COMPARATIVE MORPHOLOGY OF PRISTINE AND CHEMICAL-DISSOLUTION PRESOLAR SiC FROM MURCHISON

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Isotopic studies of meteoric presolar SiC provide detailed information about stellar nucleosynthesis and galactic chemical evolution [1]. The chemical dissolution procedures used to isolate presolar SiC from meteorites [2] are advantageous in concentrating this material for isotopic analysis, but they can also destroy other presolar mineral or organic phases that may have been associated with the SiC, and may alter the surfaces of the SiC grains in ways that are difficult to assess. In this work we attempted to circumvent these problems by isolating presolar SiC using a gentle, non-destructive procedure, in order to view presolar grains for the first time in their pristine state.

Several important kinds of information might come from the study of pristine presolar SiC. First, there are a number of ways in which other phases could be associated with SiC. During grain growth in circumstellar environments, other minerals could condense on SiC nuclei, be produced by back-reaction of SiC crystal surfaces with the gas phase, or form by exsolution. The latter has already been noted in a previous TEM study of ultramicrotome sections of presolar SiC [3] that revealed epitaxial TiC internal crystals. Observation of such associated phases would give a more complete picture of condensation processes in circumstellar environments. Second, because SiC grains may have long residence lifetimes in the interstellar medium (ISM), their surfaces can serve as sites for the condensation and chemical processing of mantles of ices and organic molecules in dense molecular clouds [4]. Because SiC grains in primitive meteorites are demonstrably presolar based on isotopic composition, their surfaces are ideal candidate sites for these interstellar compounds and/or their residues. Third, presolar SiC grains, in principle, can be used as tools to investigate the extent of grain erosion and commination that are postulated to occur in the ISM [5], as well as the corrosive effects of oxidation (e.g., weathering and formation of silicon oxide surface layers [6]) during their exposure to warm vapors and fluids in the solar nebula and meteorite parent body.

In a previous SEM X-ray mapping study [7], we located presolar SiC in situ in Al-oxide-polished sections of carbonaceous meteorites. The SiC can be distinguished within the sea of surrounding silicates because of its slightly higher Si photon yield per incident electron. In that study, the grain surfaces were not preserved, but possible associations of presolar SiC with other phases could still be evaluated in cross-sectional views. No such associations were noted, and the SiC grains that were found appeared as isolated individuals within the meteorite matrices. In the present study, we have used a similar X-ray mapping procedure to locate presolar SiC grains in disaggregated matrix from Murchison (CM). In order to minimize the possibility of contamination by terrestrial SiC, a ~2g piece of the meteorite was first coated with epoxy to fix any surface contamination, then split in half within a clean laminar flow hood. About 30 mg of matrix was excavated by a dental tool from a single ~10 cubic mm of the interior, and ultrasonicated for several hours in an isopropanol-water mixture. Material from this suspension was then pipetted onto graphite planchettes for X-ray mapping. About 40 SiC grains with an average diameter of ~1 µm were identified using a JEOL 840A SEM equipped with a NORAN X-ray microanalysis system, and half of these were imaged in an Hitachi field emission SEM, whose electron energy stability and low voltage imaging provide optimal grain surface spatial resolution. For comparison, we have also imaged SiC from the acid dissolution separate Murchison KJG (1.5 - 3 µm; [2]) under similar conditions.

Several elongated anhedral grains were observed, but most of the pristine SiC grains are subhedral to euhedral. The latter often have relatively smooth surfaces decorated with regular geometrical depressions (Figure 1). Comparison with the acid dissolution grain surfaces indicates that these are likely primary growth features, representing quenching of rapid condensation, rather than any type of surface attack due to oxidation or aqueous alteration. The laboratory acid dissolution, in contrast, preserves the overall crystal shape, but stratification often appears along cubic [111] zone directions and frequently there is fine pitting of {111} plane surfaces (Figure 3). The stratification and fine pitting are completely lacking in the pristine grains observed thus far. These are occasionally lacking in the dissolution grains as well, suggesting that they are probably due to preferential etching along stacking faults and screw dislocations (the main growth mechanism for SiC), respectively, that are present in variable concentration from grain to grain due to differences in grain growth conditions. From these observations we conclude that the response of presolar SiC to laboratory etching is sensitive to the defect concentration in the grains, which fact should be heeded when using synthetic (and generally defect-poor) SiC to gauge the efficacy of grain isolation procedures. We also note that preservation of surface growth features, in addition to overall crystal shape, indicates a lack of severe weathering or erosion in either the ISM or solar nebula for these pristine SiC grains. Whether this preservation is a function of shorter exposure time to adverse conditions in either environment, or the result of protective blanketing by icy/organic mantles, is an interesting but as yet unresolved question. Although some of the grains clearly are fragments, we have not...
yet seen any collisional “zap” pits (e.g., as in lunar soil grains). We also observe many crystals that are partly rounded. In some cases this rounding is probably due to the presence of coatings that are either extremely fine grained (grain size < 10 nm) or colloidal. We do not yet know whether these coatings are artifacts of the sample preparation or are intrinsic to the grains themselves. In other cases, the rounding is possibly the result of oxidation reactions in which the Si-oxide reaction product has not been removed from the grain surface (Fig. 2). We have noted previously that an oxygen X-ray signal is frequently associated with pristine SiC grain surfaces [8], but in general it is very difficult to tell whether this is the result of sampling of random fine grained silicates on the grain surfaces, or the stimulation of oxygen X-ray emission from adjacent silicate grains. To investigate the surface compositions in the future, we will use the high spatial resolution of the NanoSIMS, as well as prepare ultramicrotome sections of these grains for high spatial resolution TEM investigations of the grain surfaces.


Figure 1: Field emission SEM image of a pristine presolar SiC crystal from Murchison. The angular embayments in the interior are primary growth features probably due to quenching of rapid condensation.

Figure 2: Field emission SEM image of a pristine, rounded presolar SiC crystal from Murchison.

Figure 3: Field emission SEM image of a chemical dissolution presolar SiC crystal from Murchison KIG [2]. Note the stratified appearance as well as the presence of numerous surface etch pits.

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