Dust formation around evolved stars: Condensation experiments in the Al-Si-O system

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Mid-infrared spectroscopic observations of dust shells around oxygen-rich asymptotic giant branch (AGB) stars indicated that materials emitting a broad peak at 11-12 μm as well as amorphous silicate dust is abundantly present around many of these stars [1]. Amorphous aluminum oxide dust is thought to be the carrier of that emission [e.g., 2]. However, amorphous alumina used to fit the observations was synthesized by a sol-gel method [3]. It is not obvious whether amorphous aluminum oxide condenses around these stars because of the very high glass transition temperature of aluminum oxide. Dust grains emitting 11-12 μm peak should include Al-O bonds in their structures but possible compositions of amorphous materials other than pure aluminum oxide have not been examined. Silicon is about ten times more abundant than aluminum and one of the possible elements included in the amorphous dust.

In this study, we carried out condensation experiments of Al-Si-O gases using the induction thermal plasma (ITP) system (JEOL TP-40020NPS; [4]). Aluminum and silicon powders with various mixing ratios (only Al, Al/Si = 9, 3, 1, 0.08, and only Si) were used as starting materials. They were evaporated at high temperature in Ar-O_2 plasma flames (~10000 K) and rapidly cooled (10^4~10^5 K/s) [4]. The condensed particles were analyzed with X-ray diffraction (XRD, SmartLab, Rigaku) and Fourier Transform Infrared Spectroscopy (FT-IR, MFT-680, JASCO), and observed with transmission electron microscope (TEM, JEM-2100F, JEOL).

The condensate from evaporated aluminum powders without silicon was δ-alumina, which is consistent with Ishizuka et al. (2016) [5]. Particles with structures similar to γ-alumina were observed in condensates from starting materials of Al/Si=9 and 3. A small amount of mullite was observed in those of Al/Si=3 and 1. Amorphous particles were observed in samples with Al/Si<3 and no crystals was observed in condensates from samples with Al/Si<1.

The FT-IR spectrum δ-alumina shows multiple peaks on a broad feature at 11-14 μm, which is not observed in circumstellar dust emissions. More rapid cooling is required to form amorphous alumina from gas, but it is unlikely to occur around AGB stars. Those of condensates from starting materials of Al/Si = 9 and 3 shows broad features similar to amorphous alumina but their peak positions are ~0.5μm longer than that of amorphous alumina. The condensates with Al/Si<3 show stronger peaks at ~9 μm due to Si-O vibrations than those at 11-14 μm due to Al-O vibrations.

These results suggest that doped Si in Al_2O_3 causes disordering between vacancies and Al in tetrahedral and octahedral sites to form structures similar to g-alumina, which explains the absence of sharp peaks on the broad feature, In order to reproduce the relative intensities of peaks at 10 and 11-12 μm in observed spectra, the dust should contain much more Al than the solar composition. Small amounts of doped elements in addition to Si such as Mg, Fe, and Ca in Al_2O_3 may be required to reproduce the peak position and intensity of observed dust emission around oxygen-rich AGB stars.

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