Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 56 (2015) 2432–2438

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Work function measurements of olivine: Implication to photoemission charging properties in planetary environments

Hong Gan [a,b], Xiongyao Li [a,*], Guangfei Wei [a], Shijie Wang [c]

[a] Lunar and Planetary Science Research Center, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550081, China

Received 8 May 2015; received in revised form 2 September 2015; accepted 5 October 2015
Available online 13 October 2015

Abstract

For understanding the ubiquitous photoemission charging of solid surface in planetary environments, it is important to characterize the photoemission charging properties of silicate minerals such as the work function. In this study, we measured the work function of olivine mineral based on the measurements of contact potential difference by using an ultrahigh vacuum Kelvin probe force microscopy. Our results showed that work function on olivine mineral surface is mainly affected by surface morphology and crystal orientation and that the variation range of work function is 7.3–8.5 eV. It implicates that photoemission of the olivine mineral occurs under the X-ray and solar ultraviolet irradiation with wavelength of <171 nm. Consequently, it is possible to form electrostatic field of +(5–10) V on the sunlit planet, moon or asteroid surfaces due to dust photoemission charging, which even induces the migration of dust grains and the formation of dust-plasma atmosphere. Those are important problems worried to be solved for future lunar missions. Additionally, our work can help to instruct the dust mitigation technology and the electrostatic beneficiation in future space missions.

Keywords: Planet; Moon; Photoemission; Olivine; Work function

1. Introduction

The photoemission of lunar regolith induced by solar ultraviolet and X-ray radiation is one of the main reasons for creating the electrostatic field in the near-surface of the Moon. On the dayside of the Moon, the surface typically charges positive (~+10 V) because the current generated by the photoemission dominates (Manka, 1973; Freeman and Ibrahim, 1975; Colwell et al., 2007). This charging phenomenon also occurs on the surface of atmosphereless planets (e.g. Mercury) and asteroids, and is responsible for the charging of interplanetary dust grains. In fact, the solid surface exposed directly to the solar radiation acquires a potential of +(5–10) V in space and even a global photoelectron sheath above the sunlit surface (Delory, 2010).

For understanding the photoemission mechanism on the solid surface, work function of materials surface is a key parameter. Up to now, work function has been extensively measured or calculated on metal (Lang and Kohn, 1971; Ekardt, 1984; Fujii et al., 2006), semiconductor (Sadewasser et al., 2002) and even organic materials/devices (Kotani and Akamatu, 1971; Hoppe et al., 2005). However, the work function measurements of insulating materials are rarely reported. Interplanetary dust grains and solid planet surface mostly consist of silicate debris and glasses which are formed by the interaction between these materials and its space environment. These silicate

* Corresponding author. Tel.: +86 189 850 29760.
E-mail addresses: ganhong06@gmail.com (H. Gan), lixiongyao@vip.skleg.cn (X. Li).

http://dx.doi.org/10.1016/j.asr.2015.10.005
0273-1177/

materials mostly belong to insulator. The work function of the solid insulator is defined as the minimum energy required to extract the weakest bound electron from its maximum nature surface excursion distance to infinity (Gallo and Lama, 1976). In 1972, the photoelectric characteristics of lunar surface fines (No. 14259,116) were presented and the sample work function is measured to be about 5 eV (Feuerbacher et al., 1972). Based on the data of the charged particle lunar environment experiment (CPLEE), the work function of lunar surface materials was estimated to 6 eV (Reasoner and Burke, 1972). Additionally, other previous theoretical and experimental results also showed that the work function of lunar surface material exposed to the solar wind is mainly in the range of 5–6 eV (Freeman and Ibrahim, 1975).

However, for the long term of micro-meteorite bombardment and space weathering on the surface of atmosphereless bodies, the regolith becomes mature and contains abundant of agglutinate glasses with the excess nano-phase iron (np-Fe^0), which brings some difficulty for investigating photoemission charging properties of lunar regolith. In addition, the derived work function of lunar regolith (a mixture of minerals and glasses) can not characterize appropriately the crystalline components such as pyroxene, plagioclase and olivine. Therefore, it is necessary to measure the work function of different insulating minerals and glasses for further understanding the photoemission mechanism of typical minerals in the fields of material science and planetary science. In this study, we have measured the work function of olivine, which is a magnesium iron silicate with the formula $(Mg^{+2}, Fe^{+2})_2SiO_4$. Note that olivine is a common mineral within ultramafic rocks and distributed widely in solid planets, moons, meteorites and even planetary rings, comet tails, interplanetary dust particles.

Work function is not a intrinsic characteristic of bulk materials, but a physical property of the materials surface. Many techniques have been developed to measure the work function, such as Ultraviolet photoemission spectroscopy (UPS) (Kötz et al., 1986; Park et al., 1996; Kim et al., 2000), X-ray photoemission spectroscopy (XPS) (Kötz et al., 1986; Park et al., 1996) and Kelvin probe force microscopy (KPFM) (Nonnenmacher et al., 1991; Sommerhalter et al., 1999; Melitz et al., 2011). KPFM is based on contact potential difference method to determine work function of an unknown surface. KPFM has a high spatial resolution and allows the simultaneous imaging of morphology and contact potential difference (CPD) (Melitz et al., 2011). Recently, KPFM is widely applied to measure the work function of various semiconductor and organic materials (Hoppe et al., 2005; Kim et al., 2007; Sadewasser et al., 2009). Here, we employed Kelvin probe force microscopy to measure the work function of the insulator mineral, olivine. Then, we analyzed the effect of surface morphology and crystal orientation on the work function. Furthermore, we calculated the threshold wavelength of the incident photon for the photoelectric effect on olivine surface based on the measurements. This result is conducive to better understand the photoelectric properties of olivine mineral, and it also provides certain constraints for the photoelectric charging and triboelectric charging mechanism of dust grains (Gallo and Lama, 1976; Sickafoose et al., 2000; Sickafoose et al., 2001). It also implicates the formation of surface photoelectron sheath and the law of dust transport in the sheath (Grobman and Blank, 1969; Sternovsky et al., 2008). In addition, it also provides some instructions of the advanced dust mitigation technology and the electrostatic beneficiation in future lunar and Martian exploration (Gupta et al., 1993; Li et al., 1999).

2. Experiment

For characterizing the surface structure and composition of lunar samples and meteorites, we have developed an ultrahigh vacuum (UHV) surface analysis system, which integrates the SPECS Curlew (Berlin, Germany) scanning probe microscope (SPM) with X-ray photoelectron spectroscopy (XPS), auger electron spectroscopy (AES), etc. The major specifications of the SPECS Curlew SPM include that XY scan range of sample is $10 \times 10\ \mu m^2$ and Z scan range of tip is 2 μm. The SPM tip is a quartz tuning fork based the silicon cantilever of atomic force microscope (AFM) sensor (Akiyama probe). Kelvin Controller Module in the Nanonis SPM control system software is used to control Kelvin Probe Imaging. KPFM obtains work function of material surface based on the measurements of the contact potential difference between the sample surface and the AFM probe, which originates from work function difference between two materials. When the two materials remain unconnected, their local vacuum levels are aligned but with different Fermi levels. Once the two materials connect, their Fermi levels will align by electron transfer but there is difference between their local vacuum levels. Their local vacuum levels will be aligned again by compensating an external bias which equals to the CPD in theory. Hence, KPFM measures CPD between the tip and the sample surface, which is determined by

$$V_{\mathrm{CPD}} = \frac{\Phi_{\mathrm{tip}} - \Phi_{\mathrm{sample}}}{-\mathrm{Q}} \tag{1}$$

where Φ_{tip} and Φ_{sample} are the work functions of the tip and the sample surface respectively, and Q is the elementary charge. Under a potential difference between the AFM tip and the sample, the electrostatic force is given by

$$F = -\frac{1}{2}\Delta V^2 \frac{\partial C}{\partial z} \tag{2}$$

where C is the capacitance between the tip and the sample and z is the distance between them. ΔV is the potential difference between V_{CPD} and the voltage applied to the AFM tip, which is $\Delta V = V_{\mathrm{tip}} \pm V_{\mathrm{CPD}}$. Note that the $\pm$ sign depends on the bias applied to the sample (+) or the tip (−). In order to measure V_{CPD}, an AC voltage (V_{AC}) and