EFFECTS OF ANISOTROPIC EVAPORATION OF CIRCUMSTELLAR FORSTERITE ON INFRARED SPECTRA. A. Takigawa[1], S. Tachibana[1], and H. Nagahara[1], [1]Depertment of Earth and Planetary Science, University of Tokyo, takigawa@eps.s.u-tokyo.ac.jp.

Introduction: Crystalline silicates have been observed commonly in circumstellar environments such as protoplanetary disks [1, 2] and evolved stars (e.g. [3]), while interstellar silicates may consist mostly of amorphous silicates [4]. Previous studies have shown that infrared spectra of crystals change with several factors, dust temperature, composition, crystallinity, and size [e.g. 5, 6]. However, peak wavelengths of observed spectra are not always well-reproduced by optimizing these parameters [3]. Recently, effects of grain shape on IR spectra have been studied [7-9] as another controlling factor. They have shown that shapes change peak wavelength and relative strength. Possible chemical processes to change grain shapes are anisotropic condensation and evaporation of crystals, and crystallization of amorphous silicates in astrophysical environments, but there is little mineralogical constrains on shapes of forsterite, the most abundant circumstellar crystalline silicates.

Thus, we at first try to clarify what kind of information about grain shapes can be extracted from observed spectra by calculation of IR spectra for anisotropic forsterite. Then, we focus on evaporation of crystalline forsterite as one of possible processes changing circumstellar silicates shape. We conducted evaporation experiments of crystalline forsterite in hydrogen gas in order to know dependences of anisotropy on evaporation temperature and hydrogen gas pressure. Finally, we estimate shape changes of spherical forsterite dusts as a result of anisotropic evaporation in different conditions and discuss the possibility that anisotropic evaporation could form forsterite shape in HD100546.

Shape effects on infrared spectra: We tried to make it clear how the infrared spectrum and grain shape of forsterite related to each other. Fabian et al. (2001) [7] showed that the shape change of forstertie from sphere to spheroid elongated to the c-axis caused changes of peak wavelengths and strength of mass absorption coefficients (MACs), which are directly related to IR spectra. We have already shown ellipsoids flattened to the a- or b-axes give different spectra from that for elongated to the b-axis [9]. In this study, we calculated MACs for ellipsoidal forsterite in the Reyleigh limit with varying aspect ratios and showed the relationship between peak wavelength and a grain shape. Calculations were based on a classical Lorentz vibrational model with optical parameters by [6].

Although there were many peaks of forsterite in the calculated wavelength range (8-70 μm), we focus here on the 10-μm band feature, because this is the only band that is observed by ground telescopes and its feature is scarecely affected by dust temperature. The results are shown in Fig. 1. When the aspect ratio of a-axis to c-axis (a/c) became larger than unity (right panels), the peak at 9.7 μm for a sphere shifted to longer wavelength, whereas if $a/c < 1$ (left panels), it shifted to shorter side, regardless of the ratio of b/c. When b/c became larger than 1 (upper panels), the 11.9-μm peak became smaller and finally disappears, but it became stronger than that of a sphere when $b/c < 1$ (lower panels). In the case of $a/c < 1$ and $b/c > 1$, the 10.6-μm peak shifted to longer wavelength, although a ellipsoid with $a/c < 1$ and $b/c < 1$ showed a minor shift. When a/c was larger than unity, the 10.6-μm peak shifted to shorter side regardless of b/c but the peak was stronger or weaker than that of a sphere if $b/c > 1$ or $b/c <1$. This indicates that the 10-μm band is a key band to distinguish anisotropy of ellipsoidal forsterite if there is a dominant shape for circumstellar forsterite.

Evaporation experiments of crystalline forsterite: Forsterite has known to evaporate anisotropically in vacuum and the evaporation rate is dependent on temperature [e.g. 10, 11]. However, the roles of hydrogen gas and temperature on the anisotropic evaporation have been studied at only one temperature (1535°C) as we reported last year [9]. We conducted evaporation experiments at wider temperature range (1657-1153°C) and hydrogen pressures (0.2-10 Pa) in order to investigate dependence of the anisotropy of evaporation rates on temperature and hydrogen gas pressure. Details of experiments were described in [9]. We carried out experiments in vacuum for comparison, but vacuum evaporation rates at 1153°C and 1327°C were so low that we carried out experiments only in hydrogen gas. Evaporation rates along three crystallographic axes (V_a, V_b, V_c) were calculated from the weight losses and the original shapes of starting samples.

Experimental results: Forsterite evaporated anisotropically in all experiments, indicating that evaporation rates in hydrogen gas changed with crystallographic axes regardless of temperature. The anisotropy in vacuum ($V_c > V_a > V_b$) and in hydrogen gas ($V_c > V_a \sim V_b$) were different at 1535°C [9], whereas that at

1657°C was the same both in vacuum and in hydrogen gas. At 1657°C, the ratio of evaporation rates along the c- and a-axes was almost unity and that along the b-axis was smallest ($V_c \sim V_a > V_b$).

Although the evaporation rates in hydrogen gas increased roughly proportional to a square root of hydrogen gas pressure, the degree of anisotropy in hydrogen gas were not the same at all the temperatures. At evaporation temperatures of 1535 and 1657°C, anisotropy of evaporation rates in hydrogen gas did not change largely with increasing hydrogen pressure. The anisotropy at 1327°C, however, changed with increasing P_{H2}; $V_c > V_b > V_a$ at P_{H2} of 0.2 Pa and $V_b \sim V_c > V_a$ at 2 Pa. At 1153°C, the lowest temperature we experimented, the rate along the b-axis was larger than the others ($V_b > V_c \sim V_a$) at P_{H2} of 2 Pa.

Shape changes by anisotropic evaporation: Wide variations of anisotropy in evaporation rates depending on temperataure and hydrogen gas pressure may generate various shapes of circumstellar forsterite grains according to physical environments around stars. Thus we investigated shapes of forsterite formed by anisotropic evaporation at 1153-1657°C and in vacuum and hydrogen gas from an isotropic sphere.
Characteristic shapes after evaporation from a sphere are summarized as follows: A needle-like shape elongated to the b-axis is formed by evaporation in vacuum and hydrogen gas at 1657°C; a disk-like shape flattened to the a- and b-axes in hydrogen gas or an ellipsoid with b > a > c in vacuum at 1535°C; a needle-like shape elongated to the a-axis at 1327°C in hydrogen gas; a disk-like shape flattened to the a- and c-axes formed at 1153°C in hydrogen gas. Degree of flattening or elongating is dependent on the evaporation degree.

Application to HD100546: On the basis of above model, we calculated a possible aspect ratio of a ellipsoid that reproduces the observed spectrum by ISO for HD100546, which is a protoplanetary disk known as spectra similar to those of Comet Hale-Bopp. Calculation showed that a disk-shape forsterite flattened to the a- and b-axes with the aspect ratio of a : b : c = 21 : 22 : 1 well reproduced the observed spectra for the protoplanetaly disk.

Combined with our experimental results, this shape is formed by 99 vol% evaporation from a sphere in 1535°C at P_{H2} = 10 Pa. If the shape was formed by evaporation, $R/t \sim 10^6$ is required, where R is sphere radius before evaporation and t is evaporation duration. Therefore, evaporation duration become 1 or 100 seconds when we assume radius of the starting sphere is ~ 1 μm or 100 μm. If this is the case, dominant forsterite dusts in HD100546 should have experienced intensive shock heating in the disk and dispersed onto the disk surface.

References: [1] Malfait K. *et al.* (1998), *A & A*, **332**, L25. [2] van Boeckel R. *et al.* (2005) *A & A*, **189**, 208. [3] Molster F. J. *et al.* (2002a), *A & A*, **382**, 184. [4] Kemper, F. *et al*. (2004) *Ap. J.*, **609**, 826. [5] Koike C. *et al.* (2003), *A & A*, **399**, 1101. [6] Suto H. *et al.* (2006) *Mon. Not. R. Astron. Soc.*, **370**, 1599. [7] Fabian *et al.* (2000) *AA,* **364**, 282. [8] Min M. *et al.* (2003) *A & A*, **404**, 35. [9] Yokoyama M. *et al.* (2007) *LPS XXVII*, Abstract #1724. [10] Ozawa, K. and Nagahara, H. (1996) *Lunar Planet. Sci*., **XXVII**, 989. [11] Yamada, M. *et al.* (2006) *Planet. Space Sci.,* **54,** 1096.

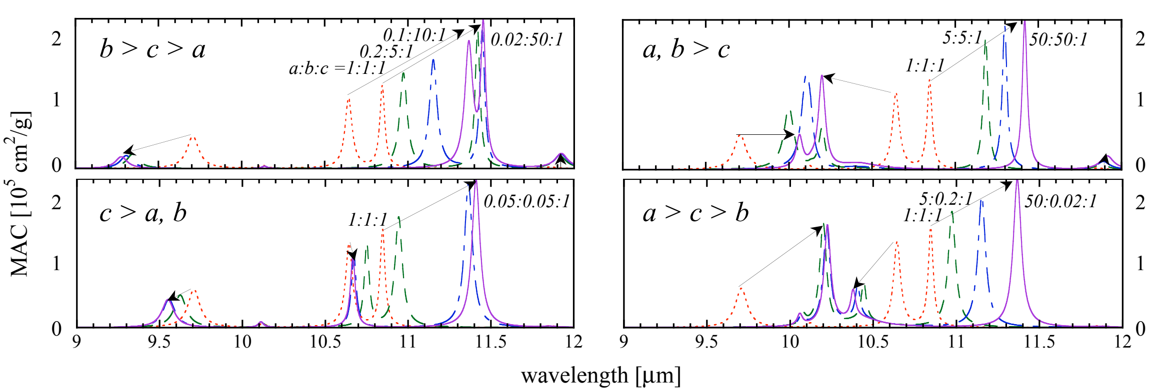

Fig. 1 : Relationship between forsterite shape and calculated IR spectra of 10 micron band. The right and left panels show spectra for ellipsoids with the aspect ratios a/c > 1 and a/c < 1, and the upper and lower panels show those with the aspect ratios b/c >1 and b/c < 1, respectively. Red-dotted lines are spectra for spheres, green-dashed, blue-dash-dotted, and purple-solid lines represent degree of shape change in the increasing order (See arrows).