EPSC Abstracts
Vol. 13, EPSC-DPS2019-449-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Sputtering of Mercury and Moon analogue materials – producing chemically and petrologically realistic samples

Noah Jäggi (1), Paul Stefan Szabo (2), Herbert Biber (2), Helmut Lammer (2), Klaus Mezger (3), Friedrich Aumayr (2), Peter Wurz (1), and André Galli (1)

(1) Physics Institute, University of Bern, Switzerland (noah.jaeggi@space.unibe.ch) (2) Institute of Applied Physics, TU Wien, Austria (3) Institute of Geological Sciences, University of Bern, Switzerland

Abstract

We examine mineral pellets as chemical and mineralogical analogues for the surfaces of Moon and Mercury in sputter experiments. This is a complementary approach to the commonly used preparation of thin films of analogue material on substrates by pulsed laser deposition. Mineral pellets have the correct chemical composition and crystallinity to mimic the surface of Moon and Mercury. They allow the inclusion of volatile elements, whereas pulsed laser deposition of silicates results in glassy films that are not chemically conservative. However, mineral pellets are more easily contaminated during preparation compared to the pulsed laser deposition technique, and their preparation is technically more demanding. We conclude that for a comprehensive understanding of sputtering, the use of both techniques is necessary.

1. Introduction

The exosphere of Mercury is a collision-free, highly dynamic system shaped by the interaction of the solar wind and solar illumination with the magnetosphere and surface of Mercury. This interaction creates singly and multiply charged ions, chemical compounds, and neutral species surrounding Mercury. The most prominent exospheric sources are micrometeorite impacts, photoionization, and sputtering [e.g. 1].

The interaction of the space environment with Mercury's surface can be modeled and compared to observations of exospheric densities [2] and spectroscopic features of the surface. Such models require an accurate knowledge of the sputtering process for a plethora of ion-surface interactions, as one has to consider various sputtering particles at different incidence angles, a range of energies hitting various mineralogic targets at a wide range of temperatures, and the microscopic structure of the surface. This knowledge must be gained from theoretical simulations [SDTrimSP-2D, 3] and from laboratory experiments. In this work, we focus on the latter.

2. Material

The recent consensus for Mercury's surface composition is a regolith dominated by pyroxene and plagioclase (~$Mg_{1.8}Fe_{0.2}Si_2O_6$ and ~$Na_{0.5}Ca_{0.5}Al_{1.5}Si_{2.5}O_8$) with locations of elevated olivine occurrence (~$Mg_{0.92}Fe_{0.08}Si_2O_4$). This is inferred from attributing common minerals that form in primitive melts to surface element ratios determined by the X-Ray Spectrometer (XRS), and Gamma-Ray and Neutron Spectrometer (GRNS) onboard MESSENGER [e.g., 6 and references therein].

Initially, we used wollastonite ($CaSiO_3$) as a chemical analogue for Moon and Mercury. In our future work, plagioclase and pyroxene are used with the benefit of being petrological analogues. For the Moon, Na-poor plagioclase and Ca-rich pyroxene is used according to its bulk composition [e.g., 6].

3. Sputter target fabrication

Glassy thin-films created by PLD, and pressed mineral dust pellets are used for sputtering experiments. The targets are complementary for investigating possible differences in sputtering behavior between a synthetically grown surface, and a natural, crystalline, pressed pellet.

3.1 Pulsed Laser Deposition thin films

Recent laboratory experiments studying potential sputtering by [4, 5] used wollastonite and anorthite-like glassy thin films as chemical surface analogues. In theory, PLD evaporates the crystal and deposits a crystalline mineral layer on a target holder. In reality, (a) unlike alkali-halides, silicates have characteristically high melting temperatures. The limited heating tolerance of the target quartz carriers, results in quenching of the mineral vapor into glass; (b) films are not stoichiometrically identical to their parent mineral [e.g. 5]. The high volatility of elements like Na and K found in more albite rich anorthite is expected to result in even stronger deviations from the target element ratios; (c) usage of minerals that can dissociate easily leads to problems during PLD. In the case of wollastonite, SiO_2 and CaO separated at pressures below 1.5 kbar (see Fig. 1). Such disintegration into micrometer-sized droplets is only observed on the surface. Avoiding volatile rich target minerals, and sputter-cleaning of the film leads to clean, glassy thin-films with chemical compositions almost ideal to the starting material.

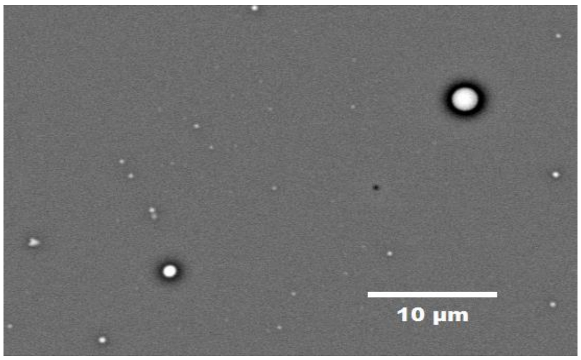

Figure 1: SEM image of a glassy wollastonite film produced by PLD, with bright, Ca-rich glass droplets.

3.2 Pressed powder pellets

For Mineral pellet creation, minerals are ground to a µm-sized powder and pressed in a pellet die. The process brings complications however, including: (a) anisotropic cleavage of a mineral such as wollastonite leads to needle formation and thus a preferred orientation of the needles during pellet pressing; (b) irregularities in the piston surfaces used for pressing cause a rough material surface, which affects sputtering yield [7]; and (c) contamination.

Minimizing roughness and removing surface contamination by sputter cleaning allows for pellets that are chemically and crystallographically identical to their parent material. This is most valuable when experimenting with material that contains volatile elements and compounds, and for observing effects of the crystalline structure on kinetic and potential sputtering yields.

4. Summary and conclusions

Even if it is not possible to deposit a stoichiometrically identical crystalline film of a silicate mineral using PLD, clean, glassy sputter targets can be reliably produced. Mineral pellets are chemically identical to their parent but prone to contamination. However, pellets are very useful for investigating the impact of crystallinity on sputtering yields, and for preparing samples from thermodynamically labile or volatile-rich minerals. For a comprehensive understanding of sputtering, the usage of complementary sample preparation is necessary.

Acknowledgements

I would like to thank Beda Hoffman, Urs Eggenberger, Christine Lemp, Andreas Riedo, and Diana Gamborino for their support with the project.

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