally severe. In the example quoted, the proportion of energy which falls within a 1 arc sec diameter aperture for an on-axis point source is no more than 50% for a roughness of 1 nm (rms). Similar calculations have been made for an X-ray microscope [7] which show that the surface profile may not depart by more than 2 nm from its theoretical form and that the surface roughness should not exceed 0.2 nm (rms).

III - PRODUCTION OF X-RAY OPTICAL COMPONENTS

Developments have taken place in three main areas in order to achieve the tolerances discussed in Section II.

1. Manufacturing Technology. - The route towards efficient production is by way of very precise machining of mirror substrates, particularly by diamond turning of metals and precision grinding of glasses, followed by lapping and polishing. Lapping and polishing machines for components ranging in sizes approaching 1 m down to 10 mm have been specially developed for X-ray components [8,9]. The surface qualities which have been achieved by polishing flat discs of some materials is shown in Fig. 1. For Spectrosil, for example, the surface roughness was about 0.02 nm (rms), measured with a lateral resolution of 50 nm, on the NPL-upgraded Talystep machine [10].

2. Metrology. - A range of instruments has been developed at NPL to cater for the measurement of axial profile, and surface roughness, to nanometre and sub-nanometre levels of accuracy respectively, as well as diameter and circularity [6,11,12].

Measurement of surface figure to an uncertainty of 2 nm is illustrated in Fig. 2, which shows the axial profile and the departure from the theoretical profile - the error curve - of the X-ray microscope, referred to in Section IV, measured with the NPL laser autocollimator [12].

3. Materials Evaluation. - The fundamental criterion in selecting a mirror material is that it must be polishable. The limits in surface figure and finish which can be achieved depend on the mechanical, chemical and physical stabilities of the selected materials as well as on their microstructural inhomogeneities. Some of the more favoured materials are (i) the very low thermal expansion coefficient materials, Corning 7971 ULE silica and the glass ceramic Zerodur, although there is some doubt about their long term stabilities, (ii) the very homogeneous silica glasses such as synthetic vitreous silica (eg Spectrosil) and remelted quartz (eg Homosil), (iii) some of the refractory materials such as silicon carbide and (iv) where the application demands a metal substrate, electroless nickel coated materials, such as beryllium or aluminium [10,13].

IV - EXAMPLES OF GRAZING INCIDENCE OPTICS

Figure 3 illustrates extremes in the sizes of Wolter optics: the Aries X-ray Telescope [14] which was successfully flown in 1980 and an X-ray microscope. An X-ray microscope jointly developed by the Lawrence Livermore National Laboratory, AWRE and NPL for laser fusion research is shown in Fig. 4. It has a magnification of 22 X but its geometry is extremely unfavourable for microstructural studies because of the very large mirror to image distance of over 6 m. This renders it very susceptible to image degradation, particularly by scatter, but nevertheless it is capable of resolving somewhat better than 1 μ m, as can be seen in Fig. 5, which is an X-ray micrograph of an hexagonal gold grid. Although the peak to background ratio is poor, the development work on this microscope has shown that resolutions of 100 nm or better should now be achievable.

To take full advantage of the potential resolution of multilayer mirrors used at normal incidence, they will require to be made to the same tolerances as Wolter microscopes. At present, multilayer substrates are generally, either plane or spherical, and for these simple forms, the necessary surface roughness tolerances have already been achieved, as illustrated in Fig. 1.

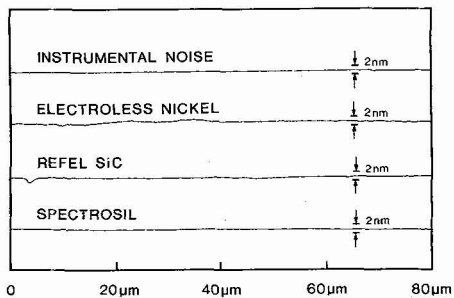


Fig. 1 - Talystep traces of polished flats showing that peak-to-valley roughnesses of 0.1 nm are now achievable.

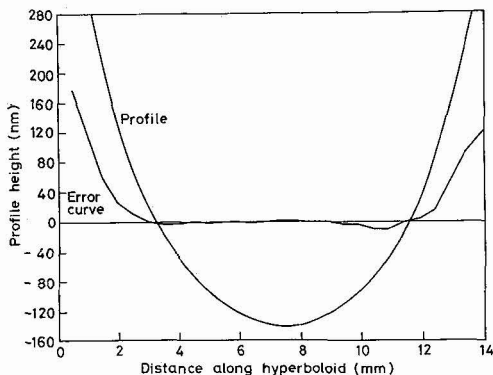


Fig. 2 - Axial profile and error curve of an X-ray microscope. Measurements can be made to an uncertainty of 1 nm.



Fig. 3 - Wolter telescope and microscope.

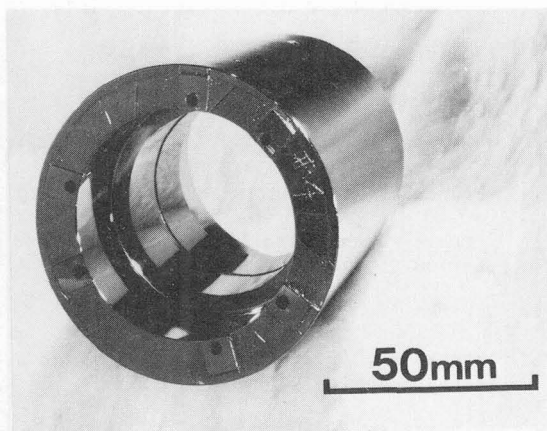


Fig. 4 - Wolter microscope.



Fig. 5 - X-ray micrograph of an hexagonal gold grid taken with Al K radiation ($\lambda = 0.83$ nm).

Another important class of focusing mirror developed at NPL is one where the optic axis is not an axis of symmetry. These may be made by directly machining the component to the required shape, or by elastically bending plane mirrors into circular, parabolic or elliptical cylinders [15,16]. The advantages of the bending technique are the simplicity of manufacture coupled with greater versatility. For example, a parabolic collimator has been constructed in which the angle is variable to cater for a range of wavelengths, while the focal length remains constant.

V - CONCLUSIONS

As a result of advances in manufacturing techniques, metrology and the understanding of materials, it is now possible to produce high quality X-ray optical components by well-defined manufacturing procedures, rather than by traditional, empirical optical craftsmanship.

ACKNOWLEDGEMENTS - Important contributions to the work described in this paper were made by Mr T.H.English, Mr A.E.Ennos, Mr K.Lindsey, Mr C.J.Robbie, Dr M.Stedman and Mr M.S.Virdee.

References

- [1] Kirkpatrick P. and Baez A.V., *J.Opt.Soc.Am.* 38, (1948) 766
- [2] Ehrenberg W., *J.Opt.Soc.Am.* 39 (1949) 741
- [3] Wolter H., *Ann.Phys.* 10 (1952) 94
- [4] Wolter H., *Ann.Phys.* 10 (1952) 286
- [5] Seward F.D. and Palmieri T.M., *Rev.Sci.Inst.* 46 (1975) 204
- [6] Franks A., *AIP Conf.Proc.* 75 (1981) 179
- [7] Franks A. and Gale B., to be published in "X-Ray Microscopy", Springer Series in Optical Sciences (1983)
- [8] Franks A., *Proc.SPIE* 184 (1979) 110
- [9] Franks A., Gale B., Lindsey K., Pugh D.J., Robbie C.J. and Stedman M., *Ann.N.Y.Acad.Sci.* 342 (1980) 167
- [10] Lindsey K., *Nucl.Inst.Meth.* (1983) in the press
- [11] Stedman M., *Proc.SPIE* 136 (1982) 2
- [12] Ennos A.E. and Virdee M.S., *Proc.SPIE* 398 in the press
- [13] Lindsey K. and Franks A., *Proc.SPIE* 163 (1979) 46
- [14] Catura R.C., Acton L.W., Berthelsdorf R., Culhane J.L., Sanford P.W. and Franks A., *Proc.SPIE* 184 (1981) 23
- [15] Franks A., *Proc. Workshop on X-ray Instrumentation for Synchrotron Radiation Research*, SSRL Report No. 78/04 (1978) VII -101
- [16] Stedman M., *Proc. Workshop on X-ray Instrumentation for Synchrotron Radiation Research*, SSRL Report No. 78/04 (1978) VII - 142