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Effects of anisotropic evaporation of circumstellar forsterite on infrared spectra

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Crystalline silicates have been observed commonly in circumstellar environments such as protoplanetary disks and evolved stars (e.g. van Boeckel et al., 2005; Molster et al., 2002). Previous studies have shown that infrared spectra of crystals change with several factors, dust temperature, composition, crystallinity, and size (e.g. Koike et al., 2006). However, peak wavelengths of observed spectra are not always well-reproduced by optimizing these parameters. Recently, effects of grain shape on IR spectra have been studied (Yokoyama et al., 2007; Fabian et al., 2000) as another controlling factor.

In order to clarify the relationship between peak wavelength and a grain shape, we calculated mass absorption coefficients for ellipsoidal forsterite in the Reyleigh limit with varying aspect ratios. Calculations were based on a classical Lorentz vibrational model with optical parameters by Suto et al. (2006). When the aspect ratio of a-axis to c-axis (a/c) became larger than unity, the peak at 9.7 micron for a sphere shifted to longer wavelength, whereas if a/c was less than 1, it shifted to shorter side regardless of the ratio of b/c. When b/c became larger than 1, the 11.9-micron peak became smaller and finally disappears, but it became stronger than that of a sphere when b/c was less than 1. In the case of a/c is less than 1 and b/c is larger than 1, the 10.6-micron peak shifted to longer wavelength, although an ellipsoid with aspect ratios that a/c and b/c were less than 1 showed a minor shift. When a/c was larger than unity, the 10.6-micron peak shifted to shorter side regardless of b/c and the peak was stronger or weaker than that of a sphere if b/c was larger than 1 or less than 1. This indicates that the 10-micron band is a key band to distinguish anisotropy of ellipsoidal forsterite if there is a dominant shape for circumstellar forsterite.

One of the possible processes that changs forsterite dust-shape is anisotropic evaporation. Forsterite evaporates anisotropically in vacuum and the evaporation rate is dependent on temperature (Yokoyama et al., 2007 and references therein). We conducted evaporation experiments in a wide temperature range (1657-1153C) and hydrogen pressures (0.2-10 Pa) in order to investigate dependence of anisotropy of evaporation rates on temperature and hydrogen gas pressure.

Forsterite evaporated anisotropically in all experiments regardless of temperature. The anisotropy in vacuum (V_c, V_a, V_b in descending order) and in hydrogen gas (V_a and V_b were similar and smaller than V_c) were different at 1535C, whereas they were the same at 1657C. At 1657C, the ratio of evaporation rates along the c- and a-axes was almost unity and that along the b-axis was smallest (V_c and V_a were similar and larger than V_b). Anisotropy of evaporation rates in hydrogen gas did not change largely with increasing hydrogen pressure at evaporation temperatures of 1535 and 1657C. The anisotropy at 1327C, however, changed with increasing P_{H2}; V_c, V_b, V_a in descending order at P_{H2} of 0.2 Pa and V_b and V_c were similar and larger than V_a at 2 Pa. At 1153C, the lowest temperature we experimented, the rate along the b-axis was larger than the others at P_{H2} of 2 Pa.

We calculated a possible aspect ratio of an ellipsoid that reproduces the observed spectrum by ISO for HD100546. Disk-shaped forsterite flattened to the a- and b-axes with the aspect ratio of a : b : c = 21 : 22 : 1 well-reproduced the observed spectrum for the protoplanetaly disk, which corresponds to 99 vol% evaporation of a sphere in 1535C at P_{H2} = 10 Pa. If the shape was formed by evaporation from a sphere and when we assume radius of the starting sphere is ˜1 micron or 100 micron, evaporation duration become 1 or 100 seconds. The short heating time of forsterite dusts suggests an intensive shock heating in the disk and dispersed onto the disk surface