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Sputtering investigations of Mercury analogue materials using solar wind ions

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Abstract

Bodies in outer space without a significant atmosphere are largely effected by solar wind ion sputtering. Its contribution to space weathering and exosphere formation is therefore expected to be quite significant. Most models are based on simulations using the SRIM code for determining the ions influence on the surface, while experimental data for relevant materials rarely exist. We aim at closing this gap by investigating sputtering yields of solar wind ions on analogue materials using two types of ion sources and a quartz crystal microbalance technique. Comparison between SRIM results and those of our measurements reveal substantial deviations, showing the need of such laboratory experiments.

1. Introduction

As part of space weathering, sputtering by solar wind ions is expected to contribute significantly to the formation of thin exospheres at airless bodies such as Mercury or the Moon [1]. Especially for refractory elements, this process plays a major role [2]. Modelling the exosphere formation therefore requires knowledge on sputtering yields of relevant materials. For such, experimental data are lacking and models mainly rely on SRIM simulations [3]. In addition to inaccuracies in kinetic sputtering yield results of SRIM, further effects, such as potential and chemical sputtering or diffusion processes are not included in the code.

The method used for our measurements is the so-called quartz crystal microbalance (QCM) technique, where the target material is deposited as thin film, some tens to hundreds of nanometres thick, on an oscillating quartz (for details see [4]). This method allows precise evaluation of sputtering yields by measuring the quartz resonance frequency during irradiation. The irradiations itself were performed using ion sources with mass over charge separation, providing very clean ion beams.

The minerals Wollastonite ($CaSiO_3$) and Augite (Ca,Fe)(Mg,Fe)[Si_2O_6] were used as source material of our thin films. Using Pulsed Laser Deposition (PLD), films with a stoichiometry close to the source material were grown on quartz. This was verified using several techniques such as X-ray Photoelectron Spectroscopy (XPS), Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA). Since surface roughness also has a large impact on sputtering yields, Atomic Force Microscopy (AFM) analyses of the deposited films were performed as well.

2. Argon irradiations as reference

Angular dependent sputtering yield measurements with singly and multiply charged Ar ions with kinetic energies from 1-8 keV were conducted. They allow for good comparison of kinetic sputtering between experiment and simulation for Ar^+, and the investigation of potential sputtering with higher charge states. This effect can be expected to happen for the investigated phases, as they are insulators [5]. These measurements provide a basis for potential sputtering investigations with solar wind ions. A further advantage is, that Ar^+ can be easily used to compare different target materials, such as the ones used for our measurements, whereas only kinetic sputtering occurs. Here, results for both target materials show very similar sputtering yields for the same kinetic energies.

For Ar^+, outcomes from SRIM and SDTrimSP

[6] simulations were compared with the experimental data, showing big deviations at flat incidence for SRIM, but good agreement for SDTrimSP.

3. Solar wind ion sputtering

For irradiations with solar wind ions, kinetic energies of 1 keV/amu were used, which correspond to energies of the slow solar wind at a speed of about 450 km/s [7].

As about 96% of the solar wind consists of H [8], we performed angular dependent sputtering yield measurements using H_2^+ with an energy of 1 keV/H on our $CaSiO_3$ target. Results from this measurements are shown in figure 1. The diagram shows that both SRIM and SDTrimSP overestimate the angular dependence of the sputtering yield measured. Best agreement between simulation and experiment can be found, when including implantation of H into the SDTrimSP simulation, which is discussed in more detail by Szabo et al. in [9].

The next important projectile is ^4He, with an abundance of about 4% in the solar wind [8]. A relevant contribution to the total solar wind yield is not only expected due to its higher mass and kinetic energy, but also due to the fact, that the dominant charge state is $^4He^{2+}$. Here, the potential energy is 77 eV and therefore is expected to cause additional potential sputtering, as seen before for multiply charged Ar. ^4He is the helium isotope prominent in solar wind, but its doubly charged ion cannot be separated from H_2^+ in an ion beam, which makes precise quantitative statements impossible in our setup. Therefore $^3He^{2+}$ has to be used, which allows producing a very clean ion beam. Having measured kinetic sputtering for both isotopes, it is found that the kinetic yield differences are small and $^3He^{2+}$ can therefore be used for the investigation of He potential sputtering.

4. Summary

We performed angular dependent measurements of sputtering yields for Mercury analogue materials using multiply charged Ar and solar wind ions. We irradiate thin films of material deposited onto quartz crystal microbalances, investigating mass changes in-situ during our irradiations. Results from kinetic sputtering experiments are compared to simulation outcomes, showing deviations and therefore the need for such laboratory work. Additionally the effect of potential sputtering of the insulating materials was investigated, as this effect is not covered in these simulation codes.

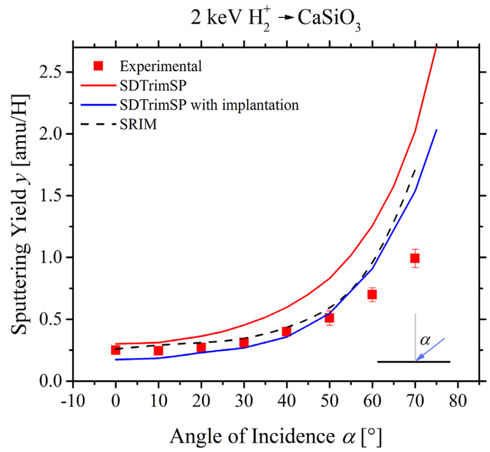

Figure 1: Measured sputtering yield for H_2 with kinetic energy of 1 keV/H on $CaSiO_3$, together with SRIM and SDTrimSP simulation results. Figure taken from [9]

References

[1] Hapke B.: Space weathering from Mercury to the asteroid belt, J. Geophys. Res. Planet., 106, 10039, 2001.

[2] Wurz P., et al.: Self-consistent modelling of Mercury's exosphere by sputtering, micro-meteorite impact and photon-stimulated desorption, Planet. Space Sci., 58, 1599, 2010.

[3] Ziegler J., et al.: SRIM – The stopping and range of ions in matter, Nucl. Instrum. Methods Phys. Res. B, 268, 1818, 2010.

[4] Hayderer G., et al.: A highly sensitive quartz-crystal microbalance for sputtering investigations in slow ion–surface collisions, Rev. Sci. Instrum., 70, 3696, 1999.

[5] Aumayr F., Winter H.: Potential sputtering, Philos. Trans. Royal Soc. A, 362, 77, 2004.

[6] Mutzke A., et al.: SDTrimSP Version 6.00, IPP report, 2019.

[7] Feldman U., et al.: On the sources of fast and slow solar wind, J. Geophys. Res. Space , 110, 2005.

[8] Bame S.J., et al.: Solar wind heavy ion abundances, Sol. Phys., 43, 463, 1975.

[9] Szabo P.S., et al.: Solar wind sputtering of wollastonite as a lunar analogue material – Comparisons between experiments and simulations, Icarus, 314, 98, 2018.