

SIMULATING LUNAR EXOSPHERE WITH MICROWAVE DISCHARGE IN POWDERS FOR MATERIALS TESTING. N. N. Skvortsova¹, V. V. Kachmar¹, V. D. Borzosekov¹, E. M. Konchekov¹, E. V. Voronova¹, A. A. Sorokin², N. S. Akhmadullina³, O. N. Shishilov⁴, V. D. Stepakhin¹, ¹Prokhorov General Physics Institute of the Russian Academy of Sciences, 119991 Moscow, Russia (vv.kachmar@fpl.gpi.ru), ²Institute of Applied Physics of the Russian Academy of Sciences, 603950 Nizhny Novgorod, Russia, ³Baikov Institute of Metallurgy and Material Science of the Russian Academy of Sciences, 119334 Moscow, Russia, ⁴Institute of Fine Chemical Technologies, MIREA—Russian Technological University, 119454 Moscow, Russia.

Introduction: The lunar exosphere is a dusty plasma system rising to altitudes of more than 100 km. The source of charged dust is the fine fraction of lunar soil, which levitates and is in motion above the Moon surface. Lunar dust poses a great risk to lunar missions since, due to its high adhesion [1], it deposits on any surface. Dust contamination may result in abrading and heating of construction materials and cause malfunctions in spacecraft and scientific instruments. Thus, studying the effects of the charged lunar dust on various materials and designing dust-mitigation techniques is as relevant as ever. However, the current infeasibility of in-situ materials testing requires methods to conduct studies with dusty plasmas imitating the lunar exosphere in the Earth laboratory conditions [e.g., 2,3]. Our study is dedicated to developing a microwave method for creating dusty plasmas in the lab and testing construction materials for lunar missions with this method.

Approach: To recreate the lunar dusty plasmas in the lab, we use a 75 GHz pulsed high-power microwave source (gyrotron) [4]. Microwave pulses irradiate a mixture of metal and dielectric powders, which serves as a lunar dust analog, whose chemical composition and particle size distribution [5] are analogous to the actual lunar samples [6]. Several physical and chemical phenomena (e.g., dielectric breakdown and microwave discharge, Coulomb repulsion, plasma-chemical reactions) raise clouds of charged dust [7], whose effects on various materials we analyze. Currently, we are applying a simplified approach to the experiments, conducting them at atmospheric pressure.

To visually control the initiation and evolution of the physical and chemical phenomena in the experiments, we use a Fastec Imaging IN250M512 high-speed camera. To evaluate the temperatures of the plasma, gas, and the surface of the irradiated powders, we use spectrometric measurements in the range of 250-920 nm, recorded by three Ava-Spec spectrometers. The temperature of the powder surface is calculated using the spectral continuum; the temperature of the non-equilibrium plasma above the powder surface is evaluated with atomic and ionic

emission lines; the gas temperature is determined from the vibrational spectra of two-atom molecules [8].

Our method is based on the analogy between the phenomena we observe in the lab and the ones accompanying micrometeoroid bombardments of the Moon surface, i.e., the heat absorption by the lunar soil upon a micrometeorite impact, chemical decomposition and synthesis of new chemical compounds at high temperatures, charging of the lunar dust by contact with surface plasmas.

We have also been developing and testing a method for treating material surfaces with low-temperature plasma [9] as a prospective dust-mitigation technique. Therefore, we run tests with treated and untreated samples of the same material and analyze how the treatment with low-temperature plasma affects the interaction between the samples and the levitating charged dust.

Results & discussion: The creation of dusty plasmas with fine lunar soil analogs requires a certain amount of microwave energy, and this amount depends on the chemical composition, percentage of metal content, and particle size of the powder mixture. If the threshold for microwave energy is achieved, we observe an explosive process resulting in elevation and transport of charged dust above the powder surface. Due to the achieved high temperatures (e.g., the plasma temperature above the powder surface may reach 0.5-0.7 eV or 6000-8000 K), the elevated dust particles glow. The temperatures suffice to initiate exothermic chain plasma-chemical reactions above the powder surface. Their duration and energy production exceed those of the initiating microwave pulse. By the end of the plasma-chemical reactions, the clouds of charged dust subside, depositing on materials, whose interaction with the charged dust we are studying. Camera frames featuring the cloud of charged dust at two consecutive stages of the experiment are shown in Figure 1.

We have run tests with stainless steel (the results are published, see [8]), molybdenum, tantalum, and aluminum (the analysis is still in progress, the results will be published elsewhere).

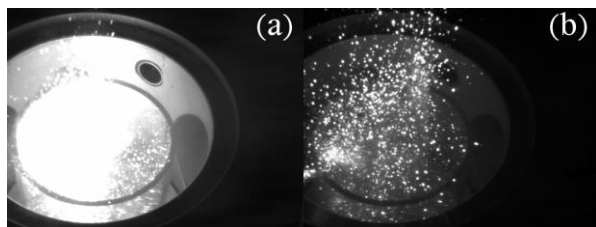


Figure 1. The development of the physical and chemical phenomena in the experiment at 24 ms (a) and 46 ms (b) following the end of the microwave pulse.

SEM images of stainless steel before and after the interaction with the charged dust are shown in Figure 2. As one may notice, the surface of the sample, not treated with low-temperature plasma, has been significantly modified by the dust and is fully covered with it, unlike the treated sample. It demonstrates the potential of low-temperature plasma treatment as a dust-mitigation technique.

The particle size distribution of the deposited dust repeats the distribution of the initial powders and is non-Gaussian due to an excessive number of particles of larger sizes [5].

Conclusions: In our experiments, we have demonstrated the possibility of creating dusty plasmas, which are analogous to the lunar ones in chemical composition and particle size distribution, by using a pulsed microwave source.

The method might be used to test not only construction materials under simulated lunar conditions but also various dust-mitigation techniques, as seen in the experiments with stainless steel.

References: [1] Walton O R (2007) Report NASA/CR—2007-214685. [2] Shu A. et al. (2012) *Rev. Sci. Instrum.*, 83, 075108. [3] Hood N. et al. (2022) *Icarus*, 371, 114684. [4] Skvortsova N. N. et al. (2019) *JETP Lett.*, 109(7), 441-448. [5] Kachmar V. V. et al. (2021) *J. Phys.: Conf. Ser.*, 2036, 012030. [6] Heiken G. et al. (1991) ISBN: 0521334446. [7] Skvortsova N. N. et al. (2017) *JETP Lett.*, 106(4), 262-267. [8] Skvortsova N. N. et al. (2021) *Mater.*, 14(21), 6472. [9] Artem'ev K. V. et al. (2020) *Russ. Phys. J.*, 62, 2073-2080.

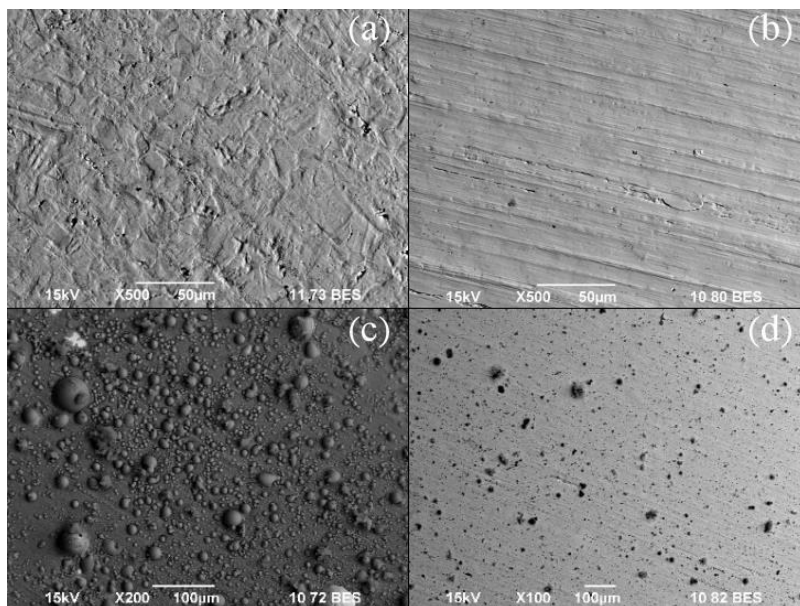


Figure 2. Samples of stainless steel: (a) untreated and (b) treated with low-temperature plasma before the interaction with the charged dust; (c) untreated and (d) treated with low-temperature plasma after the interaction with the charged dust.