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Nuclear Instruments and Methods in Physics Research B 245 (2006) 332–336
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Ion track filters in imaging X-ray astronomy

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Available online 4 January 2006

Abstract

The application of ion track filters as blocking cut-off filters for solar telescopes in imaging X-ray astronomy is presented. Ion track membranes (ITMs) of high-porosity constitute a randomly inhomogeneous medium with sub-micrometer or micrometer open pores which not only transmits X-ray or extreme ultra violet (EUV) radiation and blocks long-wavelength UV radiation, but also transfers a focused imaging pattern with high-quality for further registration by means of CCD or imaging detectors of other types. X-ray and EUV filters based on ITMs with cylindrical parallel pores were successfully used as detector filters in the solar X-ray telescopes designed and manufactured at the Lebedev Physical Institute of the Russian Academy of Sciences (LPI, Moscow).

PACS: 95.55.Ka; 07.85.Fv; 42.25.Dd; 42.30.Va; 42.70.Gi; 61.43.Gt

Keywords: Ion track membrane; X-ray optics; Soft X-ray; EUV filters

1. Introduction

Solar astronomy is one main branch of space astronomy [1]. The solar corona is the brightest source in the sky in the soft X-ray spectral region and provides a sufficient number of photons for recording high-quality soft X-ray images within a few minutes of observation using medium-size X-ray mirrors (around 10–25 cm in diameter). Almost all advanced methods of X-ray astronomy are based on the progress in multi-layer mirrors and high-spatial resolution charge coupled devices (CCD) developed as detectors for X-ray imaging.

The flux of solar UV and visible light is about 10^8 times larger than the radiation flux from strong soft X-ray solar lines. This is why the blocking filters that reject the UV and visible light are needed to avoid the long wave background. Due to the strong absorption of all materials in the soft X-ray region, all filters have to be very thin films (Al, C, Be, Mg, Si, Ti, etc.) with the thickness of 0.1–1 μm. Usually three types of filters are used in the X-ray imagining astronomy. They are front filters, detector filters and filter wheels as subsidiary filters–analyzers. The front filters mainly protect the optics and detector from solar heat, while the major attenuation and spectral selection are obtained with a filter near the detector (named "detector filter"). The replaceable filter wheels help to measure a straight light or noise signal, as well as to change the spectral and dynamic range of a mirror image, to check UV leak signal and to measure the saturation curve. They are useful for calibrating the detector systems of an X-ray telescope.

The art of fabrication and testing thin filters for X-ray astronomy and for laboratory applications has been considered in detail in [2–4]. At the Lebedev Physical Institute (LPI, Moscow) in collaboration with the Joint Institute for Nuclear Research (JINR, Dubna) a new type of optical filters for X-ray applications [5–9] was developed. These filters are based on ion track membrane technology [10]. Three identical filters of this kind were installed in the SPIRIT telescope assembly, which includes two telescopes: a Herschel telescope-coronagraph and a Rithey–Chretien (RC) telescope [11,12]. The telescopes have been successfully operating on-board the Coronas-F satellite since

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0168-583X/$ - see front matter
doi:10.1016/j.nimb.2005.11.078

August 15, 2001. In this report we consider the general principles of operation of the ion track filters in the soft X-ray telescopes and discuss the relationship between filters' characteristics and image quality. We focus for the first time on the analysis of transferring the soft X-ray image using ion track membranes, whereas all previous relevant publications were limited to determination of spectral and angular dependence of transmission of electromagnetic waves through etched tracks.

2. Samples

The ion track membranes were produced of polyethylene terephthalate (PET) foils with the thickness L of 5–25 μm. Specimens of the PET foils were irradiated with the 250 MeV Kr ions up to the track density N of 10^6–10^8 cm^{-2} on the U-400 cyclotron of the Flerov Laboratory of Nuclear Reactions JINR. The ions impinged the foil perpendicular to its surface with the maximum deviation from the normal of about 2–3°. The measurement of mass loss as a function of the time during chemical etching made it possible to stop the process upon achieving a required porosity. For the improvement of the spectral and blocking properties, the selected track-etched porous samples were afterwards sputtered with a metal and covered with additional thin layers of metals or ceramics such as Al, SiC [6] and others. The control of membrane parameters and quality of evaporated layers were carried out using scanning electron microscopy (SEM) such as S800 (Hitachi), CAMSCAN 44 and JSM-840 (JEOL). Fig. 1 represents a SEM photo of an ion track membrane which served as a matrix for the detector filters of the two soft X-Ray SPIRIT's telescopes [11,12]. The cross-section of a detector filter [6] with a sputtered Al layer is shown in Fig. 2. The filter was mounted in close proximity to the entrance plane of the image detector, designed as assembling of a multi-channel plate (MCP) detector and CCD. The membrane sample shown in Fig. 1 has the thickness L of 8.5 μm, the pore diameter $D = (1.5 \pm 0.1)$ μm and the pore density $N = (1.4 \pm 0.2) \times 10^7$ cm^{-2}. The parameters for the membrane shown in Fig. 2 are $L = 17$ μm, $D = (3.0 \pm 0.2)$ μm and $N = (4.0 \pm 0.5) \times 10^6$ cm^{-2}. The spectral range of all the telescopes was in the band of wavelength from 13.5 to 30.4 nm.

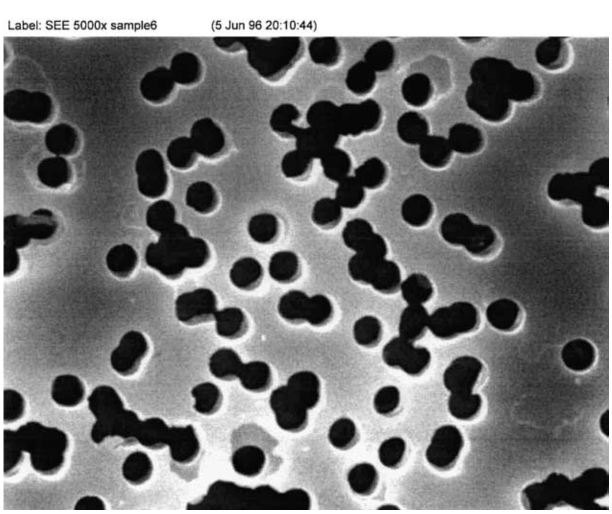

Fig. 1. SEM image of the surface of an ion track membrane used in the SPIRIT soft X-ray telescope on-board the Coronas-F satellite (launched in 2001).

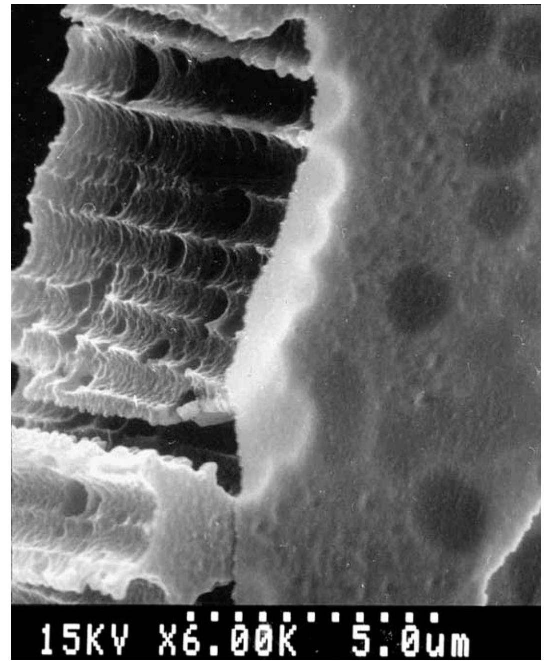

Fig. 2. Cross-section of a detector filter composed of an ion track membrane and a thin Al film installed at the Terek-C solar telescope (1994).

3. Spectral properties of optical ion track filters

Ion track membranes can be considered as a randomly inhomogeneous medium with sub-micrometer or micrometer size open pores, which transmits X-ray or EUV radiation through the pores and cuts off long-wavelength UV and visible radiation due to diffraction and absorption on pore walls. An ion track membrane with a metal-coated surface is an effective dissipative attenuator for long-wavelength light above the UV threshold of the polymer used. Depending on the proportion between the diameter of the pores D, the membrane thickness L and the wavelength λ, ITMs having different nominal porosity $P = \pi D^2 N/4$ can serve as X-ray or UV spectral filters, neutral density filters, collimators, diffraction filters, diffused phase screens, etc.

The cut-off or blocking behavior of ITMs is illustrated by the experimental results shown in Fig. 3. The transmittance normalized to one pore for the EUV radiation in the 119 ± 3 nm band is plotted as a function of the reverse Fresnel number $F = \lambda L/D^2$. Uncovered 5 μm and 10 μm thick PET track membranes of low porosity were used to measure the transmittance characteristics [5]. Overlapping