Non-Silicate Aerogels as a Next Generation Hypervelocity Particle Capture Material

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Introduction:
The Stardust Mission encountered the comet Wild2 in 2004 and captured particles from the coma of the comet in silica aerogel [1]. The information gathered from the ongoing detailed analyses of these particles has been very informative about the composition and evolution of our solar system [2]. However, the science return from the mission could have been enhanced since silicon could not be used as the reference element in geochemical studies due to the fact that the capture material is primarily silicon dioxide. Since Fe had to be used as the reference element for the Stardust geochemical analyses, comparison of Wild2 analyses and existing reference data on other samples was complicated. Using both silicate and non-silicate aerogels as capture media would mitigate this problem. Unfortunately, at the time of the Stardust aerogel development and production, non-silicate aerogels had not been sufficiently developed to be used for this purpose.

Aerogels are extremely low density materials that are typically made by the gelation of a metal alkoxide and their subsequent drying by supercritical solvent extraction [3]. The resultant materials are composed of myriad nanometer sized filaments randomly interconnected to form an open pore network. They exhibit many interesting physical properties, many of which are correlated to their very low densities, e.g., high pore volumes, high specific surface areas. The fact that they are composed of very small filaments means that they are quite efficient at decelerating and stopping tens of microns sized hypervelocity particles. For this reason, they were used as the capture media for the cometary and interstellar collection grids on the Stardust spacecraft.

Hypervelocity Impact Tests:
To test the suitability of non-silicate aerogels as hypervelocity capture media, impact tests were conducted at the Ames Research Center Vertical Gun Range (VGR). The first set of tests consisted of a series of hypervelocity impact tests firing a mixture of 20, 50 and 100 micron diameter glass spheres directly into samples of resorcinol-formaldehyde (RF), alumina, titania, germania, and zirconia aerogels. The velocities of the impacting particles were roughly 2 km/sec for three of the tests and 4.33, 5.04 and 5.69 km/sec for the other tests. At each of these velocities, the particles were captured by the aerogels. The initial point of entry was an opening, considerably larger in diameter than the particle, which led to a long tapering track, very similar to those observed from impact tests conducted with silica aerogel.

Glass micro-spheres extracted from the RF, alumina and zirconia aerogels after hypervelocity capture showed no significant damage, i.e., splitting, ablation. Particles could not be extracted from the germania and titania aerogels, since the aerogel tended to crumble when extraction of the particles was attempted.

A second set of tests consisted of a series of shots firing small aluminum spheres into samples of various meteorites that were suspended in the VGR. The initial impacts shattered the meteorite samples into much smaller fragments, which were ejected radially from the sample position. Samples of RF, carbon (pyrolized RF aerogel), alumina, germania, titania, zirconia and hafnia aerogels were facing the initial meteorite sample position to capture the meteoritic fragments created during the initial impact. Since the meteoritic fragments impacting the aerogels were secondary projectiles, the velocity of any individual fragment captured by the aerogel was not known.

Analyses of Captured Particles:
Synchrotron x-ray microprobe (SXRM) characterization was used on the Stardust samples to measure elemental abundances for elements of atomic number greater than 15 [4]. To determine the suitability of non-silicate aerogels as a capture media, this method was also used for this study. Since non-silicate aerogels are opaque, SXRM is particularly valuable in locating the particles and then conducting in situ analyses. The analyses conducted on the meteoritic particles captured in non-silicate aerogels for this study were composed of three sequential steps. First, an area of aerogel free of captured particles was analyzed to determine the levels of contamination of the aerogel. Then, mappings were done of selected areas to identify captured particles. Identification of captured particles was

made by the presence of very high local abundances of Fe. Finally, once the particles had been located, x-ray fluorescence (XRF) spectra were obtained to determine the detection limits of various sized particles. Since the background scattering levels of the carbon-based RF (Z = 6) or alumina (Z = 13) aerogels are much less than that of a zircona (Z = 40) aerogel, smaller particles can be analyzed in the lower Z aerogels. Based on observations of the tracks formed and the condition of the extracted particles from the RF, alumina and zirconia aerogels, it was decided that they exhibited the most promising capture characteristics, and thus particles captured in these materials were analyzed. Particles captured from the Murchison meteorite sample were reasonably firm and thus resulted in intact terminal particles. Therefore, the analyses conducted were done on the terminal particles. (Note: Since the particles collected during the Stardust Mission tended to break up as they were captured in the aerogel, analyses were done of the tracks and any terminal particles located.) Particle sizes were determined by recording the Fe K-alpha count rates when the beam was centered on the particles. The dimensions of the particles were determined by then conducting line scans in two orthogonal directions centered on the particles and finding where the count rates dropped to fifty per cent of the initial rates. The analyses were able to locate 22 micron diameter Murchison particles in both alumina and zirconia aerogels. For the alumina aerogel the Fe K-alpha peak (6.4 keV) from the particle was 20 times that of the background. For the zirconia aerogel, the Fe K-alpha peak (6.4 keV) was five times that of the background. Demonstrating that smaller particles can be detected in lower Z materials. Due to the very low background scattering of carbon based aerogels very small particles can be detected.

In all of the aerogel samples tested in this study, many of the minor element peaks were comparable to the contamination background and thus could not be determined. However, precise controls were not taken in the production of the aerogel to prevent the introduction of outside contaminants. For aerogel produced for a flight mission like Stardust, strict controls would be enforced and thus the background spectra of minor elements would be greatly reduced.

Aerogel Keystones:

The primary technique for the removal of the tracks and terminal particles from Stardust aerogels was accomplished by micromachining the aerogel. This was done by cutting "keystones" from the aerogel, which were then mounted on "microforklifts" [5]. Tests conducted on RF and zirconia aerogels demonstrated that RF aerogel is very well suited for this method of sample recovery. Micromachining of the RF aerogel resulted in very well defined keystones (see figure 1), whereas the zirconia aerogel tended to break apart during the micromachining process.

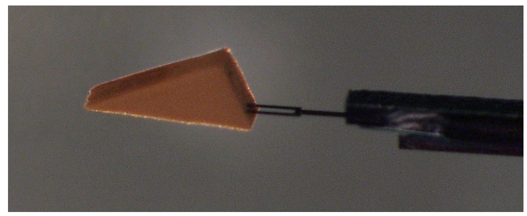

Figure 1. Keystone of RF aerogel on microforklift. Keystone is approximately 600 X 250 X 75 microns.

Conclusions:

Despite the fact that RF aerogel is not transparent and are carbon based, the studies done here indicate that it would be an attractive material to complement the use of silica aerogel in a future hypervelocity particle capture and return mission. Particles can readily be located and analyzed using standard techniques, e.g., SXRM. Once they are located, particles and their associated tracks can be removed from the bulk aerogel as keystones, mounted on microforklifts and further analyzed using a variety of other techniques, e.g., SIMS, XRD. Since the amount of silicon in an RF aerogel would be insignificant, geochemical analyses using silicon as the normalizing element could be conducted.

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