TRANSMISSION ELECTRON MICROSCOPY OF A PRESOLAR SUPERNOVA HIBONITE GRAIN.

R. M. Stroud[1], L. R. Nittler[2] and C. M. O'D. Alexander[2], [1]Code 6366 Naval Research Laboratory, 4555 Overlook Ave. SW, Washington, DC 20375 (rhonda.stroud@nrl.navy.mil), [2] Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd., Washington, DC 20015.

Introduction: Approximately 10 to 20% of presolar oxide and silicate grains are classified as Group 4 grains due to enrichments in both ^{18}O and ^{17}O. Although it was first argued that these grains originated in unusual Asymptotic Giant Branch (AGB) stars, the most likely origin of these grains is now thought be in supernova (SN) ejecta [1,2]. Strong support for the SN origin comes from measurements of grain KH2, a Group 4 hibonite (originally called 110-5 by [1]). The O, Al, Mg, K ands Ca isotopic ratios of this grain can be reproduced with simple supernova mixing models, but not with AGB models. Furthermore, most of the Group 4 grains and some Group 3 grains follow a single mixing line on an O 3-isotope plot, suggesting that all of the grains may have originated in a single SN [3].

Differences in presolar grain microstructures, as well as in isotope signatures, are believed to reflect differences in stellar origin. Microstructural differences between AGB and SN grains have been observed previously for both graphite and SiC. For graphite, the grain density is correlated with stellar origin: high-density separates are dominated by AGB grains and low-density separates by SN grains [4,5]. Differences are also evident in the subgrain populations: SN graphite grains frequently contain abundant TiC and occasional Fe-rich metal, and the AGB grains often contain Zr-Ti-Mo carbides. For SiC, the AGB grains are typically single crystals [6], whereas the SN grains are polycrystalline aggregates [7,8]. This was also observed for SN Si_3N_4 [9]. Previously, the available microstructural data for O-rich SN grains was restricted to a single forsterite grain [10]. Similarly to the SN SiC and Si_3N_4, the SN forsterite grain was composed of multiple sub-micron crystallites. However, the individual crystallites of the forsterite showed equilibrium grain boundaries, indicative of crystallization from a single melt, whereas the SiC and Si_3N_4 crystallites appear to have condensed separately and subsequently aggregated. We report here on results from the first transmission electron microscopy of a SN oxide grain, KH2.

Methods: Isotopic data for hibonite grain KH2 were previously reported [1,2]. We prepared an ultrathin section of the grain using the Nova 600 FIB-SEM at the Naval Research Laboratory. TEM studies were performed on a JEOL 2200FS field emission microscope equipped with a Noran System Six energy dispersive X-ray spectroscopy (EDS) system. The grain composition was determined from EDS data with standardless quantification routines. We obtained selected area diffraction patterns from four different crystallographic zones and indexed them using CRISP, PhIDO and EMS software packages.

Results and Discussion: Measured isotopic ratios in KH2 are compared with the results of a simple $15M_\odot$ SN zone-mixing model in Fig. 1 [2]. The mixture reproduces very well the isotopic composition of the grain, and is dominated by material from the outer H-rich envelope of the star with only a small amount of material from inner SN zones.

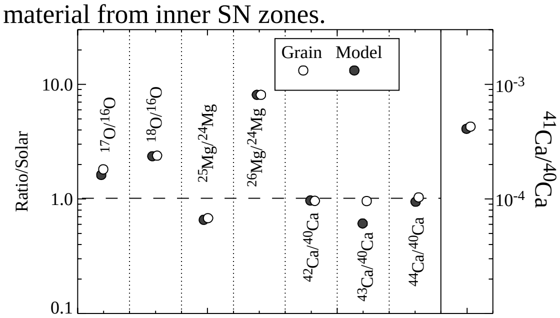

Figure 1: Isotopic compositions of hibonite grain KH2, compared with results of SN zone-mixing model [2]. Mixing model closely reproduces 7 of 8 measured ratios, supporting a SN origin for this grain.

Bright-field TEM (Fig. 2a) reveals that the section of the grain is 600 ×230 nm, with a crack extending 200 nm into the grain from the left side. The top 30 nm of the grain shows no diffraction contrast and is amorphous, most likely due to ion beam damage during the SIMS measurements. No evidence for damage from either cosmic or laboratory processing is seen on the underside of the grain. In Z-contrast STEM imaging (Fig. 2b) the grain appears mostly uniform, but slightly darker in the top amorphous region, indicative of a decrease in density. The remainder of the grain is crystalline and exhibits diffraction patterns that index to a single hibonite crystal. However the crystal orientation varies by several degrees across the grain. The crack and spread in crystal orientation are unlikely to be primary condensation features and suggest that the grain fractured during a grain-grain collision event, either in the SN outflow, the interstellar medium or the solar nebula.

Overall, the crystal structure, morphology and elemental composition of the KH2 SN hibonite appears remarkably similar to that of the four AGB hibonites studied to date [11,12]. Each of the AGB hibonites was also a single crystal. The composition of the SN KH2 grain is $Ca_{0.99}Al_{11.80}Ti_{0.13}Mg_{0.06}O_{19}$, within the range of previously reported AGB hibonite compositions, although at the low end for Mg. As noted above, the SN mixture that reproduces the grain's composition is dominated by material from the outer envelope, which has a bulk elemental composition close to that of the Sun and to O-rich AGB stars. Thus, it is perhaps unsurprisng that KH2 has a similar microsctucture to AGB hibonites, since the expanding SN envelope will be analogous to the circumstellar AGB environments. In contrast, SN SiC and graphite grains formed from mixtures of interior zones where physical and chemical conditions were vastly different from C-rich AGB outflows, thus accounting for the striking difference in microsctructures between SN and AGB grains.

References:

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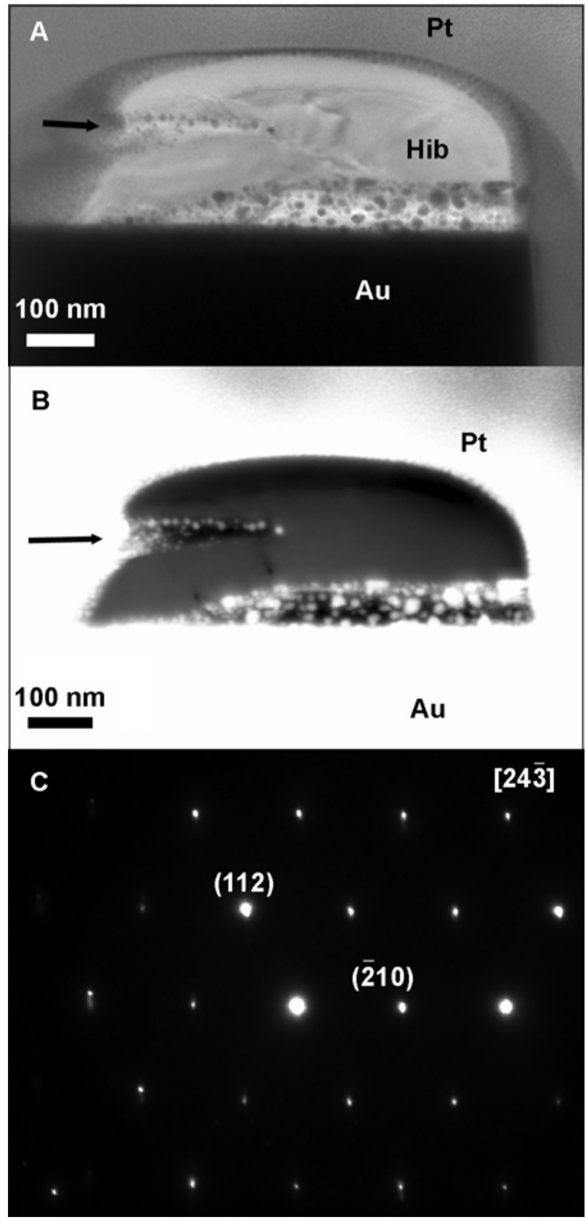

Figure 2. (A) Bright-field TEM image, (B) Z-contrast image and (C) selected area diffraction of supernova hibonite KH2. The arrows in (A) and (B) indicate the position of a crack in the grain. The Au nanoparticles that coat the crack and the space between the grain and Au support stub are due to redeposition of sputtered Au during the FIB processing.