SOLAR WIND SPUTTERING OF LUNAR SOIL ANALOGS: THE EFFECT OF IONIC CHARGE AND MASS

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**Motivation and Goal**
Solar wind sputtering of lunar regolith induces compositional changes in the lunar surface and contributes to its erosion rate, and affects the composition of lunar exosphere. Solar wind-lunar surface interactions may further play a role in the accumulation of hydrogen and water on the moon’s surface. Our goal in the present work is to assess the sputtering contribution of the highly charged, heavy minority solar wind constituents in anorthite, a lunar highlands soil analog.

**Approach**
Total absolute sputtering yields are determined using a sensitive quartz microbalance by measuring the thickness change of a thin anorthite film deposited on a gold coated quartz microbalance.

**Anorthite thin film production**
XPS anorthite (CaAl2Si2O8) film stoichiometry analysis

**Quartz crystal microbalance (QCM) measurements**
Total absolute sputtering yields for gold thin film at 500 eV/amu

<table>
<thead>
<tr>
<th>Ion</th>
<th>Neutralization energy (eV)</th>
<th>Yield (ng/cm² s)</th>
<th>Total Sputtering yield enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>H+</td>
<td>0.0038</td>
<td>0.0042</td>
<td>1</td>
</tr>
<tr>
<td>Ar+</td>
<td>0.33 ± 0.07</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Ar2+</td>
<td>0.35 ± 0.06</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Ar3+</td>
<td>0.38 ± 0.07</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Ar4+</td>
<td>0.42 ± 0.06</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Ar5+</td>
<td>0.44 ± 0.06</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Ar6+</td>
<td>0.46 ± 0.06</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Ar7+</td>
<td>0.50 ± 0.08</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Ar8+</td>
<td>0.52 ± 0.12</td>
<td>3.7</td>
<td></td>
</tr>
</tbody>
</table>

**Ar9+ on Au**

**Ar9+ on anorthite**

**Check of independently absolute calibration**

**Quadrupole mass spectrometry (QMS) measurements**
Background subtracted mass spectra for Ar9+ and Ar2+ ions incident on Ta and anorthite

**Isolation and parameterization of potential sputtering**

With above power law fit of Ar9+ potential sputtering, TRIM and QMS result, can estimate sputtering yields for all charge states of all solar wind ions

**Summary**
Using a sensitive quartz microbalance, independently absolute sputtering yields have been measured for 500 eV/amu H+, and Ar+ (q=1-9) ions incident on Au and anorthite

As a result of the combined effects of higher physical sputtering yields due to their greater mass and the presence of potential sputtering enhancement due to their high charge states, total yields of the minority solar wind constituent ions can exceed those for same velocity protons by factors much greater than 100

**Metal oxides can have different types of potential sputtering, each having unique kinetic energy, charge state, and saturation dependence**
- defect mediated desorption
- kinetically assisted potential sputtering

**Difficult to predict which dominates for those oxides not yet studied; no previous measurements at solar wind relevant velocities**
- need to use suitable analog material or actual lunar regolith sample

**Acknowledgements**
Research sponsored by NASA grant 10-LASER10-0053, by the LDRD program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy, and performed in part via the ORNL SHaRE User program and at the Center for Nanophase Materials Sciences user facility, which is sponsored at Oak Ridge National Laboratory by the Scientific User Facilities (SUF) Division, U.S. Department of Energy.

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**Table of abundances**

- **Si/Ca**
  - Ta flag: 0.3307 ± 0.0008
  - Anorthite: 0.3858 ± 0.0013

- **O/Si**
  - Ta flag: 0.3539 ± 0.0035
  - Anorthite: 0.3539 ± 0.0045

- **O/O**
  - Ta flag: 6.72 ± 0.20
  - Anorthite: 4.76 ± 0.14

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**Figures**

- **Quartz Microbalance Method**
- **Quadrupole mass spectrometry (QMS) measurements**
- **Isolation and parameterization of potential sputtering**
- **Metal oxides can have different types of potential sputtering, each having unique kinetic energy, charge state, and saturation dependence**
- **Total sputtering yields for anorthite thin film at 500 eV/amu**

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**References**


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**ORNL SHaRE User Program**
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**Facility (MRF)**

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**Abstract**

Sputtering of lunar surface due to solar wind is an important process that alters the composition of the lunar surface and contributes to the lunar exosphere. The present work is to assess the sputtering contribution of the highly charged, heavy minority solar wind constituents in anorthite, a lunar highlands soil analog. Total absolute sputtering yields are determined using a sensitive quartz microbalance by measuring the thickness change of a thin anorthite film deposited on a gold coated quartz microbalance. Background subtracted mass spectra for Ar9+ and Ar2+ ions incident on Ta and anorthite are used to calculate the sputtering yields. The results show that sputtering yields due to Ar9+ are up to 3 times greater than those for Ar+ and Ar2+. The enhanced sputtering is consistent with a potential sputtering mechanism, where the high charge states of the minority solar wind constituents can exceed those for same velocity protons by factors much greater than 100.