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Crystallization experiments on amorphous silicate with the mean composition of GEMS

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GEMS (glass with embedded metal and sulfide) are spherical objects of <500 nm in diameter and characteristic constituents of anhydrous chondritic interplanetary dust particles (IDPs), which are believed to have cometary origin. They are composed of nanometer-sized (10-50 nm) Fe-Ni metal and Fe-Ni sulfide grains embedded in silicate glass. Two origins for GEMS are proposed; interstellar dust incorporated into the protoplanetary disk in the early solar system or high-temperature vapor phase condensates in the disk. Irrespective of these origins, GEMS should be one of the most primitive materials in the solar system as they occur in dust with cometary origin. If GEMS moved into an inner region of the disk, amorphous silicates in GEMS should be crystallized by heating. Therefore, GEMS might be a precursor material for crystalline silicates that are observed by IR spectroscopy in circumstellar regions of young stars.

In order to examine crystallization behavior of GEMS by heating, we have carried out crystallization experiments of a GEMS analog. We synthesized amorphous silicate in the MgO-FeO-SiO_2system with the mean composition of amorphous silicate portions in GEMS (SiO_2= 66.0 wt.%, MgO = 29.3 wt.%, FeO = 4.71 wt.%) by sol-gel method. This composition was obtained by removing the Fe contents of metals and sulfides from the mean composition of GEMS. The starting amorphous materials were heated at 700-840°C in a one-atmosphere gas-mixing furnace for 1-24 hours. To prevent oxidation of Fe^{2+}, the oxygen partial pressure in the furnace was controlled on the IW buffer by flowing H_2-CO_2gas mixture. The starting material and run products were analyzed with XRD. The samples heated above 760°C were crystallized and olivine (forsterite) and pyroxene (clino-enstatite) were recognized. A small amount of olivine crystallized first and followed by a large amount of pyroxene.

The result that crystallization occurred around 1000 K indicates that GEMS were not heated above approximately 1000 K in general. This is consistent with previous experimental study, where GEMS in IDPs crystallized around 700°C [1]. In contrast, GEMS rarely contain tiny forsterite grains [2]. This indicates that some GEMS were heated around 1000 K and the forsterite grains crystallized from amorphous silicate. This is also consistent with the present result that a small amount of olivine crystallizes prior to pyroxene.

Infrared astronomical observation of circumstellar environments around young stars found crystalline silicates, both olivine and pyroxene. Previous crystallization experiments on amorphous silicates with the CI composition ((Mg+Fe)/Si = 1.97) and a composition obtained by removing the Fe content of FeS from the CI composition ((Mg+Fe)/Si = 1.46) produced olivine [3, 4]. Amorphous silicates with a composition obtained by removing all Fe from the CI composition (Mg/Si = 1.06) and pyroxene composition ((Mg+Fe)/Si = 1) produced mainly olivine or pyroxene [5,6]. In this study, we used the mean composition of amorphous silicate in GEMS ((Mg+Fe)/Si = 0.72), and pyroxene crystallized mainly from this SiO_2-rich composition. This result indicates that pyroxene crystals observed in the circumstellar environments were crystallized from SiO_2-rich

amorphous silicates as the composition in this study.

[1] Brownlee et al., 2005, Lunar Planet Sci., 36, 2391, [2] Bradley et al., 1999, Science, 285, 1716, [3] Murata et al., 2007, ApJ., 668, 285, [4] Murata et al., 2009a, ApJ., 696, 1612, [5] S. Simon, private communication, [6] Murata et al., 2009b, ApJ., 697, 836,