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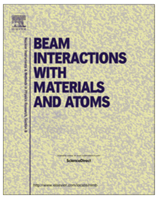

Scattering of hydrogen, nitrogen and water ions from micro pore optic plates for application in spaceborne plasma instrumentation

Joan Stude [*], Martin Wieser, Stas Barabash

Swedish Institute of Space Physics, Rymdcampus 1, 98128 Kiruna, Sweden

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Time-of-flight mass spectrometers for upcoming space missions into enhanced radiation environments need to be small, light weight and energy efficient. Time-of-flight systems using surface interactions as start-event generation can be smaller than foil-type instruments. Start surfaces for such applications need to provide narrow angular scattering, high ionization yields and high secondary electron emissions to be effective. We measured the angular scattering, energy distribution and positive ionization yield of micro pore optics for incident hydrogen, nitrogen and water ions at 2 keV. Positive ionization yields of 2% for H^+, 0.5% for N^+ and 0.2% for H_2O^+ were detected.

1. Introduction

In situ measurements of plasma populations in space require mass-, energy- and size-efficient instrument designs. In the energy range from several eV to several hundreds of keV, time-of-flight systems allow for compact and capable designs [1–5]. An ion mass spectrometer can, for example, be built by combining an electrostatic analyser with a time-of-flight cell. For the time measurement, the generation of a signal is required to start a clock when a particle passes a known start position and a second signal to stop the clock when the particle reaches a known stop position. At the start position, the particle should be as minimally affected as possible, whereas at the stop position, the particle can be absorbed. A common method of start-event generation is to detect secondary electrons generated when a particle penetrates a thin carbon foil [4]. To penetrate such a foil, ions require typically ∽1 keV per nucleon of kinetic energy. For the efficient detection of low energy, heavy ions, such as O^+ and S^+, pre-acceleration by potentials exceeding 10 kV is needed [6]. High voltages drive the instrument size (and mass) to ensure electrically insulating gaps. Surface interactions provide an alternative to carbon foils. Instead of penetrating a foil, the particles reflect on a surface at a grazing angle of incidence. In the process, a secondary electron is emitted and registered as the start-event. Surface interactions have no lower energy limit [7], and a pre-acceleration voltage of a few 100 V is sufficient to ensure a high secondary electron yield. A number of surface interaction-based time-of-flight instruments have been successfully flown in space. Examples include the Solar Wind Monitor (SWIM) and the Chandrayaan Energetic Neutrals Analyzer (CENA) [5] or the Neutral Particle Detector (NPD) [8] part of the ASPERA-3 and ASPERA-4 instrument packages flown on the Mars Express and Venus Express missions.

The energy loss of a particle during the interaction with the start foil or surface is only statistically known. This energy loss is one of the limiting factors for the mass resolution that can be obtained from such a system. The factor can be strongly improved by introducing a linear electric field ion mirror (LEFIM) section into the time-of-flight cell containing a linear electric field (LEF) [9–12] The linear electric field in the LEFIM can be seen as one half of a harmonic potential. For a charged particle of mass m and a potential polarity such that the particles are reflected in the LEFIM, the flight time t_{LEF} in the LEFIM is independent of the particle energy E and is given by

$$t_{LEF} = \pi\sqrt{\frac{m}{|q|ek}} \qquad (1)$$

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[*] Corresponding author.
E-mail address: joan.stude@gmail.com (J. Stude).

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with q being the charge of the particle, e being the elementary charge and k being a constant representing the LEFIM geometry and potential magnitudes. If the start section is field free and has a length s along the particle trajectory, the total observed time of flight is expressed by

$$t = t_{LEF} + t_S \tag{2}$$

$$t = \pi\sqrt{\frac{m}{|q|e\,k}} + \Delta s\sqrt{\frac{m}{2E}} \tag{3}$$

For carbon foils, Δs corresponds to the thickness of the foil and is negligible; however, when using surface interactions for start-event generation, Δs is an important source of uncertainty because it is normally not known where exactly along the length Δs the start electron is generated. Particles interact with the surface at grazing incidence, resulting in a large interaction length. An ideal start surface for a LEFIM combines low angular scattering, high reflection efficiency of positive ions and high secondary electron yield. The angular scattering is optimized by very smooth scattering surfaces [13–15]. The charge state fraction can be altered using different surface materials ranging from polished W(110) single crystals [16], Al_2O_3 films [15], LiF crystals [17], MgO coatings [14], to diamond-like carbon (DLC) surfaces [18]. The secondary electron yield depends on the particle type, energy and surface material [19]. The influence of Δs on the measured time of flight can be minimized by measuring the location on the start surface with a position-sensitive detector. Such a scheme is used in the Chandrayaan Energetic Neutrals Analyzer (CENA) [5]; however, the scheme increases instrument complexity.

An alternative solution is a geometric form of small, repeating, reflective surface elements shaped like a venetian blind. Despite the good availability of polished single crystals as start surfaces, it is challenging to achieve low surface roughness with a venetian-blind-type geometry. The active surfaces inside the structures are difficult to access for processing (e.g., polishing). For use as a venetian-blind-type of start surface in a time-of-flight spectrometer, micro pore optics designed for X-ray imaging applications [20] were investigated. Angular scattering, energy loss, and incident and scattered fluxes were characterized for H^+, H_2O^+ and N^+ ions. A similar idea is shown in Devoto et al. [21], using micro channel plates (MCPs). The large length to diameter ratio of MCPs resulted in a very narrow angle of acceptance however.

2. Material and methods

2.1. The sample

A common method of focusing X-rays is by reflection under grazing angles of incidence. Micro pore optics are developed as a key element of lightweight X-ray optics. To efficiently reflect X-rays with wavelengths of less than < 10 nm, surfaces with “near perfect flatness and very low roughness” [20] are required. Micro pore optics are stacks of small quadratic channels arranged as in a micro channel plate. The channel surface properties and geometrical structure make micro pore optics an interesting candidate for reflecting particles instead of X-ray photons. Micro pore optics are available with channels of different sizes and with different skew angles. We evaluated an off-the-shelf micro pore optics sample (MPO-686-SQ31x31-1H PT001-1) that was obtained from PHOTONIS [22]. The sample (Fig. 1) has straight quadratic channels with a width of 686 µm and a wall thickness of approximately 200 µm. The sample is 1 mm thick and has an area of 31 mm × 31 mm [20].

The substrate material of the micro pore optics is hydrogen-reduced glass that includes high-Z elements such as lead [23]. The surface roughness, r_{RMS}, is better than 1.5 nm [23]. The sample was not specially treated, for example, by heating or cleaning prior to the scattering experiment.

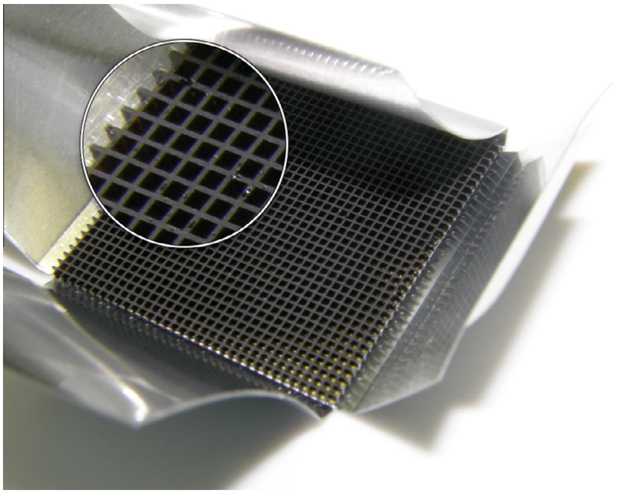

Fig. 1. Micro pore optics investigated in this study. The dimensions are 31 mm × 31 mm, with a thickness of 1 mm.

2.2. Experimental setup

The experiment was performed at the instrument calibration facility at the Swedish Institute of Space Physics in Kiruna. Fig. 2 depicts the geometry of the scattering experiment: A parallel, spatially homogeneous ion beam impinges on the scattering surfaces at a fixed angle $\alpha = 15^\circ$. A detector is freely rotated in the plane formed by the scattering surface normal and impinging beam direction. The rotation angle, or scattering angle, in the plane is denoted by Θ. The out-of-plane scattering angle is denoted by Φ. When the detector looks straight into the incident beam, $\Theta = 0^\circ$. Specular reflection corresponds to $\Theta = 2\alpha$. The experiment is placed in vacuum with an average pressure of 10^{-6} mbar. The ion beam has an average diameter of 80 mm and completely covers the sample.

2.3. Detector

As the detector, we used a modified model of the Miniature Precipitation Analyzer (MIPA) instrument for the European Space

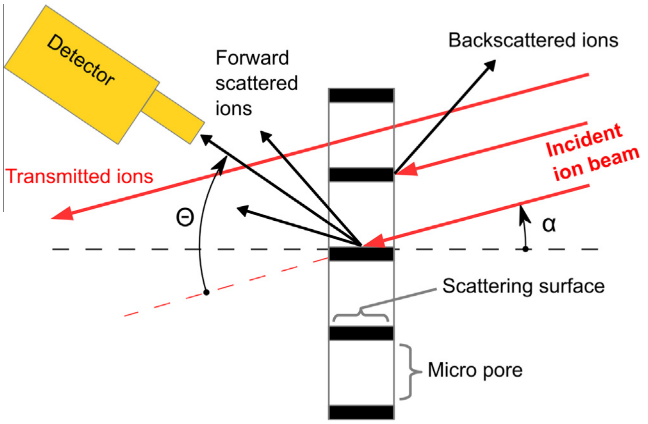

Fig. 2. Top view of the setup, with Θ as the polar scattering angle and α as the angle of incidence. Note the different parts of the beam, back-reflected, scattered and transmitted.