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X-Ray Optics as start surfaces for time-of-flight detectors

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Abstract

For compact, surface interaction-based, time-of-flight plasma analyzers for use in space missions, new types of start surfaces are evaluated. Start surfaces using a window-blind type of geometry were compared to a traditional flat surface. Two structure candidates, a laser ablated copper structure and a glass based micro pore optical element as used in X-ray optics, were tested for reflection properties of 1500 eV - 2000 eV protons. We determined the angular scattering and the ratio of reflecting protons versus incoming protons. The X-ray optical element was found to be a promising candidate for new instrument designs.

1. Introduction

Time-of-flight plasma analyzers are part of the standard payload for many space missions. Mass, power and size constraints require miniaturization while instrument performance should be kept or improved. For time-of-flight measurements in particle detectors the generation of a start signal is required when a particle passes. A common way for start event generation is to detect secondary electrons generated when the particle penetrates a thin carbon foil. Carbon foils provide an exact position (in flight direction) but require a minimum particle energy to be penetrated (~1 $keV/nucleon$). This often needs substantial pre-acceleration (>10 kV) of heavier particles (e.g. Oxygen, Sulfur) and thus larger mechanical dimensions (arcing) as well as larger power supplies.

Surface interaction provides an alternative to thin carbon foils in time-of-flight plasma analyzers: Instead of an ion to penetrate a foil, the particles impinge at grazing incidence on a surface where in the process a secondary electron is emitted. This process does not have a distinct lower energy limit and pre-acceleration of few 100 V is sufficient to keep efficiencies high. As for carbon foils, particles interacting with a surface, will undergo changes in direction, energy and charge state. In first order, angular scattering is minimized by using an as flat and as smooth as possible surface. Energy loss is reduced by using high-Z materials (e.g. tungsten single crystal).

The geometric shape of such a surface is a challenge: ions need to hit the surface at grazing incidence but the length of the time-of-flight path should be as well defined as possible. A solution is a geometric form consisting of small, repeating, reflective surface elements like a window-blind (Fig. 1).

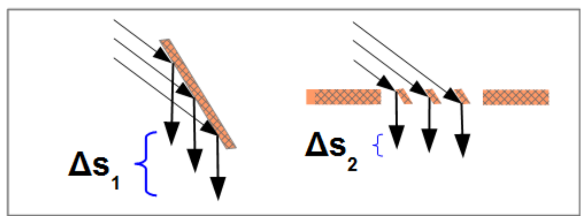

Figure 1: Beam reflection with higher position accuracy for the time-of-flight distance s: $\Delta s_1 > \Delta s_2$

2. Surfaces

We characterized two different candidate surfaces (Fig. 2) for their ion optical properties: a) A laser ablated copper surface and b) micro pore optics (MPO), an element designed to be used in X-Ray optics[3]. Both candidates were compared to a low cost reference surface consisting of diamond like carbon (DLC).

Copper was used as substrate for a) due to good secondary electron yield obtained from an oxide layer on its surface. Sample b) has been developed by Photonis® for certain X-ray imaging applications. The optical elements consists of small quadratic channels with "near perfect flatness and a very low roughness" [3]. The low cost reference surface was obtained from a hard disk drive platter, where diamond-like-carbon coatings are used to increase mechanical durability and corrosion resistance[1].

The surfaces were characterized by impinging ion beams of 1500 eV to 2000 eV at grazing incidence of

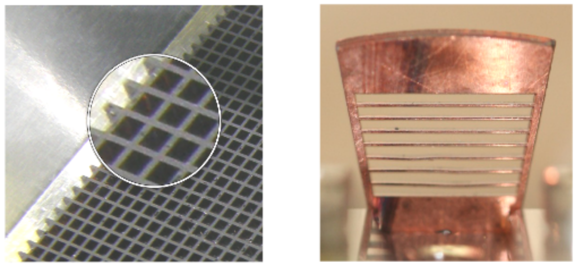

Figure 2: *left:* a) Micro Pore Optics (MPO), *right:* b) laser ablated Copper

15°. The charge states, composition, angular and energy distributions of the reflected particles was measured in two different setups: The ILENA [4] facility at the University of Bern, Switzerland provided charge states and angular scattering data while a setup at the Swedish Institute of Space Physics in Kiruna, Sweden (IRF) provided detailed energy and composition data for the positive charged ion population after interaction with the surface. The measurement in Kiruna utilize the qualification model of the Miniature Precipitation Analyzer (MIPA) [2] instrument for the European Space Agency's BepiColombo mission to Mercury.

3. Results

Main performance parameter for a time-of-flight system is the ratio R between the ions that are scattered within a defined angular cone forward (12.5° half angle around the specular reflection direction) and the ions hitting the reflective surface in first place. R is a product of the reflected portion into the cone and the desired charge state. Neglecting the charge state of the forward scattered particle, the driving factor is surface roughness, surface flatness is easier to achieve and thus given by design. The copper sample manufactured using laser ablation did perform inferior compared to a MPO sample because of the larger surface roughness of the former (Fig. 3). The MPO sample performed approximately equal to the DLC reference surface.
Considering forward scattered ions of positive charge we obtained $R_+ \approx 23 \times 10^{-3}$ compared to R_+ of $\approx 32 \times 10^{-3}$ for the reference DLC surface. The laser ablated Cu sample performed significantly worse with $R_+ \approx 5 \times 10^{-3}$.

4. Summary and Conclusions

Complex shaped surfaces offer new possibilities for surface interaction based time-of-flight mass spectrometers. We have characterized several candidate surfaces made by different manufacturing methods. Surface roughness was identified as the most important parameter. From the samples investigated, the micro pore optics sample performed most promising. MPO is a candidate material for new instrument designs.

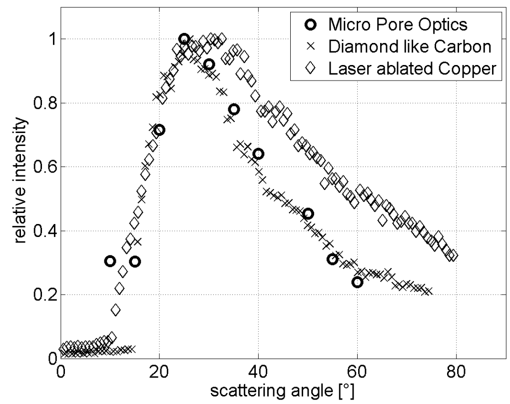

Figure 3: Measured angular scattering for proton beam incident at 15° for all three samples.

Acknowledgments

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