



Mitigation of lunar dust on solar panels and optical elements utilizing electrostatic traveling-wave

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ABSTRACT

A system for removing lunar dust from the surface of solar panels and optical elements is of great importance for lunar exploration. We have developed a method of removing lunar dust using electrostatic traveling-waves generated by four-phase rectangular voltage applied to a transparent conveyer consisting of parallel ITO (indium tin oxide) electrodes printed on a glass substrate. On the basis of basic investigations, we have demonstrated the removal of actual lunar dust. A numerical investigation predicts that the performance will improve in the low-gravity environment on the Moon.

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1. Introduction

The lunar surface is covered by a regolith (soil) layer that is typically several meters deep, and approximately 20% of the volume of this material consists of particles that are less than 20 μm in diameter [1]. Because of its small size and the low gravity, lunar dust is easily lofted when any disturbance occurs. The dust then covers solar panels and optical elements, such as lenses and mirrors, causing the degradation of their optical performance. In order to overcome this problem, we have developed a cleaning system that employs electrostatic traveling-waves for removing lunar dust. This system has no mechanical moving parts and is therefore highly reliable.

The idea of transporting particles using electrostatic traveling-waves was first proposed by Masuda [2] and many investigations have since been conducted on this technology [3–20], mainly as a toner supplier of electrophotography. Further investigation is needed to apply this technology to removing lunar dust from solar panels and optical elements in the lunar environment. Requirements for a lunar system include; (1) the system must be compact and lightweight, (2) it must work in vacuum and in 1/6 gravity, (3) must be highly transparent, with limited decrease in the transmission rate of light after repeated operations, (4) must be effective

even for charged dust particles, and (5) should consume less power than alternative methods. In this study, we have developed a practical system that meets these requirements, clarified the fundamental characteristics of the electrostatic particle transport, and demonstrated the efficient removal of lunar soil simulants. Further, we have successfully demonstrated the electrostatic removal of actual lunar dust returned by the Apollo 11 lunar surface mission. A three-dimensional hard-sphere model of the Distinct Element Method has been developed to simulate the dynamics of particles in an electrostatic traveling field and to estimate the performance of the system in the lunar environment [17].

2. Experimental

The cleaning system shown in Fig. 1 consists of a power supply used to generate four-phase high voltage and a particle conveyer with parallel electrodes printed on a substrate. Due to the Coulomb force and dielectrophoresis force acting on the particles on the conveyer, the particles are transported along with the electrostatic traveling-waves generated on the conveyer [15–18].

2.1. Electrostatic conveyer

We have developed two types of conveyers: a square vortical conveyer (Fig. 2 (a)) and a circular vortical conveyer (Fig. 2 (b)). The former is intended to be used for square panels or mirrors and the latter is intended to be used for optical lenses. In both types,

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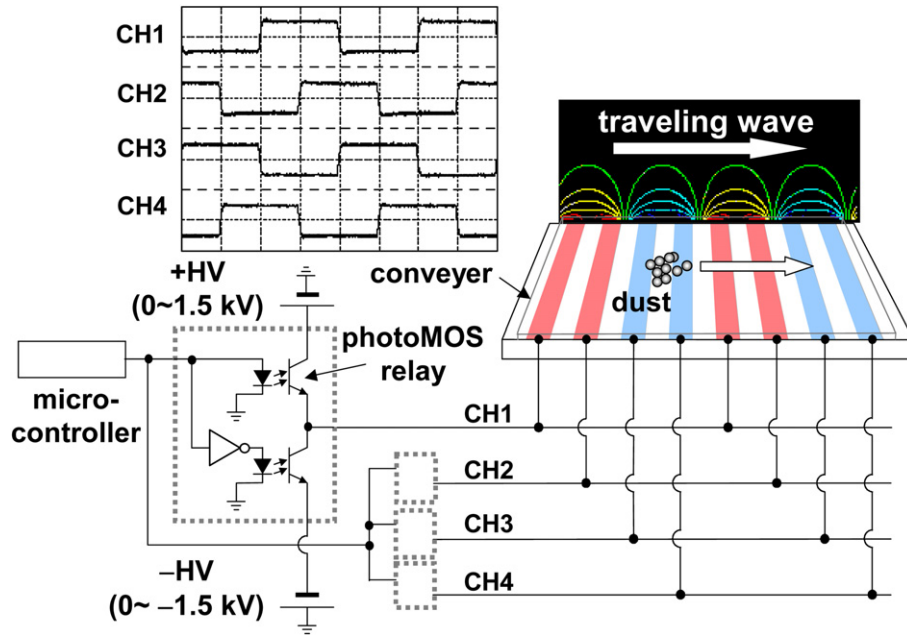


Fig. 1. Electrostatic cleaning system for removing lunar dust.

transparent ITO (indium tin oxide) electrodes are printed on borosilicate glass substrates (100×100 mm). The appropriate width w and pitch p of the electrodes depend on the size of particles to be transported. If the particle diameter is larger than 3.5 times the distance between the electrodes, the Coulomb force between the particles and the four electrodes is canceled, and the particles are not transported [16]. On the basis of previous investigations [15], we have selected the width and pitch of the electrodes to be 0.3 and 0.6 mm, respectively, because we intend to use this system for small particles with diameters less than $300 \mu\text{m}$. Very large particles may not be lofted easily. Dust on the conveyers is removed along with traveling-waves, along the arrows of Fig. 2. By adopting the vortical pattern, the end terminals for supplying four-phase voltage can be arranged in a two-dimensional configuration [19,20]. (If the electrodes are printed with a simple parallel pattern, the ends of the electrodes must be three-dimensional to prevent the intersection of phases.) The surfaces of the conveyers are coated with insulating epoxy resin to

prevent electrical breakdown between the electrodes, then they are covered with thin films, 0.1-mm thickness, made of borosilicate glass to reduce the mechanical adhesion of particles. If the surface of the conveyor is rough, particles are more likely to be trapped on the surface.

2.2. Power supply

Traveling-wave propagation was achieved utilizing a set of positive and negative amplifiers (HPM-1.5PD, ND, ± 1.5 kV, 3.3 mA max, Matsusada Precision) switched by a semiconductor relays (PhotoMOS relay AQV258, Panasonic) that were controlled by a microcomputer (PIC16F88, Microchip). Because a high through-rate is not necessary for this system, we adopted the conventional low-capacity on-board type amplifiers ($60 \text{ mm L} \times 40 \text{ mm W} \times 19.5 \text{ mm H}$, 120 g). Four-phase rectangular voltage, as shown at the upper left part of Fig. 1, was applied to the electrodes because it is more efficient than sine or triangular waves [15]. The power supply is designed to be simple, small,

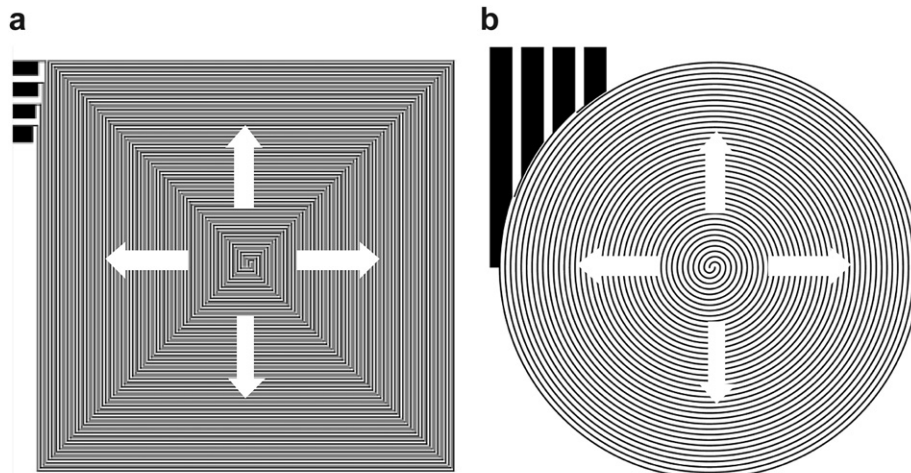


Fig. 2. Types of electrostatic particle conveyers: (a) square vortical and (b) circular vortical. Transparent ITO electrodes are printed on glass substrates (100×100 mm). The white arrows indicate the direction of traveling-wave propagation.

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