Aerogel Dust Capture for in situ Mass Spectrometric Analysis

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Introduction

The analysis of the dust grains associated with interplanetary space is a significant source of information about the evolution of our solar system. Dust grains present in the exospheres of the Galilean and Saturnian moons are of particular interest, due to the fact that these grains provide information about their parent bodies, i.e., Enceladus, Io, Ganymede, Europa, Callisto. Dust analyzers have been flown on several missions, including Ulysses [1] Gallileo [2], Cassini-Huygens [3, 4] and Stardust [5]. These instruments were designed to provide information about the velocity, electric charge, mass and composition of these particles. The composition of the dust grains is determined by time-of-flight mass spectrometry. Sample collection is achieved by having the dust grains enter the instrument and impact a target plate. The kinetic energy of the dust grains is more than sufficient to break up the constituent components to form molecular and atomic ions. The ions are directed into the mass spectrometer by electromagnetic fields, where they are differentiated by their masses. A complementary approach would be to use cells of aerogel to capture the dust grains and then desorb volatile molecules from the grains for analysis in the mass spectrometer.

Background

Cells of gradient density silica aerogels were the particle capture material in the cometary and interstellar particle collector grids for the Stardust Mission [6], which encountered the comet 81P/Wild 2 at 6.1 km s^{-1} and returned the dust samples to Earth in 2006. Aerogels are extremely porous materials composed of submicron sized filaments that form a solid network. Since the filaments are so much smaller than the high velocity particles being captured, they are crushed and melted during the capture process, allowing for the capture of the particles largely intact [7]. The cometary particles captured by the Stardust aerogel cells have provided information about the origin of our solar system [8]. In addition to minerals, the cometary particles captured by the Stardust aerogels were also found to contain polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons [9]. It was found that the hydrocarbons present in some of the particles survived the highly energetic capture process, yet were sufficiently labile to have migrated from the captured particles into the surrounding aerogel, where they were retained and eventually observed.

By capturing dusts in aerogel, the kinetic energy of the grains is dissipated over a longer duration and thus leaves much more of the grain intact. To demonstrate that organic compounds from fine particles captured in aerogel can be detected and identified by mass spectrometry, laboratory impact tests were conducted. The organics used were polycyclic aromatic hydrocarbons. This study was intended to establish and validate the methodology, while later studies will examine a larger variety of organic compounds and the concentration limits at which they can be detected.

Particle Capture and Analysis

In several tests done at the Advanced Vertical Gun Range (AVGR) at Ames research Center, porous silica particles containing PAHs were launched at 5.5 km s^{-1} and captured in silica aerogel. Figure 1 shows aerogel with several capture tracks from these tests. Once the impact tests were completed, the aerogel cells were returned to JPL for analysis.

A Direct Analysis Real Time (DART) unit (IonSense, Danvers, Massachusetts, USA) and a JEOL ACCUTOF high-resolution mass spectrometer (MS) were used to detect and identify the PAHs present in the captured particles. The DART ionization source produces metastable helium (He*) that is used to cause desorption of molecules from a sample and ionization of the molecules. The flow from the DART unit is a mixture of helium and neutral, long lived He*, which can be heated to enhance analyte desorption from a sample. Even relatively non-volatile molecules such as amino acid zwitterions can be detected [10].

Control spectra of untested aerogel and of projectiles that were not impact tested were done to verify the method. The only sample preparation of the aerogel section containing the capture tracks and terminal particles was to compress a portion of the aerogel between two glass slides. The slides were separated and the one holding the aerogel was placed in the flow of metastable helium. Since low-density aerogels are more than 99% pore volume, they can be flattened to a very small fraction of their original volume. This is done so that the full lengths of the tracks formed by the captured particles and the terminal particles are brought to the surface of the aerogel. This means that much of the analytes deposited along the tracks and in the termini are now at the surface of the aerogel. A flow of metastable helium from the DART source was directed at the aerogel, which desorbed and ionized the analytes and swept them into the MS inlet. The ionized organic samples produce a signal predominantly from the parent ion mass (M) and the hydrogen adducts (M+1). Figure 1 is the spectrum obtained from the DART-MS analysis of an aerogel cell from one of the AVGR impact tests. M+1 peaks are indicted for each of the PAHs present in the projectiles.

DART Development for Flight

DART units have been used to remove thin lithographic films of organic polymers [11]. This process is done in very low pressure environments and demonstrates that metastable helium can be used for desorption and ionization at low pressures. One of the co-Is (Anderson) has conducted a study of the development of DART units for space flight applications.

Conclusions

The results show that using aerogel to capture hypervelocity particles can preserve the integrity of organic molecules and are readily analyzed using a DART-MS. Another advantage of hypervelocity dust capture in aerogel is that the samples can be concentrated over time and stored in the aerogel. The analysis could then be performed at an optimal time for the both spacecraft and instrument operations.

In a broader spacecraft mission context, the work presented here demonstrates the feasibility of in situ mass spectroscopic analysis of dust captured in aerogel. By capturing particles in aerogel, the thermal and mechanical alterations due to the very high energy, short duration impacts are minimized. This could be a significant improvement over current flight mass spectrometers that use impactor plates that lose much of the organic molecular signature. This work expands the application of aerogel capture technology that has been established over the past three decades in laboratory experiments and on several space missions. The new methodology could be used to conduct chemical analyses of particles captured in the exospheres of planets and moons.

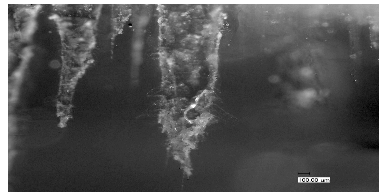

Figure 1 – Capture tracks of porous silica particles containing PAHs.

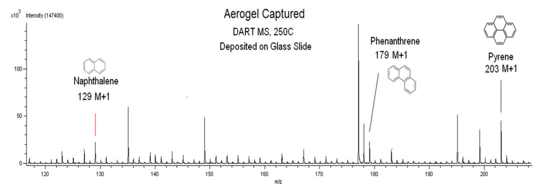

Fig. 2 – DART-MS spectrum of dust containing PAHs captured in aerogel at 5.5 km s^{-1}.

References

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