Spin-off Application of Silica Aerogel in Space: Capturing Intact Cosmic Dust in Low-Earth Orbits and Beyond

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Abstract. A spin-off application of transparent, low-density silica aerogel as a dust-capture medium in space is described. We provide an overview of the physics behind the hypervelocity capture of dust using aerogels and chronicle their history of use as dust collectors. In addition, recent developments regarding the high-performance aerogel used in the Tanpopo mission are presented.

Keywords: Silica Aerogel, Low-density Material, Cosmic Dust, Low-Earth Orbit, Astrobiology, Tanpopo.

1 Introduction

Since the 1970s [1], silica aerogel has been widely used as a Cherenkov radiator in accelerator-based particle- and nuclear-physics experiments, as well as in cosmic ray experiments. For this major application, the adjustable refractive index and optical transparency of the aerogel are very important. We have been developing high-quality aerogel tiles for use in a super-B factory experiment (Belle II) to be conducted at the High Energy Accelerator Research Organization (KEK), Japan [2], and for various particle- and nuclear-physics experiments conducted (or to be conducted) at Japan Proton Accelerator Complex (J-PARC) (e.g., [3]) since the year 2004. Our recent production technology has enabled us to obtain a hydrophobic aerogel [4] with a wide range of refractive indices ($n = 1.0026$–1.26) [5] and with an approximately doubled transmission length (measured at a wavelength of 400 nm) in various refractive index regions [6].

Silica aerogel is also useful as a cosmic dust-capture medium (see [7] as a review). Low-density aerogels can capture almost-intact micron-size dust grains with hypervelocities of the order of several kilometers per second in space, which was first recognized in the 1980s [8]. For this interesting application, high porosity (i.e., low bulk density below 0.1 g/cm^3; $n < 1.026$) and optical transparency of the aerogel are vitally important. The latter characteristic enables us to easily find a cavity under an optical microscope, which is produced in an aerogel by the hypervelocity impact of a dust particle.

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2 Spin-off Application of Aerogel in Space: A Dust-Capture Medium

2.1 Dust Impact Physics

High-energy physics researchers frequently conduct test beam experiments to evaluate the performance of particle detectors. Similarly, a gas gun experiment is often performed in ground-based laboratories to study hypervelocity impact phenomena that can arise in space. Gas gun experiments enable us to simulate dust capture in an aerogel (e.g., [9]). For example, a two-stage light-gas gun is installed at the Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), which can fire a projectile of diameter 7 mm at a nominal maximum velocity of 7 km/s. Dust particles as small as $\sim$10 μm can also be shot using a separable bullet container referred to as a sabot. The gas gun is the accelerator in the space science field.

The impact cavity (referred to as a track) created inside the aerogel is morphologically analyzed under an optical microscope (e.g., [10]). The track length, width of entrance hole on the aerogel surface, maximum track width, and track volume can be associated empirically with the impact energy, which involves impact velocity, size, and density of dust particles. Of course, the density of the aerogel influences the track morphology significantly. Researchers consider that lower aerogel density is vital for capturing more intact dust grains [8]. The track shape is also affected by the state of aggregation of the dust grains. The analysis provides physical information about cosmic dust.

2.2 Low-Earth Orbits and Deep-Space Missions

Material samples acquired from space are crucial in planetary science, astrochemistry, astrobiology, and space debris research. This is because ground-based state-of-art analysis instruments can be used for biochemical, mineralogical, and other related analysis of cosmic samples. The first space missions that used aerogel as a dust-capture medium were conducted in low-Earth orbits (LEO) in the 1990s. These include space shuttle missions (using the shuttle's cargo bay) by the U.S. National Aeronautics and Space Administration (NASA) [8] and the European retrievable carrier (Eureca) mission (freefrying spacecraft) by the European Space Agency [11]. Similarly, the series of Micro-Particles Capturer (MPAC) experiments conducted by JAXA was a LEO mission aboard the International Space Station (ISS) in the 2000s [12]. In addition, the Large Area Debris Collector (LAD-C) on the ISS was meant to be used for exploring near-Earth orbital debris by the U.S. Naval Research Laboratory (however, it was canceled in 2007) [13]. The Stardust spacecraft, a deep-space comet flyby mission by NASA, retrieved cometary dust (from 81P/Wind 2) back to Earth successfully in 2006 (e.g., [14]). Recently, an Enceladus (Saturn's moon) flyby plume sample return mission has been proposed to search for a signature of chemical evolution and possible extraterrestrial life [15, 16].

2.3 Tanpopo Mission

The Tanpopo mission proposed in 2007 is Japan's first astrobiology experiment in space to investigate possible interplanetary transfer of life [17, 18]. This latest, ongoing mission is a multifaceted experiment involving cosmic dust capture and determining exposure to terrestrial microbes/organic compounds in LEO aboard the ISS. In support of present-day endeavors, we developed the world's lowest density (0.01 g/cm^3; $n = 1.0026$) aerogel (within the dust-capture application) for the Tanpopo capture experiment [19]. To strengthen the mechanical properties of the entire capture media and to withstand rocket launch vibrations, a 0.01-g/cm^3 ultralow-density aerogel layer was combined chemically with a relatively robust 0.03-g/cm^3 density layer [20, 21]. In addition, a dedicated casing comprising a capture panel (CP) together with the double-layer aerogel was designed for interfacing an exposure mechanism [22]. A total of 36 CP units for three years were launched in 2015. The first-year samples were retrieved in 2016, and the analysis is in progress.

3 Summary

Since its first use was reported approximately 25 years ago, silica aerogel has been used as a cosmic dust-capture medium in many space mission in LEO and beyond. The aerogel can provide fruitful, almost-intact cosmic materials for detailed analyses on the ground. A high-performance ultralow-density aerogel was developed for the ongoing astrobiology mission Tanpopo in LEO. This technique for capturing intact dust particles will be applied in future missions to the moons of outer planets to search for possible extraterrestrial life.

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