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プレソーラーアルミナ粒子の内部構造分析による形成・変成履歴の推定
Crystal structure, morphology, and isotopic compositions of presolar alumina grains in unequibrated ordinary chondrites

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Corundum, the thermodynamically stable phase of Al_2O_3, is predicted to be the most abundant refractory dust species condensed in envelopes around oxygen-rich asymptotic giant branch (AGB) stars. Many presolar Al_2O_3 grains, which are the survival circumstellar dust grains, have been identified from acid-residues of chondrites. The grain morphology and crystal structure of presolar grains may reflect condensation conditions in circumstellar envelopes of AGB stars and processing in the interstellar medium (ISM) and protosolar disk.

Using scanning electron microscopy (SEM) we obtained detailed secondary electron images, energy dispersive X-ray spectroscopy (EDS), electron backscattered diffraction (EBSD) patterns, and cathodoluminescence (CL) spectra of each Al_2O_3 grain prior to isotopic measurements. Focused ion beam (FIB) lift-out sections were made from the identified presolar grains and the interior structures were observed with a transmission electron microscope (TEM).

The Al_2O_3 grains were identified from acid residues of QUE97008 (LL3.05) by EDS and observed in detail by field emission (FE) SEM at the Carnegie Institution of Washington (CIW). Previously identified alumina grains from Semarkona (LL3.0), Roosevelt County 075 (H3.1), and Bishunpur (LL3.15) were also used in this study. CL spectra were obtained with a FE-SEM equipped with a Gatan Mono CL4 system at NIST. EBSD analysis was performed with an FEI Nova 600 FIB-SEM equipped with an HKL EBSD system at the Naval Research Laboratory (NRL). Isotope measurements were performed with the Cameca NanoSIMS 50L ion-microprobe at CIW. Oxygen isotopes of 163 grains were measured using ~100 nm Cs^+ beam rastered over each of the grains. An O^- beam was used to measure the Mg-Al isotopic compositions of the presolar and some solar Al_2O_3 grains. Ultra-thin sections of presolar grains QUE053, 060, and 067 were prepared with the NRL FIB-SEM. TEM studies were carried out at NRL with a JEOL 2200FS field-emission scanning transmission electron microscope (STEM).

Eight presolar grains from QUE97008 and one from RC 075 were newly found. Grain QUE060 is classified into Group 2 and has a subhedral shape with clear flat facets. The surface is smooth except for a face with a cavity. TEM diffraction patterns of the FIB section indicated that the grain consists of multiple corundum crystallites. Dark-field TEM image showed large (>100 nm) and small (<30 nm) scale orientation variation. The large-scale misorientation observed on the right side of the grain seems to relate to the cavity. Small-scale distortions occur uniformly within the grain. EDS spectra showed that the Mg/Al ratio of QUE060 is ~0.01, and the NanoSIMS measurement revealed this high Mg content to be essentially pure radiogenic ^{26}Mg, with inferred initial $^{26}Al/^{27}Al$~0.01, similar to other Group 2 grains.

QUE067 is a thin Group 4 grain with very irregular morphology. Its $^{27}Al/^{24}Mg$ ratio was three times lower than in QUE060, but its inferred $^{26}Al/^{27}Al$ ratio was similar. No EBSD patterns of crystals were obtained from the grain surface but TEM observation on the FIB section showed that the interior of QUE067 was corundum, not amorphous.

The subhedral shape and smooth surface of QUE060 suggest that this grain was likely single crystalline corundum when it condensed in a circumstellar envelope of a low-mass AGB star, and that the polycrystalline nature, voids and distorted crystal structure inside the grain are secondary features.

A possible process to form large-scale misorientation and the cavity is grain-grain collisions in a SN shock in the ISM. A high velocity collision creates a shockwave propagating inside the grain, finally forming a crater. Small-scaled distortions may have also formed by collisions with small particles in the ISM. Such collisions are less destructive than with larger grains, but their probability is high. Ion bombardment in the ISM may also contribute to the small-scale distortions.

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