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Measurement of reflection and scattering of mirrors in the VUV and soft X-ray region using synchrotron radiation

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Abstract

The design and calibration of soft X-ray telescope and synchrotron radiation monochromator require a knowledge of optical properties of mirror surface for various mirror materials over a fairly wide range of grazing angle and photon energy. For this purpose, the reflection and angle resolved scattering curves of four mirror samples (fused quartz, optical glass, zerodur and electroless nickel) were measured in the photon energy region from 0.1 to 1keV at grazing angles from 0.6° to 30°. The measurement was carried out at the beam line 11 is mainly used for the Baker grasshopper monochromator and PF reflectometer. All the samples were polished by CIOM*. The rms roughness of the sample surface were measured by the stylus method at KEK** and CIOM successively. It was in the order of 1nm. The electroless nickel sample was formed by plating an aluminum disk with Kanigen. A part of the results shown in Figs. 1 and 2 are of electroless nickel which is more often used as a mirror material in soft X-ray telescope and synchrotron radiatio nmonochromator.

The development of soft X-ray telescopes and synchrotron radiation facilities requires optical elements of higher quality. The only optical elements which can be used in the VUV and soft X-ray region are reflection mirrors. Since indices of refraction of most materials are nearly unity in the X-ray region, the reflectance is very small except at grazing incidence. Practical single surface X-ray mirrors must thus be used at grazing incidence. The performance of these mirrors is strongly affected by the near angle scattering of X-ray radiation at angles from a few seconds of arc to a degree or so from the specular direction. If they are used for synchrotron radiation as beam splitters, they must be able to absorb a high flux of short wavelength components without thermal distortion and degradation.

In recent years, a lot of experimental and theortical work has been done[1~6] on X-ray reflectivity and scattering from optical surfaces. Although available optical constants can be used to predict reflectivities and some theoretical interpolations

* CIOM——Changchun Institute of Optics and Fine Mechanics

** KEK——National Laboratory for Nigh Energy Physics, Japan

exist, such methods do not always provide reliable predictions of the reflectivity of a completed mirror, as the surface roughness and composition can exert a strong influence on the reflectivities achieved. Few data have been obtained on practically availabie mirrors. Published experimental data on reflectivities exist only for restricted wavelength bands and limited angles of incidence. For this reason, the reflectance spectra and e angular distributions of scattered light on various practical materials were measured in the photon energy region from 0.1 to 1 keV at grazing angles from 0.6° to 30°.

I. Measurement Procedure

The measurement was carried out at the beam line BL-11A of Photon Factory in June 1984. The Photon Factory is a national synchrotron radiation research facility affiliated to KEK. It consists of a 2.5 GeV electron linear accelerator and a 2.5 GeV electron storage ring as a dedicated synchrotron radiation source. Four beam-lines have been constructed for VUV and soft X-ray experiments[7]. Beam line 11 is mainly used for solid state spectroscopy in the VUV and soft X-ray spectral region. A grasshopper monochromator[8] is installed on BL-11A. A horizontal 1.3-mrad beam of radiation is deflected by 4° using a Pt-coated, flat SiC mirror and is then incident on a cylindrical mirror in the grasshopper monochromator. The grating mounted in the grasshopper monochromator is a 2400 lines/mm gold-coated replica with a blaze angle of 1°45′. The light beam impinges on it at a grazing angle of 2 degrees. Photons of energies between 90 and 1000 eV are available. The ratio of scattered and higher order light to the desired monochromatic beam was found to be 5% or less in the energy region below 300 eV. The resolving power at about 250 eV, with a slit width of 15 μm, was estimated to be 2×10^3. For a stored electron current of 100 mA, and entrance and exit slits set to 15 μm, the output flux was $10^8\sim10^9$/s. The monochromator is evacuated by a 500 l/s ion pump, and a 30 l/s ion pump mounted on the grating chamber. After low-temperature bakeout, a vacuum of 2×10^{-9} Torr was achieved. The wavelength reading, scanning system, and data acquisition system are controlled by a microcomputer.

The grazing incidence reflectometer was designed by the soft X-ray spectroscopy working group of Photon Factory. In general, the soft X-ray reflectivity is very low at incidence angles other than near 90 degrees. Therefore, the reflectometer enabled accurate measurements to be made for grazing incidence. It was constructed in the following manner:

1) A rigid frame is fixed inside on the bottom of the chamber.

2) The precision goniometers are attached to the outside of the chamber and are jointed to their respective internal axes with bellow couplers. It has been ascertained

that the displacement between the axes is less than 30 μm and the tilting angles less than 0.01°. The absolute accuracy of the rotational angles is within 0.02°, the same as that of the goniometers. Pressure in the reflectometer was 10^{-8} Torr during measurement. The soft X-ray beam is focused on the 0.2-mm slit of a detector by a refocusing mirror. In order to collimate the incident beam, an entrance diaphragm of 0.1 mm width is located 120 mm before the sample. The sample holder is tilted a few degrees from the rotational axis by a linear feedthrough to pass the incident beam. The reflectivities were obtained by normalizing the reflection intensity with the incident light intensity and the stored electron current in the ring.

II. Results

We have carried out the measurements of the reflection and angle resolved scattering curves for four mirror samples made of fused quartz, optical glass, zerodur and electroless nickel respectively. All the samples were polished at CIOM and exposed to ambient atmosphere without any protection for several months before measurement. The rms roughness of sample surfaces was measured by the stylus method[4,9] at KEK and CIOM succesively. It was in the order of 1 nm. The electroless nickel sample was formed by plating an aluminum disk with Kanigen. A part of the results shown in Figs 1 and 2 are of electroless nickel which is more often used as a mirror material in soft X-ray telescopes and synchrotron radiation monochromators[10].

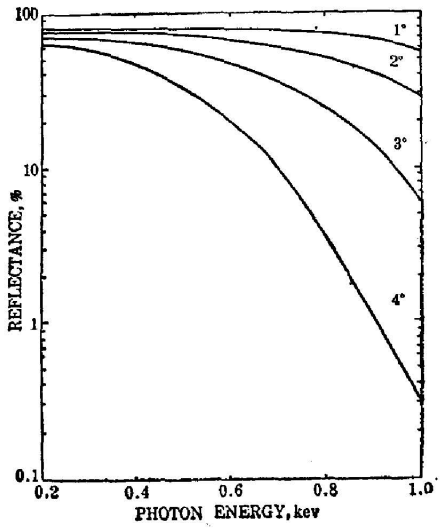

Fig.1 Reflectance spectra of electroless nickel mirror at variours grazing angles

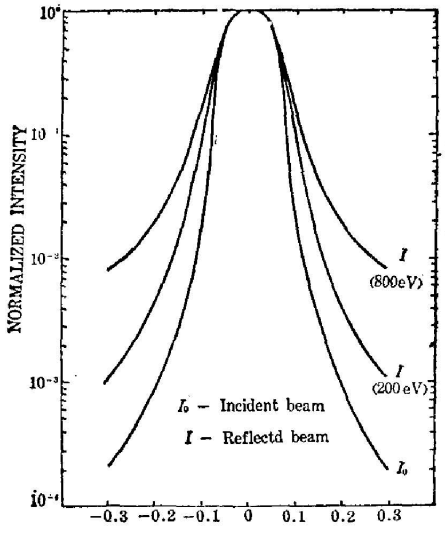

Fig.2 Scattering properties of electroless nickel, mirror at grazing angle 2°

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用同步辐射测量镜子在真空紫外和软 X 线区的反射和散射

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提 要

在真空紫外和软 X 线区镜子表面的反射和散射研究，不论在理论上和实际应用上，都有重要意义。近几年来，随着 X 线天文望远镜和同步辐射实验装置的兴起，对超光滑表面镜子的加工和测试进行了大量的研究工作。这是因为在上述光谱区，镜子的反射和散射与所照射的光子能量、入射角、镜子表面的状况等的关系更为复杂。这些数据，对研制 X 线天文望远镜和同步辐射光谱仪器是必不可少的。由于工作的需要，作者于 1984 年 6 月在日本高能物理研究所同步辐射实验室，测定了四种不同材料的反射镜在真空紫外和软 X 线区的反射和散射。这四种材料是融熔石英、普通光学玻璃、微晶玻璃和镍磷合金。所使用的同步辐射光子能量从 0.1～1 keV(波长 12.4～1.24 nm)，掠射角从0.6°～30°。这些镜子都是中国科学院长春光学精密机械研究所磨制的，其均方根表面粗糙度在日本高能所和长春光机所先后测定，为 1 nm 数量级。镜子抛光后没有镀膜，并放置在大气中达数月之久，然后测试。本文叙述了测量的情况，并图示了镍磷合金镜子的典型曲线。这种材料，目前广泛用作 X 线望远镜的抛物面反射物镜和同步辐射反射镜。

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