National Aeronautics and Space Administration

FY24 R&TD Innovative Spontaneous Concepts (ISC)

Enabling ionization of unprocessed solid samples in their native environment

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Strategic Focus Area: Innovative Spontaneous Concepts

Objectives: The objective of this research was to develop a direct ionization technology for analyzing solid samples in a Mars-like environment without sample handling or manipulation. Ionization is crucial for detection instruments such as mass spectrometers and ion mobility spectrometers, which rely on ionized molecules for chemical analysis. This capability is vital for planetary exploration, particularly for detecting organic biosignatures that provide insights into planetary habitability and potential life. Our goal was to create a compact ionization source capable of functioning in Mars' low-pressure (5 Torr) CO_2-rich atmosphere, enabling real-time analysis of solid samples. This research aims to eliminate external sample manipulation and reduce the size, weight, and power (SWaP) requirements, making the technology suitable for aerial mobility platforms like drones.

Background: Detecting organic biosignatures is essential for planetary exploration, especially in the search for life on Mars. Current instruments often require complex sample handling subsystems, which present challenges for aerial platforms due to their size and weight. We explored ambient desorption/ionization mass spectrometry (ADI-MS), a plasma-based technique for real-time chemical analysis of solid samples. Coupling this technology with mass spectrometers simplifies the instrumentation needed for biosignature detection. ADI-MS is especially relevant for missions involving aerial drones, enabling exploration of remote or otherwise inaccessible terrains, including shielded environments like caves.

Approach and Results: We developed an ionization source capable of operating in a low-pressure environment (~5 Torr) simulating Mars' atmosphere. Initially, we planned to use direct current (DC) plasma ionization with helium gas to ionize organic molecules, but realized it might be inefficient due to helium's weight and moderate ionization energies in a CO2-dominated atmosphere. We then shifted to alternating current (AC) ionization, which offers tunable plasma energies and densities, making it better suited to Mars' conditions. AC ionization may eliminate the need for external gas, utilizing the plasma's natural flow, ideal for weight-sensitive aerial platforms like the Mars Science Helicopter. We designed and built a chamber compatible with small thermal vacuum (TVAC) systems at JPL. The setup used two chambers: one with the ionization source in a Mars-like environment and the other housing a residual gas analyzer (mass spectrometer). This configuration overcame the limitations of mass spectrometers requiring large pressure differentials. However, the turbopump in the high-vacuum chamber was susceptible to damage from Mars-analog dust. We iterated the design, creating an ionization unit supporting both DC and AC ionization, with or without gas flow, and adjustable electrode configurations. The compact prototype (~70 mm × 30 mm × 30 mm) includes a pin-to-capillary flowing afterglow and dielectric barrier discharge ionization. The sealed chamber (~20 cm × 15 cm × 15 cm) fits TVAC systems and features a mass spectrometer feedthrough. The design also includes a dust-protection mesh for redundancy. This system offers fine control over parameters such as source-to-sample distance, attack angle, and electrode geometries. Although no experimental data were collected during this phase, developing the hardware is a key milestone in validating this method in Mars-like conditions. Additionally, an independent PICASSO proposal for a low-pressure ion mobility spectrometer for in-situ organic analysis was selected, which will benefit from this ionization research.

Significance/Benefits to JPL and NASA:

The development of a compact ionization source for Mars-like environments provides significant benefits for future NASA/JPL missions, particularly those using aerial platforms like the Mars Science Helicopter. The AC ionization method, which may eliminate the need for external gases like helium, reduces size, weight, and power (SWaP) requirements for instruments. This technology is well-suited for exploring hard-to-reach terrains, such as Martian caves, where traditional instruments may not work. Real-time analysis of solid samples will enhance mission capabilities by providing immediate, high-value data, supporting more autonomous science missions and the search for biosignatures.

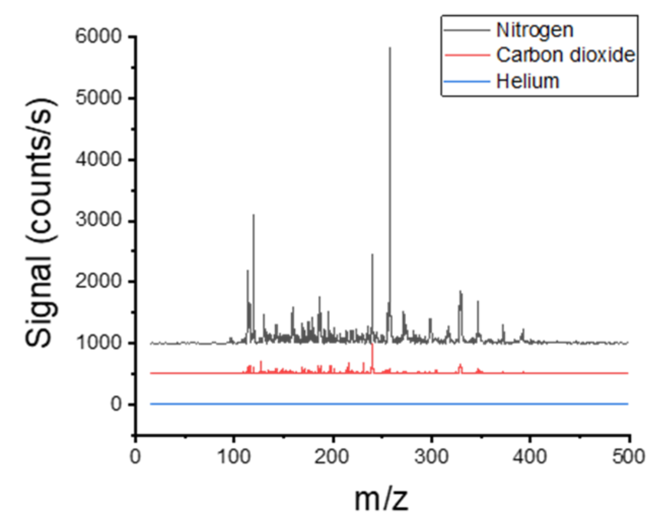

Figure 1. The ionization efficiency of fatty acids using nitrogen, carbon dioxide, and helium at ambient pressures using DC-generated corona discharge plasma under optimal conditions, such as distance, temperature, and pressure. Helium is most efficient leaving no detectable larger molecules, and carbon dioxide the least efficient. Consequently, AC-generated plasma became the focus to improve sensitivity when leveraging Martian CO2.

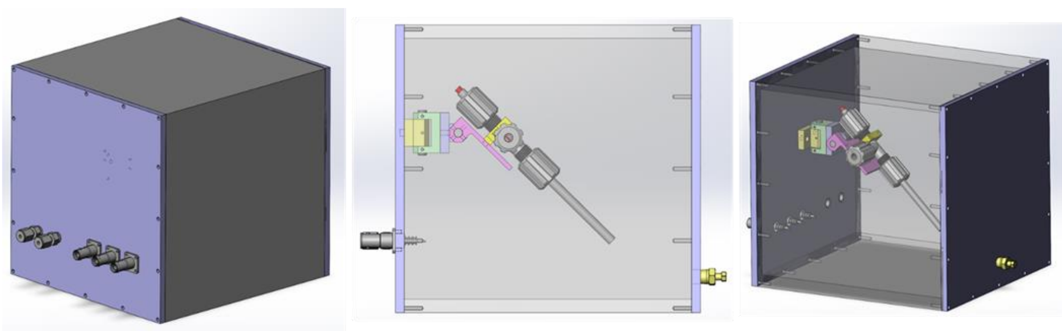

Figure 2. CAD model showing the sealed chamber that fits into a small TVAC and the highly adaptable plasma ionization source with adjustable position and angle.

Figure 3. The fabricated and assembled sealed plasma ionization source sitting inside a TVAC.

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