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Realistic ice sputtering experiments for the surfaces of Galilean moons

A. Galli (1), A. Pommerol (1), P. Wurz (1), B. Jost (1), J.A. Scheer (1), A. Vorburger (1,2), M. Tulej (1), N. Thomas (1), M. Wieser (3), and S. Barabash (3)
(1) Physikalisches Institut, University of Bern, Bern, Switzerland (andre.galli@space.unibe.ch), (2) Division of Physical Sciences, American Museum of Natural History, New York, USA, (3) Swedish Institute of Space Physics, Kiruna, Sweden

Abstract

We use an existing laboratory facility for space hardware calibration in vacuum to study the impact of energetic ions on water ice. The experiment is intended to simulate the conditions on the surface of Jupiter's icy moons. The first results of hydrogen, oxygen, and sulphur ions sputtering a sample of porous salty ice confirmed extrapolations from previous sputtering experiments obtained at different impact angles for non-porous water ice [3]. Here, we present additional measurements for a larger range of ion impact angles and different ice samples.

1. Introduction

The vast majority of celestial objects in the outer solar system are bodies with ice-rich surfaces. This includes icy moons like Europa, Ganymede, Callisto, Enceladus, and Triton, but also the Trans-Neptunian Objects and comets. The surface of these objects directly interacts with the space environment, resulting in sputtering, radiolysis, and sublimation. These processes lead to a tenuous, surface-bound atmosphere. Properties of ices at low pressures and temperatures, such as the sputtering efficiency due to ion bombardment, are difficult to predict theoretically and are not better constrained than one order of magnitude from laboratory experiments [5]. This limits the predictive capability of any surface and atmosphere model. The JUICE mission [1], scheduled to visit Europa, Ganymede, and Callisto in the years 2030–2032, will allow to directly sample the particles ejected from the surface and also to observe the atmosphere at infrared, visible, and ultraviolet wavelengths. The instruments' design would greatly benefit from better constrained parameters for surface release processes. For this purpose we use a facility at the University of Bern, Switzerland, to simulate ion sputtering processes on icy surfaces in vacuum.

2. Experiment set-up

In contrast to most previous ice sputtering experiments [2], we shoot ions at a 1 cm thick sample of porous water ice to simulate the regolith on the surface of an icy moon. This approach allows us to produce samples with chemical impurities and to study the impact of porosity on release processes. The experiments are performed in the MEFISTO test facility, which consists of a vacuum chamber and an electron-cyclotron-resonance ion source [4]. The ice samples are prepared with the technique described by [6]: we use an ultrasonic nebulizer to produce micrometer-sized droplets of salty water, which are then frozen to a porous sample of ice grains. The density of the ice sample ranges between 200 and 300 kg m^{-3}, corresponding to an average porosity of 0.75.

During experiments, the ice sample holder is mounted on a steel plate cooled with liquid nitrogen (see Fig. 1). The ice temperature of 90 K and the pressure in the vacuum chamber (10^{-7} mbar) are representative for conditions on the surface of Europa.

3. Results

We measured sputtering yields for singly charged hydrogen, oxygen, and sulphur ions, which are most relevant for the Jupiter system [7]. For sulphur, these are the first experimental data ever obtained. The first series of results were obtained for a very flat ion incidence angle of 15° (see Fig. 1) and at energies between 1 and 30 keV. The results at these settings agree with the predictions by Famá et al. 2008 [2]; the sputtering yield is indiscernible from the one for oxygen ions. Since the sputtering yields are consistent with previous laboratory measurements with compact ice layers on a microbalance, this implies that sputtering from porous water ice is similar to that from a dense sample. The particles ejected from the ice surface are purely molecular water. The relative abundance of ra-

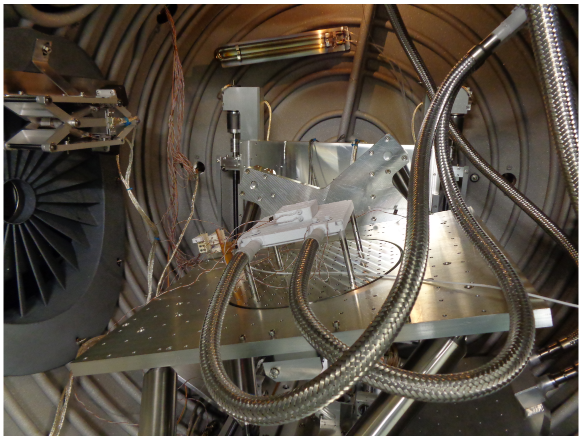

Figure 1: Picture of ice sample in MEFISTO vacuum chamber at the end of a sputtering experiment. The ion beam exiting the fan-shaped structure to the left hits the ice sample at a flat angle (15° by default).

diolysis products, such as molecular hydrogen or oxygen, is smaller than 2 % at our ice temperatures. Currently, surface charging of the ice sample due to the ion beam limits the number of unbiased sputter yield measurements per experiment [8]. An irradiated area of ice takes several hours to completely discharge, which is consistent with the permittivity of dry snow.

4. Conclusions

The MEFISTO facility can be used to study ion sputtering relevant for the icy moons of Jupiter. The first measured sputtering yields at shallow ion incidence angles followed theoretical extrapolations for a smooth surface [3]. We disentangle the potential effects of porosity and surface roughness on the sputtering yield with new experiments by increasing the ion incidence angle and by generating ice samples with much larger grains. The electron-cyclotron-resonance ion source also allows us to generate a beam of multiply charged ions to check if the sputtering yield depends on the charge state. Measures to limit the surface charging of the porous ice during ion sputtering are investigated to increase the number of data points per experiment.

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