STRUCTURE AND CRYSTALLIZATION OF AMORPHOUS ENSTATITE SYNTHESIZED BY INDUCED THERMAL PLASMA AND SOL-GEL METHOD

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Introduction: Infrared spectroscopic observations of astronomical environments show that silicate dust is almost amorphous in the interstellar medium, while both crystalline and amorphous silicate dust are present in protoplanetary disks [1, 2]. This indicates that amorphous silicate dust, a precursor of dust in protoplanetary disks, transforms into crystalline dust due to thermal processes in protoplanetary disks. Amorphous silicate dust is mainly formed by non-equilibrium condensation from oxygen-rich gas in the winds of evolved stars and by destruction of crystalline dust in the interstellar medium [3, 4]. The structural property of amorphous silicate could vary with its formation process, and could affect its thermal evolution in protoplanetary disks. In this study, we investigate the structures and crystallization behaviors of amorphous enstatite synthesized by induced thermal plasma (ITP) and sol-gel methods to study the effect of amorphous structure on thermal evolution on amorphous enstatite dust in protoplanetary disks.

Experiments: Amorphous enstatite was synthesized by a sol-gel method following the procedure of [5] to compare the structure and crystallization behavior with ITP-synthesized amorphous enstatite [6]. Solid state ^{29}Si-NMR (JEOL RESONANCE ECA600II) and Raman spectroscopy (Acton SP-2750) were applied to investigate the amorphous structure, and TG-DTA (Thermo plus EVO TG 8120) was used to estimate the amount of water in the sol-gel amorphous enstatite. Crystallization experiments of amorphous enstatite were conducted at 780, 800 and 850°C in air and at P_{H2O}~10^{-4} Pa using a muffle furnace (Thermolyne FB1314M) and a gold-image vacuum furnace (Thermo-Riko GFA430VN), respectively. Starting materials and the heated samples were examined with FE-SEM (JEOL JSM-7000F), XRD (Rigaku SmartLab), and FT-IR (JASCO FT-IR).

Results and Discussion: The XRD profile showed that ITP amorphous enstatite has a typical halo of amorphous silicate at 2θ of 26°, while the sol-gel amorphous enstatite has broad peaks at 2θ of ~23, 35 and 60°, suggesting its close relation to magnesium silicate hydrate [7]. The TG curve of sol-gel amorphous showed a 10.6 wt% weight loss at 50−800°C most likely due to dehydration. The sol-gel amorphous enstatite in this study is hydrated and has a structure similar to magnesium silicate hydrate. The solid state ^{29}Si-NMR and Raman spectroscopy showed that the sol-gel amorphous enstatite has a larger number of bridging oxygen than the ITP amorphous enstatite, suggesting that the sol-gel amorphous enstatite has a more polymerized network structure of SiO_4 tetrahedra and could be chemically heterogeneous with SiO_2-rich and SiO_2-poor regions.

The XRD spectra of the heated samples showed that the sol-gel amorphous enstatite transforms into forsterite at 500−600°C and into enstatite and forsterite at ~800°C, while ITP amorphous enstatite transforms into enstatite with a small amount of forsterite in the entire temperature range. The 10-μm infrared feature of the heated sol-gel amorphous enstatite has a shoulder at 8 μm as SiO_2 glass, and its 20-μm infrared feature is similar to that of SiO_2 glass. This suggests that the sol-gel amorphous enstatite crystallizes into primarily forsterite leaving silica-rich amorphous.

The time evolution of infrared spectra of samples heated at 780°C and P_{H2O}~10^{-4} Pa showed that crystallization of the sol-gel amorphous enstatite occurred faster than the ITP amorphous enstatite. This could be because the sol-gel amorphous enstatite crystallizes into forsterite, which has a lower energetic barrier for crystallization [8], within the SiO_2-poor region. Alternatively, crystallization of forsterite may be enhanced by the presence of OH in the amorphous structure [9]. The crystallization experiments of dry amorphous enstatite synthesized by the sol-gel method [10] also showed that the amorphous enstatite crystallizes into forsterite at temperatures below the glass transition temperature, which indicates that the structure of amorphous enstatite affect its crystallization behavior.

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