

PPS025-14

Room:101

Time:May 23 17:45-18:00

Heating experiments on the reductive condition of amorphous silicates with the mean composition of GEMS

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GEMS (glass with embedded metal and sulfides) are spherical objects of < 500 nm in diameter and characteristically included in anhydrous IDPs (Interplanetary Dust Particles), which are considered to be of the cometary origin. They have nanometer-sized (10-50 nm) Fe-Ni metals and sulfides embedded in the matrices of amorphous silicate. In spite of several propositions for the origin of GEMS [e.g. 1, 2], non of them were widely accepted. Infrared astronomical observations strongly suggest that interstellar silicates are almost amorphous [3]. If the amorphous interstellar silicates were brought into the early solar nebula and heated, the reduction of the silicates might occur. It is proposed that metallic Fe in GEMS are reduction products of FeO-bearing amorphous silicates with carbonaceous materials based on reduction experiments of thin amorphous olivine foils in a reducing atmosphere [4]. However, detailed discussion of metal formation process in the glass was not made. In this experiment, in order to study possible GEMS origin by reduction of interstellar silicates, we synthesized amorphous silicates with the mean composition of GEMS and performed heating experiments under reducing atmosphere.

The amorphous silicates as the starting material of the reduction experiments were prepared by quenching the melt of the mean composition of GEMS in a simple MgO-FeO-SiO₂ system (MgO = 28 wt.%, FeO = 22 wt.%, and SiO₂ = 50 wt.%). The quenched glass was cut and shaped for cubes of about 2 mm on a side. The starting materials were heated at 923 K and 973 K for 3 hours, and at 1023 K for 1-48 hours at one-atmosphere in a gas mixing furnace using a H₂-CO₂ gas mixture. The oxygen fugacity in this reduction experiment was -1.5 log unit above the IQF (Iron-Quartz-Fayalite) buffer ($f_{O_2} \sim 10^{-23}$ atm).

The X-ray diffraction (XRD) analysis shows that clino-pyroxene was crystallized in the heated samples. Many cracks (typically ~10μm in length and ~1μm in width) were observed both on the surfaces and cross sections, and metallic Fe grains of a few microns in size were recognized nearby clacks under a field emission-scanning electron microscope (FE-SEM) observations. Metal grains present in the cracks have euhedral shapes. Magnetite or maghemite grains of 50-100 nm in size were also observed inside of the sample under FE-SEM and a transmission electron microscope (TEM). For the TEM observation an ultra-thin sections was made by focused ion beam (FIB).

These results suggests that cracks were formed by volume change of the pyroxene crystallization and metallic Fe grains were formed on the surface or along the cracks by reaction with the reducing gas. The crystallization of the metallic grains and the magnetite or maghemite nano-particles shows that reduction did not occur inside of the glass but only near the glass-gas interface.

If metallic iron grains were formed by the reduction of FeO-bearing amorphous silicates for GEMS, metallic nano-grains can be formed only around the interface. In contrast, TEM observation for natural GEMS shows that metal grains are uniformly embedded in amorphous silicates. So, the present study suggests that metal grains in GEMS is not reduction products.

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Keywords: amorphous silicate, GEMS, reduction experiment