INDICATION OF MINERAL WORK FUNCTION IN LUNAR DUST ELECTROSTATIC MIGRATION.
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Introduction: Although electrostatic transport of lunar fine charged dust had not been detected in LADEE mission [1], fine dust grains charged by photoelectric emission (PEE) and secondary electron emission (SEE) are actually present on the lunar surface and have been verified by lunar surface exploration missions, such as Apollo missions with Dust Detector Experiments (DDEs) and Lunar Ejecta and Meteorite (LEAM) experiment [2-3]. With solar ultraviolet (UV) and X-ray irradiation, dust grains can be charged positively by photoelectric emission (PEE) and secondary electron emission (SEE). Accumulation of such charged dust particles would change surface potential of the Moon. Lunar Prospector mission detected the surface potential of the luneusunlit side risen from several voltages to tens voltages [4-5]. Varieties of local surface potentials might form an electrical field and drive the charged dust grains migrating at the lunar surface. Such movement of charged dust might increase the risk of manned or unmanned lunar surface exploration, and it might also be the main cause of lunar horizon glow formation [6]. On the sunlit side, the dominant process charging the lunar dust grains has been identified as photoelectric emission induced by solar UV radiation [7-8]. Photoelectric emission is dependent on the UV photon energy and the work function (WF) of the dust grain. The WF is a character of physical properties of one mineral. Therefore, the WF of dust grains composed of different mineral may vary and play a key role controlling energy of the produced photoelectrons and consequently the grain dynamics.

In this study, we experimentally measured work function of several common minerals composed of the lunar dust and discussed their charging characteristics at the lunar sunlit surface.

Methods: Work function represents the electron binding strength of a solid surface and is usually used equivalent to the difference between Fermi energy and Vacuum energy. When two different type of solid surface contact with each other, there is a contact potential difference (CPD) which could be measured by Scanning Probe Microscopy (SPM). In order to diminish the effect of surface adsorption during our CPD measurement, we used the Curlew SPM integrated with ultrahigh vacuum (UHV) surface analysis system produced by SPECS Surface Nano Analysis GmbH (Fig.1) to measure the CPD between the SPM tip and the sample.

![Fig. 1. Ultrahigh vacuum (UHV) surface analysis system (above) and Curlew SPM integrated in the UHV system (down)](image)

Calibration of WF of the SPM tip by measuring HOPG and Ag standard s. In Curlew SPM, the tip is made of n-type quartz, of which suggested WF is about 4.43eV. To calibrate the actual value of the tip before measuring samples, HOPG and Ag standards are used. The measured WFs of HOPG and Ag standards are marked at 5.0eV and 4.26eV, respectively. The CPDs between standards and tip were also measured. At last, use Eq(1) with measured values of the two standards, the reference WF value of the n-type quartz tip is calculated as 4.43 eV.

$$\Phi_{\text{std}} = \Phi_{\text{tip}} + e \cdot V_{\text{CPD}}$$ (1)

Where, $V_{\text{CPD}}$ is the CPD between standard and tip, which can be obtained by experiment. $\Phi_{\text{tip}}$ and $\Phi_{\text{std}}$ are WFs of the tip and the standard, respectively.

Fitting reference values and measured values of standards and n-type quartz (Fig. 2) The fitting function is written as follow,

$$y = x - 0.075$$ (2)
Based on the fitting function, we calibrated the WF of n-type quartz tip to be 4.36 eV.

Scanning the smooth surface of minerals can get CPDs between individual mineral and tip. The WF of each mineral ($\Phi_i$) can be calculated by Eq (3) as follows,

$$\Phi_i = 4.36 + e \cdot V_{CPD}$$

Fig.2. Calibrating the WF value of the n-type quartz tip. Dashed line and solid line are fitting lines of reference values and measurement values, respectively. After calibrating by fitting function, the WF value of n-type quartz tip is 4.36 eV.

Results and Discussion: We measured the WFs of olivine, plagioclase, pyroxene, ilmenite with the SPM (table 1). As shown in Fig. 3, the WF of olivine is the highest and of ilmenite is the lowest in the four minerals. This might indicate that the ilmenite grains in lunar dust are relatively easier to be charged with solar UV radiation.

Table 1. WFs and Q of several minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>WF (eV)</th>
<th>Charge (Q)</th>
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<tbody>
<tr>
<td>olivine</td>
<td>7.90 ± 0.35</td>
<td>1696 ± 243</td>
</tr>
<tr>
<td>plagioclase</td>
<td>5.58 ± 0.38</td>
<td>3309 ± 264</td>
</tr>
<tr>
<td>pyroxene</td>
<td>5.14 ± 0.36</td>
<td>3615 ± 250</td>
</tr>
<tr>
<td>ilmenite</td>
<td>4.29 ± 0.11</td>
<td>4207 ± 76</td>
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According to the study of Sickafoose [9], the maximum charge of an isolated grain (Q) can be calculated as follows,

$$Q = 4\pi \varepsilon_0 \varepsilon r \left(\frac{h}{\lambda} - W\right)/e$$

Where, $\varepsilon_0$ is permittivity of vacuum, $r$ is radius of grain, $h$ is Planck’s constant, $c$ is the speed of light, $\lambda$ is wavelength of incidence UV, $W$ is WF of grain surface, $e$ is elementary charge.

Irradiated by UV wavelength 120 nm, the maximum charge of each mineral type with 1 $\mu$m radius grain size are calculated using Eq (4) and the results are listed in Table 1. Ilmenite grains are charged much more comparing to olivine, plagioclase, and pyroxene, and thus suggests that ilmenite grains may lift and migrate more easily on the lunar surface than the other three.

Conclusions: Different minerals have different WF values, which has been suggested to dominantly control the charging characters of one grain under solar UV radiation. Our preliminary experiments measured WFs of olivine, plagioclase, pyroxene, ilmenite using the SPM. The WF values are 7.90 ± 0.35 eV, 5.58 ± 0.38 eV, 5.14 ± 0.36 eV and 4.29 ± 0.11 eV, respectively. These mineral grains can be charged to several thousand positive electrons under solar UV irradiations. Also, under the same irradiation condition, different minerals might show different charging characters and consequently, a different electrostatic migration process at the lunar surface.


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