ULTRASONIC MICRO-BLADES FOR THE RAPID EXTRACTION OF IMPACT TRACKS FROM AEROGEL. H.A. Ishii[1*], G.A. Graham[1*], A.T. Kearsley[2], P.G. Grant[1*], C.J. Snead[3*] and J.P. Bradley[1*], [*]Bay Area Particle Analysis Consortium (BayPAC), [1]Institute for Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA (hope.ishii@llnl.gov), [2]Department of Mineralogy, The Natural History Museum, Cromwell Road, London, UK, [3]Space Science Laboratory, University of California at Berkeley, Berkeley, CA 94720, USA.

Introduction: The science return of NASA's Stardust Mission with its valuable cargo of cometary debris hinges on the ability to efficiently extract particles from silica aerogel collectors. The current method for extracting cosmic dust impact tracks is a mature procedure involving sequential perforation of the aerogel with glass needles on computer-controlled micromanipulators [1,2]. This method is highly successful at removing well-defined aerogel fragments of reasonable optical clarity while causing minimal damage to the surrounding aerogel collector tile. Such a system will be adopted by the JSC Astromaterials Curation Facility in anticipation of Stardust's arrival in early 2006. In addition to Stardust, aerogel is a possible collector for future sample return missions and is used for capture of hypervelocity ejecta in high power laser experiments of interest to LLNL [3]. Researchers will be eager to obtain Stardust samples for study as quickly as possible, and rapid extraction tools requiring little construction, training, or investment would be an attractive asset. To this end, we have experimented with micro-blades for the Stardust impact track extraction process. Our ultimate goal is a rapid extraction system in a clean electron beam environment, such as an SEM or dual-beam FIB, for *in situ* sample preparation, mounting and analysis.

We have found that piezo-driven ultrasonic frequency (U/S) oscillations applied to very sharp, thin blades (Fig. 1b-c) generate unprecedented rapid and smooth cuts with minimal damage to surrounding aerogel (Fig. 1-4). (Analogous vibrating blade technology is used for microtoming tissue sections without freezing or embedding [4] and has been used at LLNL to machine polymer foams for development of laser inertial confinement fusion targets.) With this technique, still under development, we have extracted several impact tracks from aerogel tiles flown on NASA's Orbital Debris Collector (ODC) Experiment (Fig. 1a). Additional tracks were dissected into two halves exposing the main cavity (Fig. 2). Complete or dissected tracks can be extracted in less than an hour. Impact debris can be analyzed *in situ* in the extracted aerogel fragment and/or particles can be isolated for in-depth microscopy/spectroscopy study.

Micro-Blades: We experimented with a range of blades from simple surgical scalpel blades to laser-cut diamond blades mounted in a commercially-available piezo-driven holder (Eppendorf MicroDissector) on a 3-axis micromanipulator (Eppendorf TransferMan NK2) controlled by hand under a stereomicroscope with a long working distance objective.

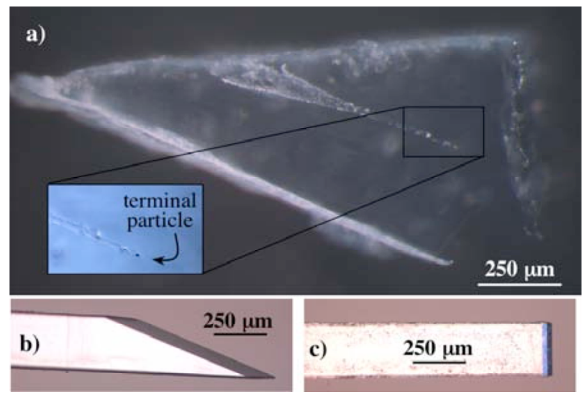

Fig. 1: a) Optical micrograph of ODC track in an aerogel wedge extracted using U/S oscillating diamond micro-blades. The top surface shows some additional pre-existing damage. Inset: Closeup of terminal particle at the end of the stylus. b) Diamond utility knife used for vertical cuts and c) diamond chisel used for undercuts.

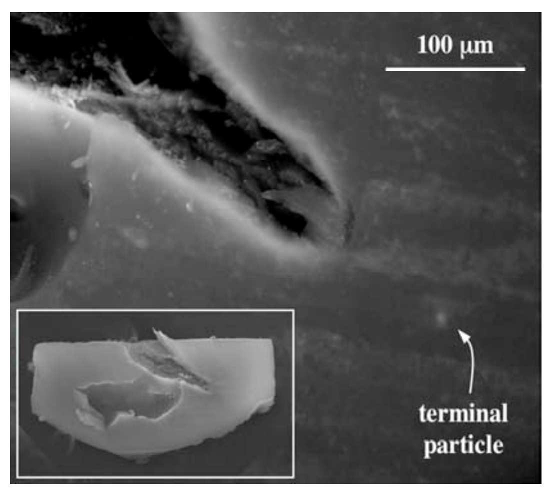

Fig. 2: SEM backscattered electron image of an ODC track dissected using a diamond utility knife. The terminal particle lies below the smooth, cut surface, and spectroscopy indicates it is likely non-terrestrial. It will be extracted for further analysis. Inset: Secondary electron image of entire dissected aerogel fragment. Tearing below track propagated from the pre-existing damage at the track's bottom surface.

Readily available cutting tools, scalpels and standard razor blades (~200 µm thick), have already been used to extract hundreds of impact tracks [5]. With piezo-driven U/S oscillations, even these less elegant blades cut flight-grade aerogel cleanly with little to no fracturing. They do, however, create wide channels in the aerogel and tend to generate tearing at depths beyond a few hundred microns.

To reach greater depths, ultrathin micro-blades of high-carbon steel and diamond were developed. Two basic blades, laser-cut from diamond to very narrow, sharp cutting edges, were designed in collaboration with Norsam Technologies (Hillsboro, OR): a utility knife shaped blade and a chisel shaped blade (Fig. 1b and c) both 25 or 55 µm thick at the start of the cutting edges. High-carbon steel micro-blades with utility knife shapes were produced from 16 µm thick, breakable razor blades (Electron Microscopy Sciences). Both blade materials have advantages and disadvantages that will be discussed.

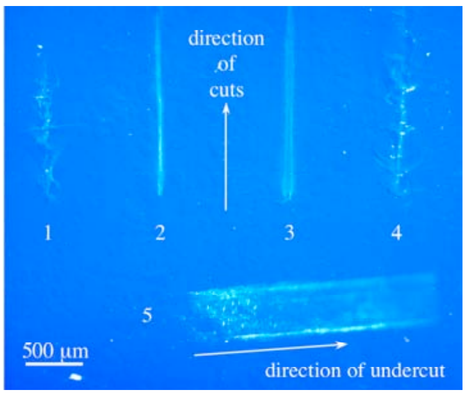

Fig. 3: Test cuts on flight-grade aerogel: Cuts 1 and 4 (200 µm deep) were made without piezo-driven U/S oscillations, and cuts 2, 3 and 5 (500 µm deep), with U/S oscillations. Cuts 1 and 2 were made by the diamond utility knife; cuts 3 and 4, by the steel blade; and cut 5, by the diamond chisel at an angle of 25°.

Aerogel Cutting: The U/S oscillations applied to the blades by the piezo-driven holder break up and compress aerogel locally creating a wedge-shaped channel for a lower friction interaction as the blade passes through. (See Fig. 3 for cuts made with and without the U/S frequency applied.) We have found U/S frequencies of 30-45 kHz (tuned for each blade, see Fig. 4) and amplitudes of ~1.5 µm to be optimal for clean aerogel cutting with diamond and steel micro-blades well-aligned with the micromanipulator axes of motion. The unprecedented smoothness of the cut surfaces reduces imaging artifacts in secondary and back-scattered electron imaging. These and other imaging and spectroscopic techniques can be susceptible to roughness effects. Two approaches using U/S oscillations of micro-blades have been developed: 1) Using utility-knife-style blades, the blade is drawn slowly across the surface and lifted to return to the starting position, and the next cutting pass is made ~50 µm deeper. 2) The second technique involves slowly pushing a vibrating blade directly into the aerogel to the desired depth. By rotating the entire micromanipulator on its stand, the chisel-style blade was used in this manner to make angled cuts beneath the impact track in Fig. 1a.

Future Work: We are installing a micromanipulator with an additional axis for angled blade motions in order to free an aerogel fragment completely from a tile without adjusting the entire micromanipulator angle. For tracks nearly perpendicular to the surface (vertical), an inverted regular pyramid can be extracted with 3 or 4 angled cuts. For tracks at more oblique angles, one or more of those cuts may be vertical. To assist in such extractions, modified chisel-style diamond micro-blades have been designed and will be tested.

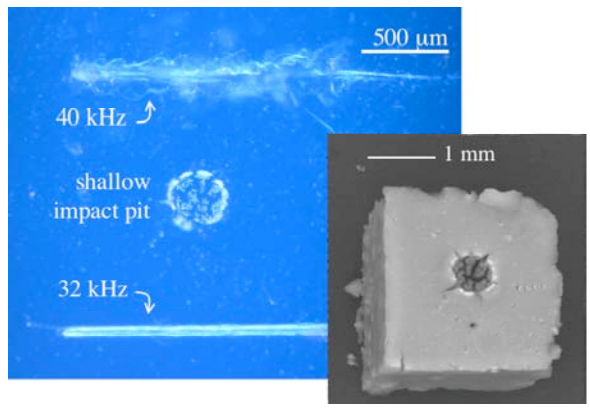

Fig. 4: Two cuts (1.4 mm deep) made with the diamond utility knife and U/S oscillations at different frequencies. The cut below the shallow pit was made at the optimized frequency. Lower right: Secondary electron image of the final extracted aerogel cube showing smooth surfaces cut at optimized frequency.

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