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Comet dust analog capture experiments in silicon nitride membrane “spiderwebs”

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Motivation

For the Stardust mission, aerogel was used as a collection medium for capturing particles during a relatively high-speed (6.1 km/s) pass through the coma of comet Wild 2 [1]. While spectacularly successful at capturing hypervelocity particles, the aerogel has been a challenging capture medium for later extraction and analysis of the cometary material [2-4].

The motivation for this study is to develop a capture medium that is well-suited to low-speed coma dust capture. Measurements from GIADA indicate that the dust velocity in a comet nucleus ranges from ~2-10 m/s [5] reaching highest values of ~30 m/s at perihelion [6]. For this purpose, we have developed a new dust-capturing device made out of layered silicon nitride grids, a.k.a. “spiderwebs”.

Methods

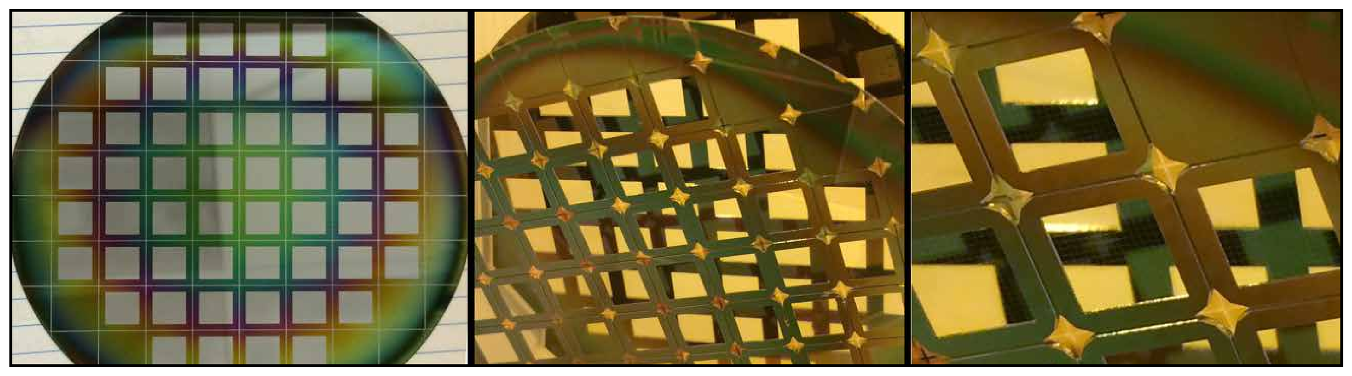

Fig. 1: Images taken during wafer processing. The image on the left was taken after nitride etching, and the other images after Si etching.

Membrane fabrication @ UC Berkeley Marvell NanoLab
Process summary

- **Deposition:**
  - Double-sided Si_3N_4 deposition on Si wafer, nitride thickness variable between 0.7-1.1 µm
- **Photolithography:**
  - Coat wafers with photoresist
  - Expose w/ mask to create membrane patterns
  - Develop
- **Etching:**
  - SF_6 + He etching to remove Si_3N_4 from mesh (Fig. 1a)
  - KOH bath to etch Si wafers (Fig. 1b,c)

A total of ~300 membranes were made in five grid sizes, labeled A through E: A=500µm; B=250µm; C=125µm; D=60µm; and E=30µm (Fig. 2, below).

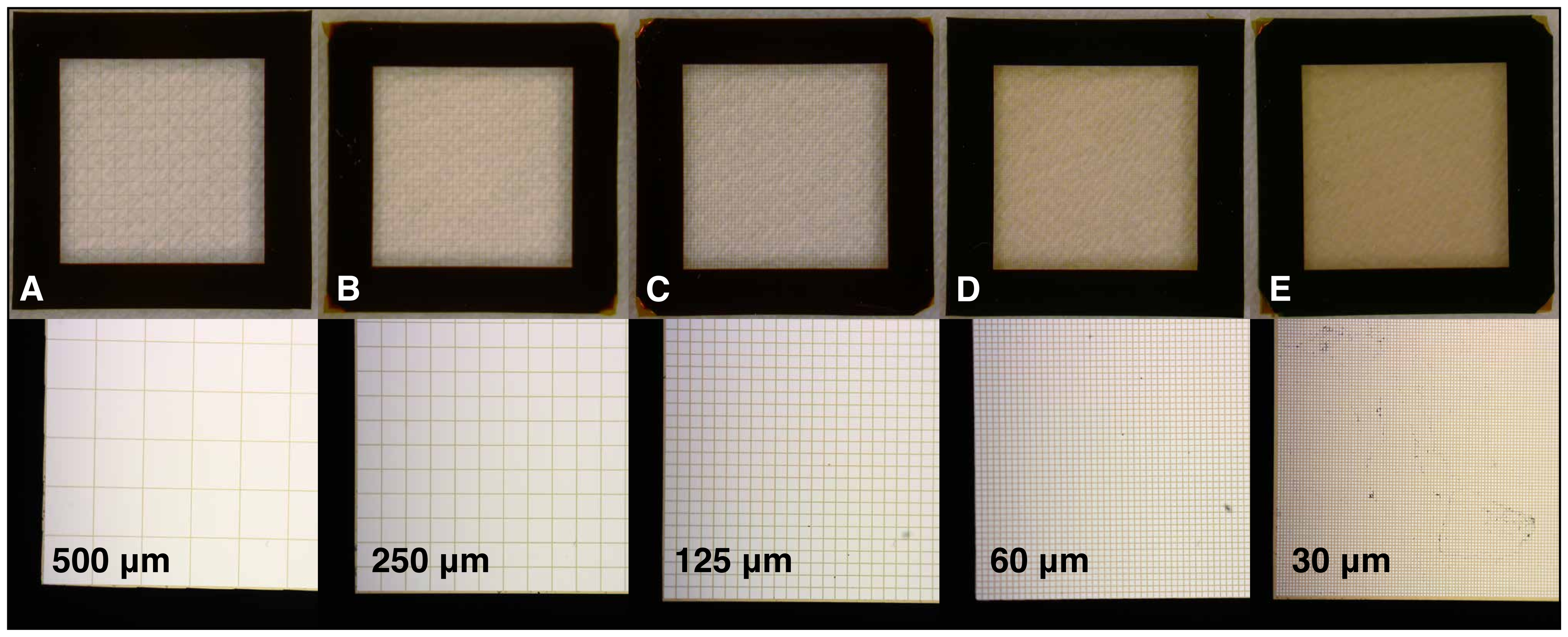

Fig. 2: (Left) Images of the Si_3N_4 membranes. The grids were made with five different grid spacings, to collect particles of different sizes. Actual membrane size: ☐☐

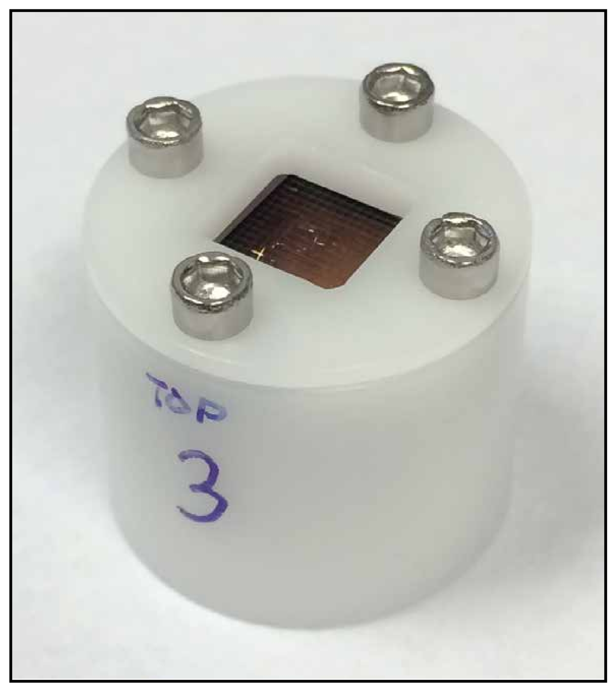

Fig. 3: Sample holders for capture tests made of delrin, designed to hold stacks of ~25-30 membranes. Approximately five membranes of each grid size were stacked such that the smallest grids were at the bottom of the collector, and the largest at the top, acting as a “sieve” for the collected dust.

Capture tests @ Istituto di Astrofisica e Planetologia Spaziali in Italy

- **Shot velocities:**
  - 1 m/s (low speed drop)
  - 30 m/s (high speed shot)
- **Shot materials:**
  - Glass spheres (100 µm)
  - Single-crystal olivine particles (20-50 µm and 100-250 µm)
  - Kaolinite aggregates (Fig. 4) (20-50 µm and 100-250 µm)
- **Conditions:**
  - Class 100 clean lab
  - Pressure of 8.6×10^{-3} mbar
  - Room temperature

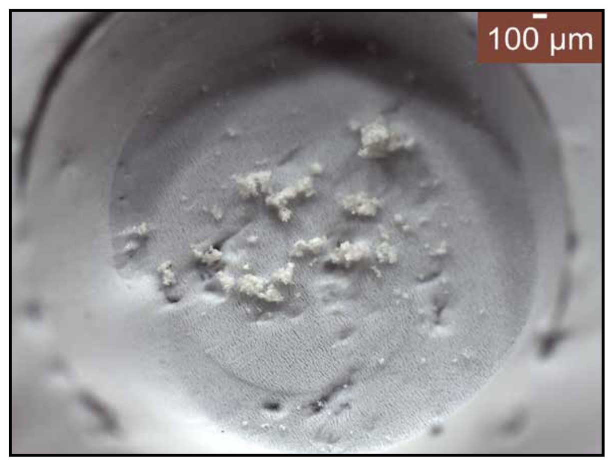

Fig. 4: Image of well used for low-velocity drop experiments, here filled with kaolinite aggregates from test 2.

We conducted eight capture tests (Table 1) simulating the potential dust velocity extremes in the cometary coma [e.g., 6]. Kaolinite and olivine were chosen as useful analogs for IDPs and asteroid-like material seen in comet Wild 2 [1, 7], as they represent a variation in texture and composition.

Test #	Velocity (m/s)	Material	Grain Size (µm)	# Particles Shot
1	1	Glass spheres	100	21
2	1	Kaolinite	20-50	1 scoop
3	1	Olivine Kaolinite	20-50 100-250	30 ~30-35
4	1	Olivine	100-250	36
5	30	Olivine	20-50	1 scoop
6	30	Olivine	100-250	1 scoop
7	30	Olivine Olivine	20-50 100-250	1 scoop 1 scoop
8	30	Kaolinite Kaolinite	20-50 100-250	1 scoop 1 scoop

Results and Discussion

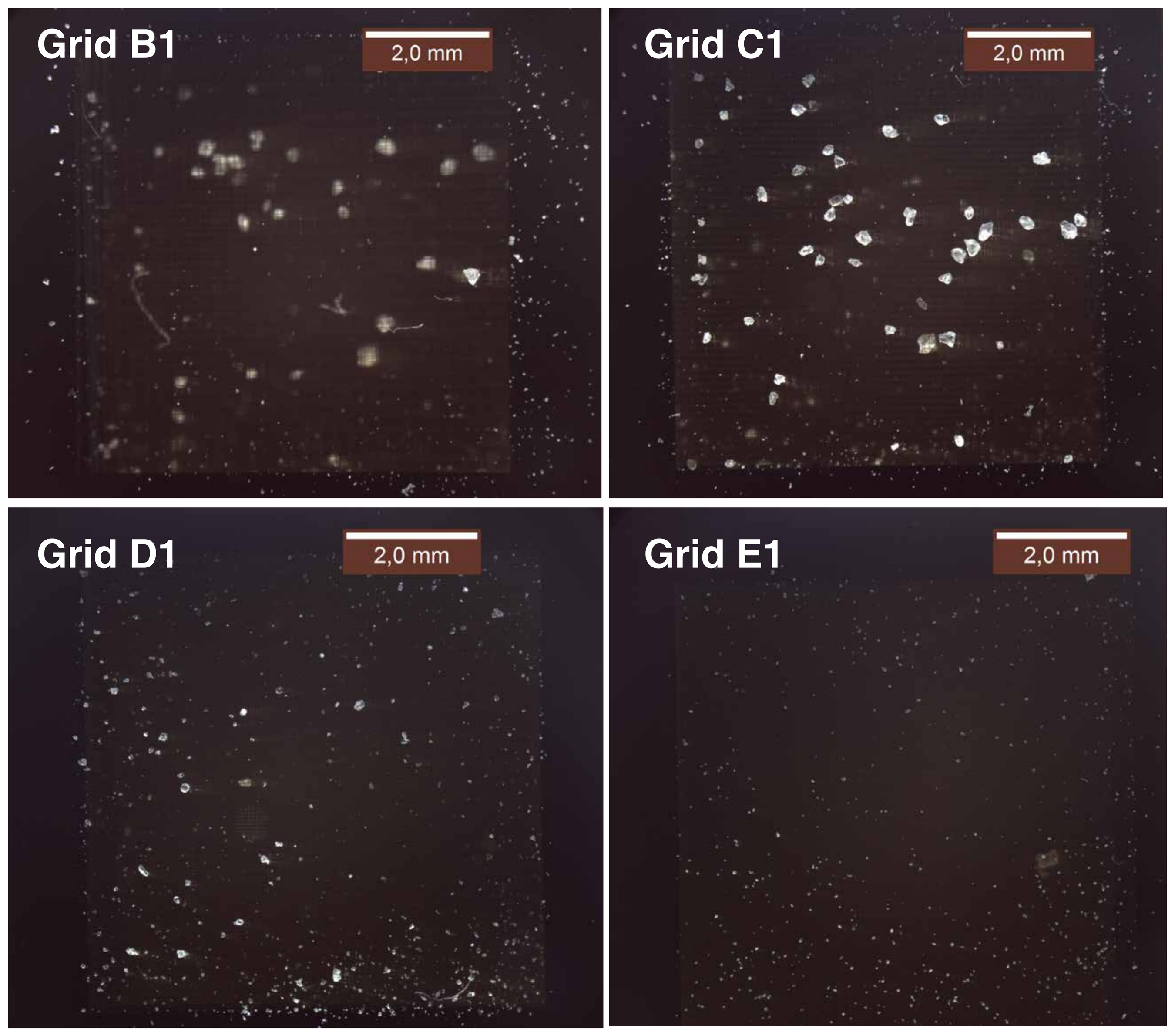

Fig. 5: Photomicrographs of grids B1, C1, D1, and E1 mounted in the holder after high velocity olivine test 7. Olivine grains were 20-50 and 100-250 µm.

Quantitatively, the capture rate was over 95% (based on tests 1 and 3). For tests with a large number of grains, counting was impractical, and only a qualitative assessment was conducted. Qualitatively, the membranes were excellent at capturing the sample materials. The stacked membrane grids acted as a sieve, sorting the shot material by size.

- **Low-velocity tests:**
  - Large grains/aggregates trapped primarily on first C grid
  - Smaller grains captured on the first D and E grids. (Fig. 5)
- **High-velocity tests:**
  - Olivine grains behaved same as in low-v tests.
  - Kaolinite aggregates were disaggregated either from the high-speed shot process, or from fracturing upon impact

The glass spheres statically “adhered” to the Si_3N_4 grids. In contrast, the olivine grains and kaolinite aggregates were much less “sticky”. The larger (>50µm) particles were caught and trapped, but rolled around if jostled. The Si_3N_4 membranes were mechanically robust throughout the tests. The only damage occurred during high-speed test 7, where the large olivine particles damaged the top two grids (Fig. 6).

This first capture test demonstrates the capability of the Si_3N_4 spiderwebs as a collection medium for small cometary-like particles. Designs for the holder are still in development, and future models will take into account the results of this test.

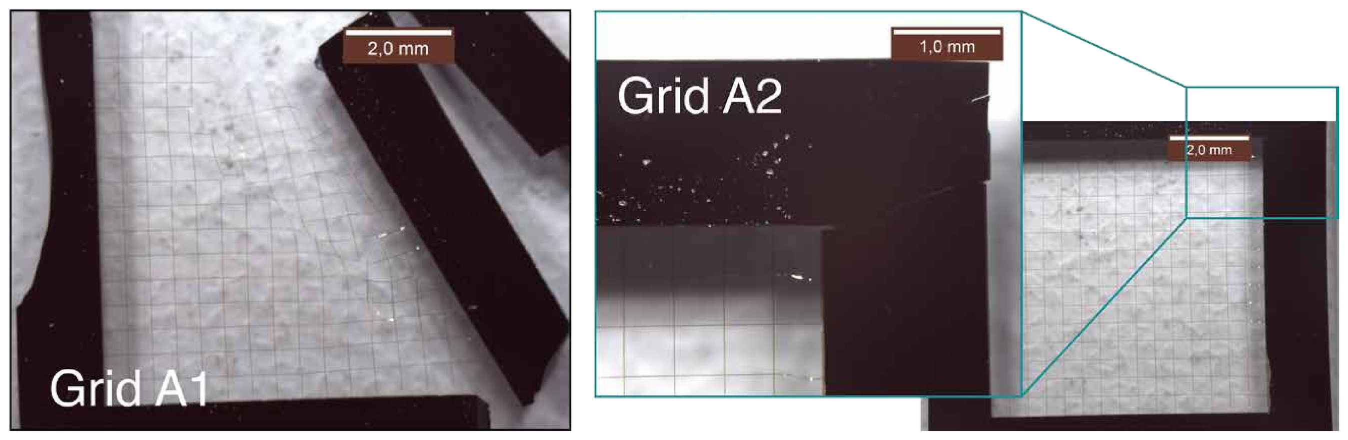

Fig. 6: (Right) Damage to grids during test 7, from olivine grains impacting the edges of the brittle Si frames. Despite this damage, the assemblages still captured grains.

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