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Ion Implantation into Presolar Diamonds: Experimental Simulation

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Ion implantation is an important mechanism by which many elements are incorporated into solar system materials such as regolith, meteorites, interplanetary dust etc. Adequate knowledge of this process will allow insight into the formation history of such materials. With the discovery of presolar grains [1] investigations of implantation processes were then extended to the interstellar and circumstellar environments. In particular it was recently shown [2] that noble gases in presolar diamonds have been incorporated by ion implantation at low energy in a number of separate episodes. Implantation leaves a number of characteristic records in presolar diamonds the study of which should ultimately constrain the process itself. Examples of the records include a) chemically non-selectiveness of incorporation, b) grain-size dependence of concentrations, c) thermal release pattern (i. e. in the case of volatile components which can be extracted by heating). The release pattern is the least well understood in these three examples but in principle should contain important information about the diamond irradiation history.

In the present study we used an experimental approach to investigate implantation into presolar diamonds. As an analog material we used ultra-dispersed synthetic diamonds (UDD) formed by detonation from an explosive substance (TNT). The most important property of the diamonds, which makes them the closest analog of the natural presolar ones, is their grain size (in the range of few nm). To implant noble gases we used a modified mass spectrometer which allows us to control certain parameters of the implantation process, for instance we can (i) vary implantation energy in the range from 0.5 to 5 keV, (ii) implant different monoisotopes of the same element, (iii) make a precise record of implantation dose.

A sample of UDD diamond (30-50 micrograms) was loaded onto Al-foil using acetone suspension; the foil was then put into Faraday cup of one of the ion collectors and irradiated with selected ions for different amounts of time (from 10 minutes to 12 hours) depending on the type of ions. Ion beams were created by pure noble gas components introduced to the mass spectrometer through a needle valve regulated so that the pressure in the ion source was in the range from 10^{-7} to 10^{-5} torr. The intensity of the ion beam was recorded during the entire time of irradiation. After irradiation the sample was recovered from the ion collector, removed from the Al-foil, put into Pt-foil and loaded into the extraction system of multicomponent isotope analyser ("Finesse" [3]) for analysis. Since monoisotopic components were implanted it is simple to make a blank correction as the isotope ratio of the implanted species is significantly different from the blank. For instance, when implanting ^{40}Ar the measured ^{40}Ar/^{36}Ar ratios are as high as a few thousand (compared to about 300 in the blank) at amounts measured of about 10^{-8}cc. In the case of ^{36}Ar implantation the measured ^{40}Ar/^{36}Ar ratios are as low as 2-5 at about 10^{-10} cc. Beside Ar, Ne and Kr were also used in the implantation experiments. To release the implanted gases we used a combination of pyrolysis and combustion. The samples were first pyrolysed up to 700 °C and then combusted from 400 °C to 700 ºC, which allowed us to separate the low- and high-temperature releases of implanted species. As well as determining the yield (and isotopic composition) of the implanted component we also measured the amount of carbon released. This allowed detailed release profiles to be expressed in the form of the [amount of implanted species]/[amount of carbon released].

One of the results is that for a single noble gas component implanted at a constant energy, the observed release pattern is bimodal [4] with a low-temperature release below 700 ºC, and a high-temperature one at about 1200 ºC, which is similar to what is observed for presolar diamonds separated from the most primitive meteorites such as CIs and CMs [4,5]. Obviously, having control over the implantation parameters means that we can now vary these to understand the subtle differences observed between diamonds from different meteorites. We have found that the most important of these is the integral radiation dose. In general, the higher the dose the higher the ratio of low/high temperature components. We obtained a good correlation between these two parameters in the range of doses from $6x10^{12}$ to $7x10^{15}$ ions/cm^2. Taking the implantation data we can speculate that the diamonds from Boriskino [6] had a dose of about 10^{15} ions/cm^2 for P3 noble gases. However the release pattern of the implanted species is governed by radiation damage made by the impinging ions. If the damage in the Boriskino diamonds was caused only by implanted noble gases, then we suggest that only a small fraction (~10^{-3}) of the diamonds was actually irradiated and the majority of them are noble gas free. In order to corroborate this suggestion we need to find out whether radiation by species that would be more abundant in the interstellar medium (hydrogen, for example) can cause similar damage in the diamonds.

Apart from these observations, our implantation experiments confirmed our previous conclusion [2,6] that P3 and HL noble gases were implanted in two separate events with the former occurring during residence of the diamonds in molecular clouds.

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