Synthesis of GEMS analogue particles by condensation experiments in the system Mg-Fe-Si-S-Al-Ca-Ni-O

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GEMS (Glass with Embedded Metal and Sulfide) are main component in interplanetary dust particles with cometary origin (CP-IDPs) (Keller and Messenger, 2011). GEMS is regarded as one of the most primitive material in solar system, and thus it is important to elucidate its formation conditions and process to understand the origin of solar system. The origin of GEMS is still under debate, and several theories are proposed; formation by irradiation in interstellar region (Bradley and Dai, 2004) and condensation from gas in circumstellar regions around late-type stars or in the solar nebula (Keller and Messenger, 2011). Condensation experiments which simulate condensation process of interstellar gas have been conducted in the previous studies, and fine particles similar to GEMS have been formed (Matsuno, 2015; Kim et al., 2017; Kawano, 2019). Particularly, Kawano (2019) carried out experiments with major elements in the system Mg-Fe-Si-S-O, and showed systematical change of run product by changing redox condition. In this study, we conducted new condensation experiments in the system Mg-Fe-Si-S-Al-Ca-Ni-O, which is closer to the natural system, by adding Al, Ca, and Ni for further understanding of GEMS formation.

The experiments were performed using induction thermal plasma (ITP) system (Kyoto univ., TP-40020NPS, JEOL). As the starting materials, powders of chemical regents were mixed to make GEMS average compositions (Keller and Messenger, 2011). Three kinds of sample were made with different Si/SiO_2 ratios to change redox condition. Powder X-ray diffraction (XRD), scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FT-IR), and transmission electron microscope (TEM) were used for analysis.

In XRD, halo patterns due to amorphous silicates were observed. In addition, and the peaks of different crystalline phases were observed depending on the redox conditions. Absorption due to amorphous silicate was also observed in the IR spectrum. Based on the SEM observation, the run products were divided into two types, condensates composed of fine particles (about 10-100 nm) and coarse grained evaporation residues (>1 μm). For this reason, the condensates were analyzed in detail with TEM/STEM-EDS.

Under all experimental conditions, condensates were composed by aggregates of spherical amorphous silicates particles about 10-100 nm in daiameter, which contain nanoparticles of Fe and Ni <~10 nm in size. These texturtes are similar to those of Kawano (2019) and roughly resemble natural GEMS. However, the chemical compositions of amorphous silicates and nanoparticle inclusion phases varied according to the redox conditions. In oxidizing condition, amorphous silicates were relatively Fe-rich, and (Fe, Ni) metal and Ni-rich Fe,Ni sulfide formed as nanoinclusions. In reducing condition, in contrast, amorphous silicates are poor in Fe, and Fe_3Si and FeS including minor amounts of Ni formed. Al and Ca did not form any independent phases but were homogeneously distributerd in the amorphous silicates.

Natural GEMS consists of Fe-poor amorphous silicates with Fe,Ni metal and sulfide nanoinclusions. In this experiments, any product which has exactly the same texture and mineral assembladge as GEMS was not obtained. It is expected that natural GEMS formed in an evironment between the oxidizing and reducing conditions in the present experiments.

Keywords: GEMS, condensation experiment, system Mg-Fe-Si-S-Al-Ca-Ni-O