

TRACE ELEMENT DEPTH-PROFILES IN PRESOLAR SiC. A. King¹, T. Henkel¹, D. Rost¹ and I. Lyon¹
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Introduction: Presolar SiC was first isolated from meteorites in 1987 [1] and is the most extensively studied presolar phase. Analyses of both bulk samples and individual grains have shown that they fall into several isotopically distinct groups, although the majority (~90%) probably originated from 1-3M_☉ AGB-stars [2]. Trace element abundances within the grains provide information regarding the physical and chemical conditions under which they condensed [3]. However, most studies of trace elements in SiC have used direct current (DC) beam ion probes. With this technique sample consumption is high, so that the elemental abundances represent an average over a large volume of the grain. Potential heterogeneities within the grains, such as TiC sub-grains [4] or implanted material [5,6], may not be detected.

We have been undertaking systematic analyses of presolar SiC grains isolated with different separation methods using time-of-flight secondary ion mass spectrometry (TOFSIMS) [6,7,8]. A major advantage of TOFSIMS is the simultaneous detection of all masses. This allows isotopic ratios and elemental abundances to be measured together, providing a more efficient use of each grain. As sample consumption is much lower during a single analysis it is also possible to depth-profile through grains at high spatial and high depth resolution. Here, we present trace element depth-profiles for 7 SiC grains isolated from the Murchison meteorite by John Arden using the acid-extraction procedure described by Amari *et al.* [9].

Samples: A small aliquot of the separated residue was distributed upon a cleaned, ultra-pure (>99.999%) gold foil. Silicon carbide grains were located using an Environmental Secondary Electron Microscope (ESEM), with energy-dispersive X-ray analysis used to confirm their composition. High resolution images were taken and locations relative to a Cu finder-grid recorded. The sample was then transferred to a TOFSIMS instrument.

TOFSIMS Procedure: Each grain was analyzed by rastering a pulsed Au⁺ primary ion beam over its surface and detecting positive secondary ions. The field-of-view of the resulting secondary ion images was selected to be just larger than the grain. Each image contained 64 x 64 pixels, with each pixel containing a complete mass spectrum. Raw data was collected for offline analysis where only spectra from the region of interest (i.e. the grain) were selected. Data could also

be corrected for instrumental drift over long measurement times (typically several hours). As there is a lack of SiC standards with well known trace element concentrations, abundances within the grains were calculated using relative sensitivity factors determined from homogeneous silicate standards [10].

Depth-profiling was achieved by applying a DC-beam at regular intervals between measurements. By controlling the time the DC-beam sputtered the grain and the size of the area over which it was applied, we could control the depth of material removed. When a significant amount of the grain had been sputtered away, it was re-imaged using the ESEM before being returned to the TOFSIMS and the remaining grain analyzed.

Results: Measured $\delta^{29}\text{Si}$ and $\delta^{30}\text{Si}$ values for six of the grains fall within the range -29 to +160‰, with 1 σ errors ~55‰, and are likely mainstream grains from AGB-stars. Grain Delta-2 has a positive $\delta^{29}\text{Si}$ value and a $\delta^{30}\text{Si}$ value of -160‰.

Figure 1 shows examples of typical trace element depth-profiles in the 7 SiC grains analyzed as part of this study. The grains G0-1, Delta-1, 5-1 (shown in Figure 1), G1-1 and N1-1 have been completely sputtered away, whilst grains M0-1 and Delta-2 have only been partially sputtered. Characteristics of each grain's depth-profile are described below. Grain sizes are given in brackets.

G0-1 (0.5 × 1.1 μm). The Mg, Ti and Cr abundances are higher within the outer layers than in the grain core, producing symmetrical depth-profiles. The decrease in abundance for these elements between the core and outer regions is approximately a factor of 4. In contrast Al abundances are higher in the grain core by around a factor of 6.

Delta-1 (1.4 × 2.0 μm). The Mg/Si ratio is 2.8 near the grain surface but then decreases throughout the grain. This initially high abundance is likely due to surface contamination. Calcium has a symmetrical profile with abundances enriched in the outer regions by around a factor of 3. Lithium, Al and Cr abundances rise, by approximately a factor of 3, to a peak between 150-250nm before decreasing in the grain core. Abundances of the other elements show no peak but also decrease in the grain core.

5-1 (0.6 × 3.9 μm). Trace element profiles for most elements show very little variation with depth except Mg and Cr, which rise, by a factor of 3, to a peak at ~350nm.

G1-1 ($0.4 \times 2.9 \mu\text{m}$). At a depth of $\sim 150\text{nm}$ the Al/Si ratio peaks at 3.8. Similarly, the Li, Mg, Ti and Cr abundances also peak at this depth, with abundances increasing by an order-of-magnitude or greater, relative to the outer layers of the grain.

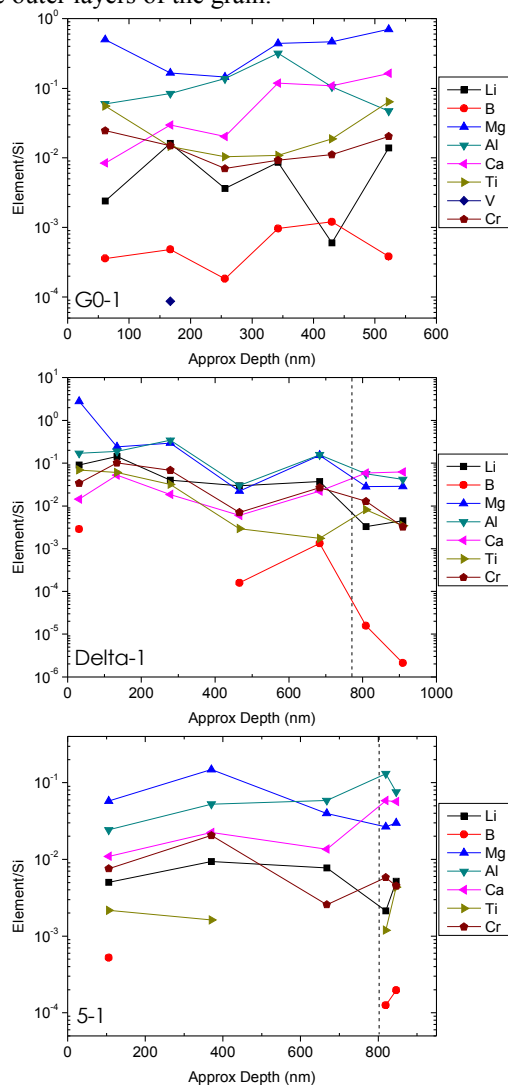


Figure 1. Examples of trace element depth-profiles which show either abundance peaks, are symmetrical, or vary little with depth. Dashed lines indicate the approximate depth at which the grain was removed from the TOF-SIMS and re-imaged.

N1-1 ($1.0 \times 1.8 \mu\text{m}$). Mg is enriched in the outer part of the grain by a factor 2, whilst Li, B and Al abundances are highest in the grain core. Lithium abundances in the core are greater by an order-of-magnitude, and B and Al by a factor of 5.

M0-1 ($0.9 \times 1.4 \mu\text{m}$). The Mg/Si ratio is consistently high at ~ 1 , although this grain has only been partially sputtered. Other elements also show little variation in their abundances except V, which rises by over 2 orders-of-magnitude, to a sharpe peak at $\sim 100\text{nm}$.

Delta-2 ($1.6 \times 2.4 \mu\text{m}$). The Mg, Al and Ti abundances show a steady increase, whilst the Cr abundance decreases while depth-profiling towards the grain core.

Discussion: Lyon *et al.* [6] measured peaks in Li and B abundances within the outer 500nm of some SiC grains and attributed this to implantation by SN-shock-waves. Several elements in the grains G1-1, Delta-1, 5-1 and M0-1 show similar peaks in abundance at depths of 100–350nm, providing further evidence for implanted material in presolar SiC. In the case of G1-1 however, peaks in Li, Mg, Ti and Cr coincide with the Al/Si ratio of 3.8. This exceptionally high Al abundance may in fact result from an AlN sub-grain [4] rather than implantation.

We have previously reported symmetrical trace element depth-profiles, with elevated abundances within the outer part of a grain relative to its core [7], similar to those seen in G0-1, Delta-1 and N1-1. When sputtering through a 3-D grain we are unable to resolve any enriched outer layer from the grain core [8]. This results in higher abundances in the core, as material from the enriched outer layer also contributes to the signal. However, for symmetrical profiles we can use a simple geometrical model to estimate the thickness of the enriched outer layers [7,8]. For grains G0-1, Delta-1 and N1-1 these layers are estimated to be $\sim 100\text{--}200\text{nm}$ thick, consistent with implantation depths.

Increases in Al abundances within the cores of G0-1 and N1-1 might be explained as an effect of the acid extraction process. Aluminium is often present in presolar SiC as AlN, which is not acid resistant. Similar trends have previously been interpreted as the potential loss of AlN from grain surfaces during extraction, leading to Al depletions within the outer layers [11].

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