Three-dimensional microstructure of a presolar silicate in the Acfer 094 carbonaceous chondrite

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Introduction

Cometary dusts and primitive meteorites often contain presolar grains, which show unusual stable isotope ratios. Most of the grains are thought to have been formed by condensation from gasses in circumsteller regions of evolved stars and incorporated into the Solar System [e.g., 1]. However, the detailed processes of the grain formation in circumstellar environments are still poorly understood. For further understanding, it is neccesarry to investigate individual presolar grains intensively.

Previous observations on presolar grains have been mainly performed using a scanning electron microscope (SEM) [e.g., 2]. On the other hand, a transmission electron microscope (TEM) has been rarely used for the studies though it is suitable for observations of small presolar grains (usually under one micrometer). Therefore, there is a lot of presolar grains whose crystal phase and microstructure remain unknown, particularly in the case of silicate grains [e.g., 3]. In this study, we performed selected area electron diffraction (SAED) and STEM-EDS (energy dispersive spectrometer) tomography on a presolar silicate in the Acfer 094 carbonaceous chondrite to investigate its microstructure and formation process.

Sample & Methods

The presolar silicate was discovered by oxygen isotope imaging using NanoSIMS in an ultra-thin section extracted from an Acfer 094 section by a focused ion beam (FIB) system. After the NanoSIMS analysis, we obtained SAED patterns and high spatial resolution (~ a few nanometer) three-dimensional (3D) elemental maps of the presolar silicate using a scanning TEM (STEM) equipped with an EDS. The 3D elemental maps were reconstructed from two-dimensional (2D) STEM-EDS elemental maps taken at every 4-degree tilt (total 37 sets) by using an iterative reconstraction technique.

Results & Discussion

The presolar silicate is located in the matrix consisting mainly of amorphous silicates which escaped from significant alteration (Fig. 1). The size of the grain is as small as ~100 nm (Fig. 1). The δ^{17}O value of the presolar grain (1458.4±232.0 (1σ) ‰) is significantly different from those of the surrounding matrix materials (5.7±6.5 (1σ) ‰), on the other hand, the δ^{18}O value (57.4±57.2 (1σ) ‰) coincides with those of the surrounding matrix materials (32.5±5.1 (1σ) ‰) within the error range of 1σ. The high δ^{17}O value of the presolar silicate suggests that it was originated from a red giant star or a star in the asymptotic giant branch (i.e. classified into Group-1 [e.g., 4]).

From the SAED patterns and the chemical composition, the presolar silicate was identified as Al-rich diopside. A few Ca-Al-rich presolar silicates have been reported from the Acfer 094 meteorite but their crystal phases were not identified [e.g., 3]. We obtained the 3D morphology of the presolar Al-rich diopside by STEM-EDS tomography. The CT images of the presolar Al-rich diopside shows a hexagonal-platy shape normal to the *c*-axis and surrounded by {010}, {110}, and {-210} planes (Fig. 2). In addition, the 3D elemental maps revealed that the presolar Al-rich diopside contains a few nanometer-sized inclusion of Fe-rich material (Fe-metal or Fe-oxide). Such a nano-inclusion has not been recognized in the previously reported presolar grains. The 3D elemental maps ensure that the Fe-rich grain is not be attached on the surface of the Al-rich diopside but is embedded inside the Al-rich diopside. The presence of the Fe-rich inclusion strongly suggests that a nano-grain of Fe-metal or Fe-oxide nucleated first and then Al-rich diopside was grown by heterogeneous nucleation on the Fe-rich nano-grain in a circumstellar environment. The condensation of Fe-metal or Fe-oxide in a circumstellar environment is important for understanding the existence form of Fe phase in the circumstellar and interstellar regions, which is not well understood by astronomical observation.

Our study shows that 3D microstructures of presolar grains have important information for understanding not only their formation processes but also additional phases condensed. Further STEM-EDS tomography study on presolar grains will lead to unravel grain formation in circumstellar environments.

References

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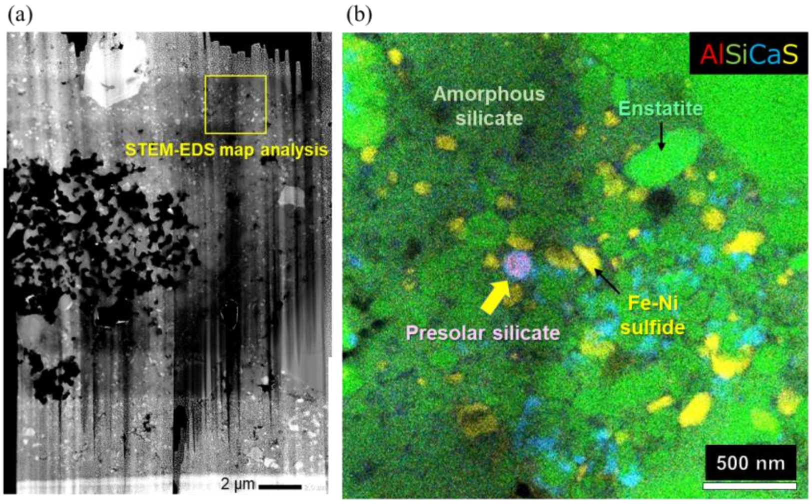

Fig. 1. (a) ADF-STEM image of the ultra-thin section after nanoSIMS. (b) STEM-EDS elemental map of the rectangle area in (a). The presolar silicate is indicated by a yellow arrow.