Stardusts in Meteorites –Precursors of Planets–

Hisayoshi Yurimoto

Department of Natural History Sciences, Hokkaido University (HokuDai), Sapporo 060-0810, Japan

Abstract. Presolar circumstellar grains have been surveyed in 18 primitive meteorites. More than hundreds presolar grains have been identified. Presolar silicates are the most abundant species among presolar grains. The typical size is ~300 nm and the abundance is ~50 ppm in the most primitive chondrites. Main source of silicate presolar grains is from AGB and red giant stars. The average O-isotopic composition of presolar silicates is enriched in ^{17}O relative to the solar composition. The counterpart to form solar isotope ratios having ^{17}O-depleted compositions are missing in the chondrites. The missing matter would be supernovae ejecta but it is difficult to identify because the grain size is expected to be ~10 nm.

Keywords: presolar grain, silicate, carbon, meteorites, SIMS, isotopes
PACS: 96.30.Za, 32.10.Bi, 68.49.Sf, 82.80.Ms, 91.65.Dt, 97.10.-q, 81.05.Uw

INTRODUCTION

Meteorites are basically classified into primitive and differentiated ones. The primitive meteorites are named chondrites. Among the chondrites, petrographic type 3 chondrites, which are characterized as the matrix is less altered and less metamorphosed, are often named primitive chondrites.

The primitive chondrites are mainly composed by mechanical aggregates of dusts existed in the protoplanetary disk around the proto-sun. If the most parts of the disk have maintained in low temperature below evaporation temperatures of rocky dusts, most dusts in the matrix corresponds to circumstellar dusts that mean presolar grains. Isotope ratios of circumstellar dusts would be distinctive each other because isotope ratios of star are diverse among the stellar types. However, chondrite matrices have homogeneous isotope ratios within % order variations down to micrometer scale [1].

Recently it is discovered that circumstellar silicates have survived in matrices of primitive carbonaceous chondrites [2, 3]. The circumstellar silicates are characterized by clearly distinct isotope ratios of oxygen having more than % order variations from the solar composition. Because of the very small grain size of hundreds nanometers and small abundances of tens ppm, existence of the circum stellar silicates is consistent with the isotopically homogeneous feature of the matrix in micrometer scale.

Here we report that circumstellar silicates have been ubiquitous in various chemical groups of chondrites.

EXPERIMENTAL

A HokuDai isotope microscope system (Cameca ims-1270 + SCAPS; originally installed in Tokyo Institute of Technology and now in Hokkaido Univ. (HokuDai)) [4] has been used for in-situ survey of presolar grains. We obtained secondary ion images of $^{12}C^-$, $^{13}C^-$, $^{12}C^-$, $^{27}Al^-$, $^{28}Si^-$, $^{16}O^-$, $^{18}O^-$, $^{16}O^-$, $^{17}O^-$, and $^{16}O^-$ for one analytical sequence. We used a 50 μm contrast aperture (CA) except for C isotopes. A 150 μm CA was used for C isotopes. Beam irradiation time for the sequence was ~1 hour. The primary beam intensity was adjusted to ~0.3 nA. The sputtering depth was less than 100 nm for the sequence. An image processing method of moving average with 3 x 3 pixels was applied to reduce the statistical error of an isotope image (isotopograph). The other analytical methods for the isotopography were same as those in [3]. The selection criterion for distinguishing presolar grain is that one of their isotopic ratio is >2σ away from the 3σ ellipse of the distribution of isotopically normal matrix.

Thin sections of primitive chondrites were prepared for the in situ survey. The mineralogical and petrographical characterization of matrices was conducted using a scanning electron microscope (JEOL JSM-5310LV or JEOL JSM-7000F) equipped with energy dispersive X-ray spectrometer (Oxford LINK ISIS or Oxford INCA). This characterization was operated before and after in situ survey of circumstellar materials.

RESULTS AND DISCUSSION

Survey of presolar circumstellar grains has been performed for 13 carbonaceous chondrites (Murchison CM2, Targish Lake C2, LEW 85332 C3ung, MAC 87300 C3ung, Acfer 094 C3ung, Adelaide C3ung, ALHA 77307 CO3.0, Y-81025 CO3.0, Vigarano CV3, NWA 530 CR2, SAH 00182 CR3, Acfer 214 CH3 and HaH 237 CB), and 5 ordinary chondrites (Semarcona LL3.0, Krymka LL3.1, Bishunpur LL3.1, JaH 026 and Dhofer 008 H/L3.2/3.3). The total survey area is ~1 mm^2, corresponding to ~7000 sets of isotope ratio images), of matrices in these primitive meteorites. We found 60 carbonaceous-, 77 silicate- and 2 oxide- presolar circumstellar grains from the survey areas. Electron microscope images of presolar circumstellar grains are shown in Fig. 2. Relatively larger grains are selected for the figures in order to show clear shape images. Grain size distributions of presolar silicates are shown in Fig. 3. Presolar silicates are smaller than 1 μm and typically ~300 nanometers. Size limit of smaller side of the distribution is ended at 100 nm. The small size limit may be due to spatial resolution limit of the measurements. The maximum abundance for presolar silicates is observed in Adelaide and in Y-81025 for ~50 ppm, and for carbonaceous grains is in Murchison for ~10 ppm.

Most presolar silicate grains from the primitive chondrites are enriched in ^{17}O relative to the solar composition, categorizing into group 1 of presolar oxide grain defined by [10] (Fig. 3). Some grains are depleted in ^{17}O and ^{18}O categorizing into group 3. Minor grains are enriched in ^{18}O and are categorized into group 4. The characteristics for the most presolar silicate grains enriched in ^{17}O would be an origin of O-rich red giant or AGB stars. Grains highly enriched in ^{18}O and depleted in ^{17}O and ^{18}O, suggesting an origin of metal-rich stars or super novae and of metal-poor red giant or AGB stars, respectively [10]. Therefore, O-rich red giant and AGB stars are the main source for presolar silicates found in meteorites. This conclusion from the isotope ratios is supported by the size distribution of the circumstellar silicates which size is estimated theoretically to be ~200 nm [11].

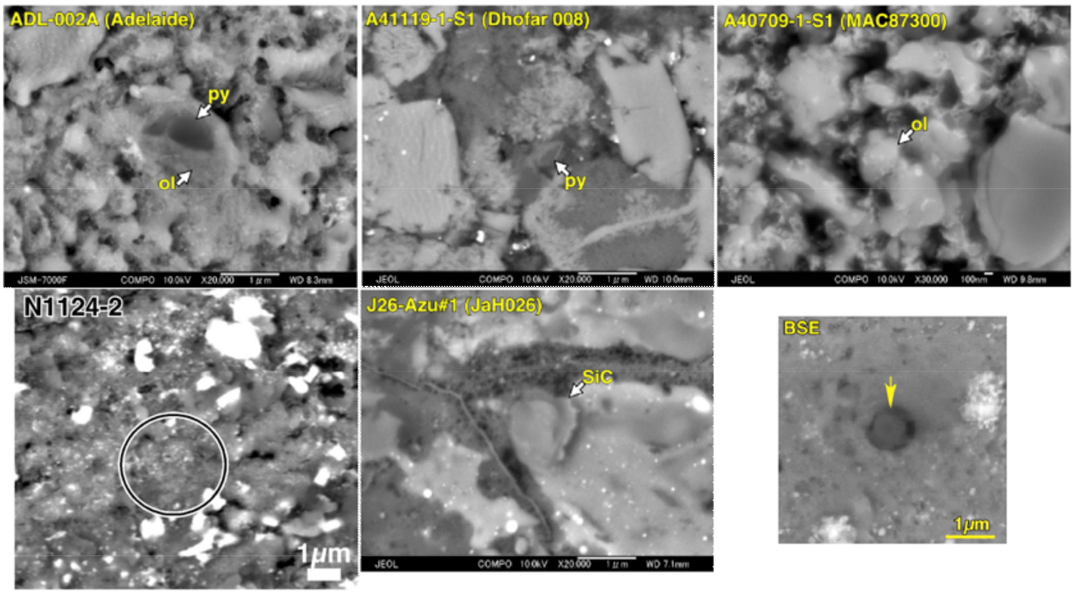

FIGURE 1. Back-scatter electron images of presolar circum stellar grains. (Top left) $MgSiO_3$ pyroxene from Adelaide. Scale bar: 1 μm. (Top center) $MgSiO_3$ pyroxene from Dhofer 008. Scale bar: 1 μm. (Top right) Mg_2SiO_4 olivine from MAC 87300. Scale bar: 100 nm. (Bottom left) Amorphous silicate from NWA 530. Scale bar: 1 μm. (Bottom center) SiC from JaH 026. Scale bar: 1 μm. (Bottom right) Graphite from NWA 530. Scale bar: 1 μm.

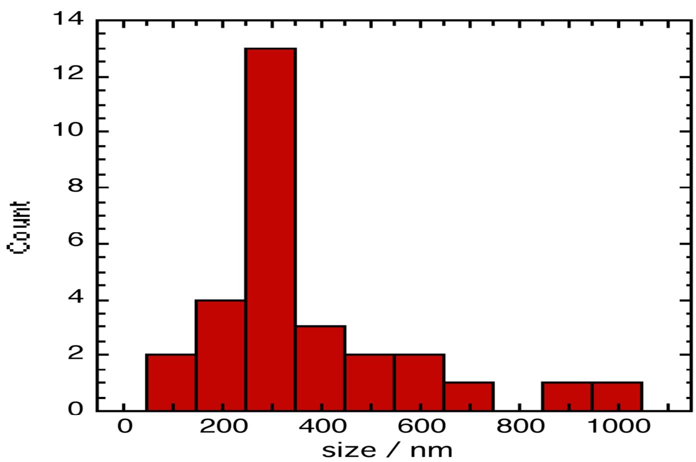

FIGURE 2. Size distribution of presolar circumstellar silicates. Data from [2, 3, 5, 6, 7, 8, 9] and this study.

Figure 3 shows that average O-isotopic composition of presolar circumstellar grains is clearly apart from the solar composition. This is a serious puzzle because all oxygen atoms composed of solar system were synthesized in stars. The circumstellar grains in meteorites are not an appropriate representative for interstellar oxygen. Supernova ejecta are a possible candidate for the missing counterpart because average O isotopic composition of supernovae is expected to be depleted in ^{18}O. Therefore, the contribution of supernovae for solar system oxygen should be comparable to those of red giant and AGB stars. However, silicate grain size formed in supernova ejecta is theoretically estimated to be ~7 nm [12]. Therefore, an isotope nanoscope with real nano-scale spatial resolution power should be necessary to detect presolar grains formed in supernova ejecta and discuss the contribution to the solar system formation quantitatively.

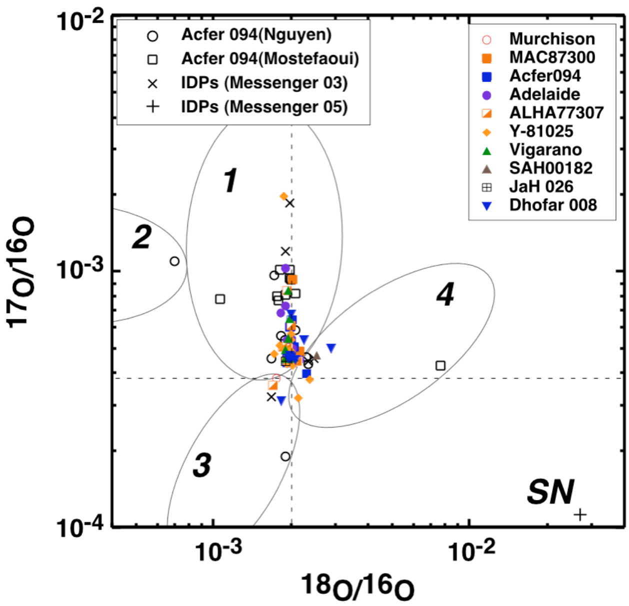

FIGURE 3. Oxygen isotopic compositions of presolar silicates in primitive chondrites. Dashed lines correspond to the solar isotopic compositions. Data from [2, 7, 9] and this study.

ACKNOWLEDGMENTS

I thank K. Nagashima, S. Kobayashi, N. Sakamoto, A. Tonotani for their collaboration. I also thank A. N. Krot and S. S. Russell for providing meteorite samples. This work supported by Monka-sho grants.

REFERENCES

1. T. Kunihiro, K. Nagashima and H. Yurimoto, *Geochim. Cosmochim. Acta* **69**, 763-773 (2005).
2. A. N. Nguyen and E. Zinner, *Science* **303**, 1496-1499 (2004).
3. K. Nagashima, A. N. Krot and H. Yurimoto, *Nature* **428**, 921-924 (2004).
4. H. Yurimoto, K. Nagashima and T. Kunihiro *Appl. Surf. Sci.* **203-204**, 793-797 (2003).
5. S. Mostefaoui, P. Hoppe, K. K. Marhas and E. Groner, *Meteorit. Planet. Sci.* **38**(Supplement), A99 (2003).
6. S. Mostefaoui, K. K. Marhas and P. Hoppe, *Lunar and Planetary Science* **XXXV**, #1593 (2004).
7. S. Messenger, L. P. Keller, F. J. Stadermann, R. M. Walker and E. Zinner, *Science* **300**, 105-108 (2003).
8. S. Messenger, L. P. Keller, *Meteorit. Planet. Sci.* **39**(Supplement), A68 (2004).
9. C. Floss and F. J. Stadermann, *Lunar and Planetary Science* **XXXV**, #1281 (2004).
10. L. R. Nittler, *Earth Planet. Sci. Lett.* **209**, 259-273 (2003).

11. H.-P. Gail and E. Sedlmayr, *Astron. Astrophys.* **347**, 594–616 (1999).
12. T. Kozasa, H. Hasegawa and K. Nomoto, *Astron. Astrophys.* **249**, 474-482.