Condensation experiments in the sytem Fe-Mg-Si-O-S using induction thermal plasma: implication to GEMS forming condition

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GEMS (Glass embedded metal and sulfides) are the major component of CP-IDPs, which are thought to be one of the most primitive materials in the solar system [1]. Synthetic experiments based on the condensation model [1] are performed to form GEMS analogue particles [2, 3], but systematic experiments including sulfur are not performed so far. In this study, synthetic experiments are performed in the system Fe-Mg-Si-O-S, with systematic change in redox condition, to understand the GEMS forming condition.

Induction thermal plasma (ITP) system was used for the condensation experiment. This system creates high temperature plasma (up to 10^4 K) which evaporates the starting material, and forms condensates in the rapid cooling environments. Plasma gas is Ar and He, with chamber pressure 70 kPa. Starting material are mixture of powder regents (SiO_2, Si, MgO, Fe, FeS_2) with GEMS mean composition [1]. Redox condition change by SiO_2/Si ratio and feeding rate (fd) of the starting material. 10 experiments are performed in total. Products were analyzed by X-ray diffraction, scanning electron microscope and transmission electron microscope.

Products were composed of fine grained condensates and coarse grained evaporation residues (1-100 μm). All condensates were formed of amorphous silicate (AS) spheres, 10-100 nm in diameter. They coexist with Fe bearing particles (<30 nm), inside and on the surface of the AS. Condensates were categorized into the following five types.

A: Fe-rich AS, including Fe metal particles

B: Fe-rich AS, with FeS particles on the surface

C: Fe-rich AS showing biphasic separation texture, with FeS particles on the surface

D: Fe-poor AS showing biphasic separation texture, with Fe particles coexisting with FeS on the surface

E: Fe-poor AS showing biphasic separation texture, with Fe_3Si (gupeiite) particle coexisting with MgS (niningerite) or FeS particles on the surface

Type A, B and C were observed in the oxidative experiment, type A and D in the intermediate experiment and type E in reductive experiment.

Formation process was considered, taking into account the grain formation process model [4]. As a basic process, AS condensates first, followed by Fe particles and finally formation of sulfides. In oxidative condition, some Fe are taken into AS as FeO (type A, B), and for the lack of Fe in gas, Fe particles did not condensate or minor condensates sulfidated into FeS (Type B, C). If there was abundant Fe in gas, Fe particles condensates on the surface of AS at relatively high temperature above glass transition temperature, and moves inside the melt before sulfidation due to surface energy (type A). In reductive condition, Fe is scarcely included in AS (type D, E). In type D, Fe metal particles condensates on the surface of the AS glass and partially sulfidized. Type E is the most reductive condition, Fe_3Si occurring instead of Fe metal, with MgS and FeS.

In this study, synthesized condensates had some of the features of GEMS, but condensates completely similar to GEMS (Fe-poor AS including many Fe metal particles, with FeS on the surface) was not observed. Considering the formation model in the study, GEMS is thought to be formed in the redox condition similar to type C-D. In their formation, Fe particles condensates at relatively high temperature on the surface of AS and moves inside the melt (like type A), and condensation of Fe particles continues at the surface of the AS below glass transition temperature, which is followed by sulfidation.

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