Exploring the Effects of Chemical Composition and Metallic Iron on Amorphous Silicate Dust Spectra

Hanako Enomoto[1], Aki Takigawa[1], Hiroki Chihara[2], and Chiyoe Koike[2]

[1] *The University of Tokyo, Japan,* [2] *Osaka Sangyo University, Japan*

Amorphous silicate is the dominant form of refractory dust in interstellar and circumstellar environments (Kemper et al. 2004, 2005). Asymptotic giant branch (AGB) stars are the main amorphous silicate dust suppliers, and their infrared spectra show different amorphous silicate features from star to star. However, identifying dust properties from observed spectra is challenging due to the difficulty in distinguishing the spectral change due to chemical composition, size, shape, and temperature. Numerous dust analogs have been synthesized (e.g., Dorschner et al. 1995; Rietmeijer et al. 1986; Mutschke et al. 1998), but it remains unclear which factors (chemical composition, mixtures of different dust components, or physical parameters) are responsible for the observed spectral diversity. Especially, presence and form of iron — whether as metallic inclusions, separate grains, or oxides — remain poorly constrained. Although there are theoretical studies assuming amorphous silicate dust with metallic iron particles (Draine & Lee 1984; Ossenkopf et al. 1992; Speck et al. 2015), laboratory experiments have focused mainly on pure amorphous silicates, and amorphous silicate dust containing metallic iron has not been studied spectroscopically. In this study, we experimentally investigated the effects of metallic iron inclusions and chemical composition on the mid-infrared spectra of amorphous silicate dust.

Condensation experiments in the system including Na, Al, Ca, Mg, Fe, Ni, Si, and O were carried out using the induction thermal plasma (ITP) system (JEOL TP-40020NPS, Kim et al. 2021) and produced dust analogs with Fe, Ni-free CI chondritic composition, metallic Fe, Ni-containing CI chondritic composition, systematically changing Al/Si, Ca/Mg ratios from the CI chondritic composition. The products were analyzed by XRD (Rigaku RINT-2100), EPMA (JEOL JXA-8530F), and TEM (JEOL JEM-2800). In addition to infrared transmittance measurements (JASCO FT/IR-4200), reflectance spectra of the condensates were measured (Thermo NICOLET6700) using pressed pellets of the particles with and without Au coating. We determined the optical constants of products from transmittance and reflectance spectra, assuming the Lorentz oscillator model. We also try to calculate multi component dust spectra using the program DUSTY (Ivezic & Elitzur 1995; Nenkova et al. 2000).

The products were amorphous silicate nanoparticles ($\phi 10-200\,\mathrm{nm}$). In the system with Fe-Ni, silicate grains contained kamacite ($Fe_{0.9}Ni_{0.1}$) particles. The size proportion of metallic cores ranged from 0 to 0.87, and the average was 0.50. Despite a high Fe abundance (Fe/Si$\sim$0.83), close to the Solar value (Fe/Si$\sim$0.85),the spectral peak positions of samples with Fe cores showed no significant shift compared to those without. This suggests that the infrared spectra are primarily governed by the size distribution and number density of metallic cores. If metallic iron condenses into relatively large cores but most grains contain only small inclusions, the cores may remain undetectable in MIR observations. In the Mg-Ca-Al-Si-O system, peak positions shifted from 9.4 to 9.6 μm as Al/Si increased from 0.07 to 0.53, and from 9.4 to 9.7 μm and 17.7 to 19.1 μm as Ca/Mg increased from 0 to 1. The observed dust emission features of certain AGB stars were reproduced by modeled spectra based on the optical constants of our samples, under varying assumptions of grain size and dust temperature, indicating compositional diversity in AGB silicate dust.