A Closer Look at Solar Wind Sputtering of Lunar Surface Materials

Poster No. P31B-1402

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CONTEXT: Solar-wind induced potential sputtering of the lunar surface may be a more efficient erosive mechanism than the "standard" kinetic (or physical) sputtering. This is partly based on new but limited laboratory measurements which show marked enhancements in the sputter yields of slow-moving, highly-charged ions impacting oxides.

Lunar surface sputtering yields are important as they affect, estimates of the compositional changes in the lunar surface, its erosion rate, as well as its contribution to the exosphere.

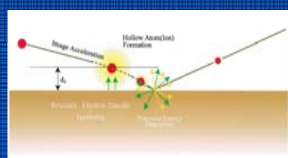
GOALS: The enhancements seen in the laboratory can be orders of magnitude for some surfaces and highly charged incident ions, but seem to depend very sensitively on the properties of the impacted surface in addition to the fluence, energy and charge of the impacting ion. For oxides, potential sputtering yields are markedly enhanced and sputtered species, especially hydrogen and light ions, show marked dependence on both charge and dose.

Potential puttering data for lunar regolith analogs are nonexistent. Limited data and the rudimentary nature of our understanding of the underlying processes, however, keep the question of the relative importance of potential sputtering an open one.

APPROACH: To help answer this question, we plan to (1) measure some relevant sputter yields at Oak Ridge National Laboratory's Multicharged Ion Research Facility (MIRF) using lunar simulant materials, (2) develop a kinetic model to quantify the degree and temporal behavior of the contribution of potential sputtering to solar-wind sputtering of lunar surface materials.

Interactions of the solar-wind ions with lunar regolith

- Protons and multiply charged ions striking amorphous surfaces at 1 keV/amu
- Surface atoms (in addition to ions, electrons, and photons) are ejected as the solar-wind ions gets neutralized in the surface
- The penetration depth of these ions is ~ 10s nm, i.e., comparable to the thickness of the rim found on regolith soil grains



A schematic of an interaction between a slow, highly charged ion and a surface. [From Yamazaki and Kuroki (2002).]

- 80% of ejected (or sputtered) species are neutral atoms with rather wide energy and angular distributions

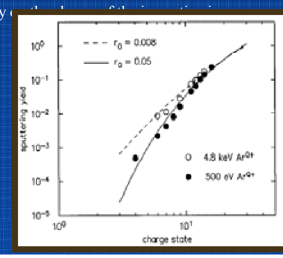
Kinetic vs. potential sputtering

- Kinetic sputtering is an inelastic microscopic process with kinetic energy transfer to a small number of surface atoms via binary collisions
- It is the dominant sputtering mechanism for metals and semiconductors, where any induced electronic excitation can be rapidly accommodated
- Insulator surfaces have reduced electron mobility, hence fast electron removal from the target leads to structural modifications (defects) that cannot be restored
- This is enhanced for highly charged ions since they 'carry' a large amount of 'potential energy' (given by the sum of the ionization potentials of the ion). This energy is dissipated rapidly through electron transfer and Auger de-excitation processes
- For many surfaces potential sputtering is significantly more effective in removing target material than kinetic sputtering

For insulators, potential sputtering is the dominant mechanism by which surface atoms are lost in impacts of slow ions!

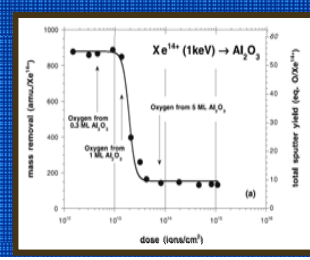
Some observed characteristics of potential sputtering

- Proton yield from potential sputtering have been shown to depend very sensitively on the charge of the ion:



Dependence of the proton sputter yield from a hydrocarbon surface on the charge state of the impacting ion. [From Burgdorfer and Yamazaki (1996).]

- Potential-sputtering yield from some surfaces has also been shown to depend on dose:

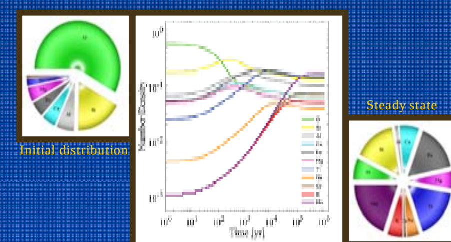


Dependence of the total sputter yield on dose for 1 keV Xe^{14+} ions striking an Al_2O_3 surface. [From Hayderer et al. (2001).]

Potential sputtering, in addition to significantly enhanced sputter yield, has some exceptional sensitivities!

Demonstrated effects on lunar regolith

- Changes in the elemental abundances of a KREEP soil exposed to solar wind ions (p-Fe) as a function of time assuming kinetic sputtering only:



Advantages of this Formulation:

- Response function of the system
- Sensitivity to structure variables
- Optimized (+controlled) measures

Can objective adherence to ALARA be quantified?