Motivation

The origins of meteoritic nanodiamonds, first separated from meteorites in 1987 by acid dissolution and size separation [1], remain an enigma: isotopic anomalies in trace elements Xe [1], Te [2], Pa [3], and size separation [1] remain an enigma: isotopic anomalies in trace elements Xe [1], Te [2], Pa [3], and size separation [1]—but the ion beam). Asymptotic giant branch star like features demonstrating void microtip with a layer HG01.

Where did the nanodiamonds originate?

In the absence of grain-by-grain isotopic data, many mechanisms have been suggested. The nanodiamonds are likely to be drawn from some combination of these sources.

- Condensation in the expanding remnant, mixing between 12C- and 13C-rich shells, inclusion of trace elements from r-process and p-process nuclease synthesis.
- Condensation in the outflows of AGB stars [11].
- Shock-transformation of amorphous, sp2-bonded sheets [10].
- Condensation or shock formation in the circumstellar disk. Infrared signals consistent with emission from hydrogenated nanodiamond surfaces have been observed in the circumstellar disks around young stars [12,13].

HG01-B: a FIB-sharpened sample microtip with a layer of Allende DM residue, demonstrating void-like features (indicated by arrows).

Results

(1) Secondary electron images show the Allende DM acid residue deposition layer (arrow) between Pt layers. (2) TEM bright-field images and (3) high angle annular dark field images show low-density features, as well as a hydrocarbon cap on HG01-C.

HG01-C: Demonstrates we can distinguish between the sample layer and contamination (hydrocarbon cap laid down by the ion beam).

Experimental

Using focused ion beam microscopy, (1) nanodiamonds from the Allende DM residue are embedded between sputter-deposited Pt layers, (2) lifted out, (3) attached to an electropolished micropipet on a TEM half-grid, and (4) sharpened.

Transmission electron microscopy (TEM) at 200 kV, electron energy loss spectroscopy (EELS), and energy dispersive x-ray spectroscopy (EDS) are used to find and characterize the position, size, and crystal structure of carbonaceous features in microtips. Instrument: JEOL 2100F at the Institute for Materials Science and Engineering at Washington University.

Atom-probe tomography is used to conduct point-projection-microscopy and time-of-flight mass spectrometry, allowing us to reconstruct the carbonaceous features and identify 12C and 13C isotopes. Instrument: LEAP 4000X SI at Northwestern University.

HG04-C: Deposition is oriented parallel to the electron beam. Based on elemental identification using EELS and EDS, and lattice spacings, we identify (A) Pt surrounding the low-density layer. In the low-density layer we find features consistent with (B) diamond surrounded by (C) graphite.

 HG04A: Deposit is oriented parallel to the electron beam. Based on elemental identification using EELS and EDS, and lattice spacings, we identify (A) Pt surrounding the low-density layer. In the low-density layer we find features consistent with (B) diamond surrounded by (C) graphite.

Discussion

TEM showed low-density features consistent with nanodiamonds, that were not detected by APT on the same microtip.

Possible explanations:

- Voids created as Pt (top, gray) sputter-coated a rough sample deposit (purple dash), onto a Pt substrate (bottom, gray). The dashed green line indicates the final microtip shape.
- Clumps of amorphous, sp2-bonded C.
- NDs that were undetected by APT.

In each case, the C in the reconstructed deposition layers most likely represents amorphous, sp2-bonded C. The density is too low for precise isotopic measurements. We are targeting lower-density regions of the acid residue deposit for our next samples. Correlated TEM/APT of microtips containing only isolated, nanodiamond-sized carbonaceous regions, as has been previously observed in some cases [7–9], should resolve the question of which of the above explanations is correct.

HG01-B: a FIB-sharpened sample microtip with a layer of Allende DM residue, demonstrating void-like features (indicated by arrows).

HG01-C: Demonstrates we can distinguish between the sample layer and contamination (hydrocarbon cap laid down by the ion beam).

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References


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