Reactive Effect of Microwave Hydrogen Plasma with Silicate Powder

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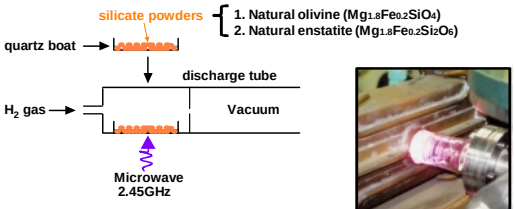
Introduction

A component of crystalline silicates was detected in IR spectra of some evolved stars or around some young stars. On the other hand, amorphous silicates are suggested as the carrier of a broad 9.7 and 18μm absorption feature detected in interstellar medium (ISM). The disappearance of crystalline silicates in the ISM is supposed to be due to their amorphization caused by a continuous processing such as annealing, cosmic ray and shockwave in interstellar environments. Ion irradiation experiments aimed at simulating this process were performed by several groups. Demyk et al. performed the irradiation of olivine with 4-10keV He+ ions [1]. Jäger et al. performed the irradiation experiments on enstatite with He+ and Ar ions in the 50-400keV energy range [2]. These experiments by energetic ion bombardment showed that crystalline silicates are transformed into amorphous structures. Ion and solid reactions with high energy ion irradiation lead to physical sputtering of atoms and formation of defects in their structure. During their life cycle, silicate dust are supposed to suffer from a processing by an ionized gas. During their life cycle, silicate dusts are supposed to suffer from a processing due to an ionized gas. In order to study the reaction between silicates and hydrogen plasma with low energies, we exposed the silicate powders to hydrogen plasma generated by a microwave discharge at 2.45GHz. We investigated the structural and chemical alteration of crystalline silicate powders before and after hydrogen plasma treatment.

Experimental procedure



Look of the plasma

Enstatite

before after

olivine

before after

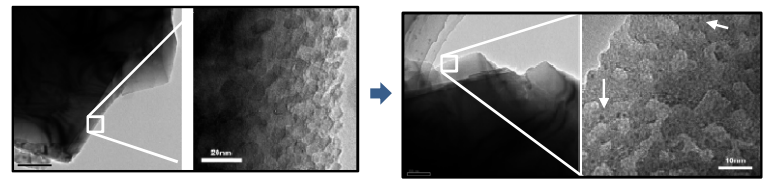
Figure is a schematic drawing of the apparatus used for exposing the silicate powders to hydrogen plasma. We placed the silicate powders on a quartz boat and then put the boat into the discharge tube. We exposed the silicate powders to hydrogen plasma generated by a microwave discharge at 2.45GHz. When the olivine powder was exposed to the plasma, the color of the powder changed from white to brownish gray. On the other hand, the color of the enstatite changed to brown. When the silicate powders were exposed to Ar plasma, the color didn't change.

Plasma conditions

electron energy	:	～10eV
species	:	H_2, H, H^+, H_2^+, e^-
sample's temperature	:	600～800K
gas density	:	1～15Torr

TEM observation

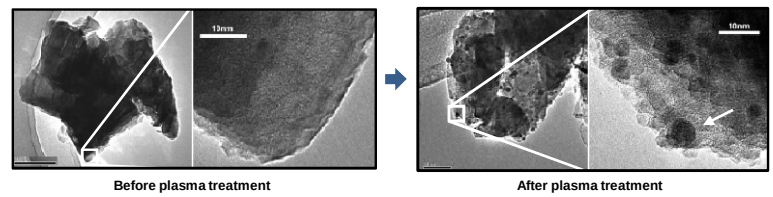
Olivine



Before plasma treatment — After plasma treatment

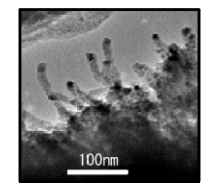
TEM images of untreated olivine powder and olivine powder after hydrogen plasma treatment. Although the surface of the untreated particle is angular shape, **the surface is changed into round shape after plasma treatment.** As shown by arrows, black spots with the size of about 1nm are seen in high resolution TEM image. This result suggests that the particles react with hydrogen plasma to cause the surface alteration.

Enstatite

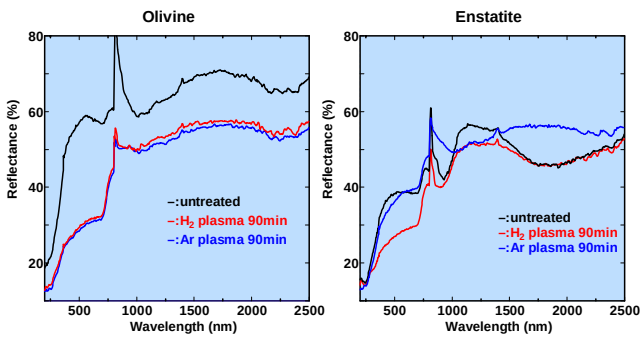


Before plasma treatment — After plasma treatment

TEM images of untreated enstatite powder and enstatite powder after hydrogen plasma treatment. **Small grains with the size of about 10nm are formed on the surface of the particles after plasma treatment.** TEM image of different position observed in same sample is shown in right figure. A growth of comet-like particles indicates a condensation from vapor phase [3].

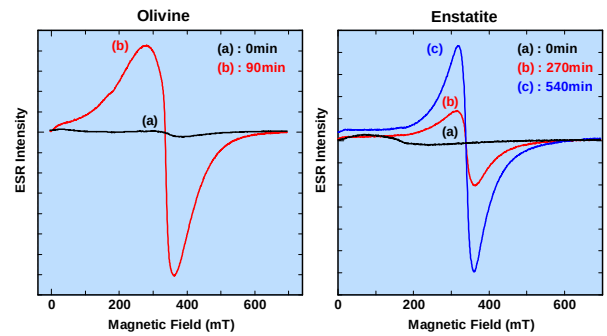


UV-VIS spectra



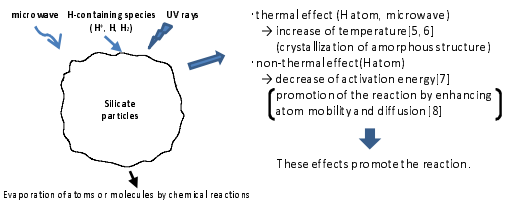
Reflectance spectra of olivine powder and enstatite powder before and after hydrogen plasma treatment. The reflectance of olivine powder exposed to hydrogen plasma or Ar plasma decreases to lower values in the range from ultraviolet to near-infrared wavelength. Although the reflectance of enstatite powder after hydrogen plasma treatment decreases in the range of visible wavelength, the feature doesn't change in near-infrared region. When the enstatite powder was exposed to Ar plasma, spectral change can be seen at near-infrared. The difference of the spectral change suggests that **olivine reacts with the plasma more easily than enstatite.** The decrease of reflectance in the visible region is due to a change of scattering effect resulted from the alteration of the surface or the formation of Fe particles.

ESR spectra



ESR spectra of olivine powder and enstatite powder before and after hydrogen plasma treatment. **Strong ESR signal is detected in the plasma-treated samples.** The g-value is estimated to be 2.07, which is very close to the value of Fe-bearing meteorites [4]. ESR spectra suggest that an iron ion in silicates is reduced to give a ferromagnetic material by hydrogen plasma treatment. ESR signal were not detected in the samples of olivine and enstatite with Ar plasma treatment. The difference is caused by a highly reactive effect due to hydrogen atom in the plasma.

Hydrogen plasma effect



When the silicate powders are exposed to hydrogen plasma, microwave, UV rays, and H-containing species affect the particles. Chemical reaction of H-containing species is considered to be an important process for the alteration of the silicate powders because the change was not found in the powders with Ar plasma treatment. Even if the silicate powders are heated at 600K, the change doesn't occur. The hydrogen plasma promotes effectively chemical and structural alterations of silicates at the low temperature of about 600K.

Summary

The hydrogen plasma promotes chemical and structural alterations of silicates effectively.

1. **TEM images reveal that the shape of silicate particles become round after hydrogen plasma treatment. Many small grains with about 1nm in diameter are produced on the surface of olivine particles. In the case of enstatite particles, many grains with about 10nm in diameter are produced.**

2. **The reflectance of silicates treated by hydrogen plasma decreases in the range of visible wavelength. When silicates are exposed to Ar plasma, the reflectance of olivine decreases in the region from UV to near-infrared wavelength. In the case of enstatite, the reflectance doesn't change in the range from UV to visible wavelength. The result suggests that the erosion rate of olivine is large than that of enstatite.**

3. **A strong ESR signal is detected in the plasma-treated samples of olivine and enstatite. The g-value is estimated to be 2.07, which is very close to the value of Fe-bearing meteorites. ESR spectra suggest that an iron ion in silicates is reduced to give a ferromagnetic material by hydrogen plasma treatment.**

4. **The change of particle shape is caused by the effect of highly reactive sputtering due to hydrogen plasma.**

References

[1] K. Demyk, Ph. Carrez, H. Leroux, P. Cordier, A. P. Jones, J. Borg, E. Quirico, P. I. Raynal, and L. d'Hendecourt, 2001, Astron. Astrophys., 368, L38-L41.
[2] C. Jäger, D. Fabian, F. Schrempel, J. Dorschner, Th. Henning, and W. Weich, 2003, Astron. Astrophys., 401, 57-65.
[3] J. R. Stephens, A. Blanco, E. Bussoletti, L. Colangeli, S. Fonti, V. Mennella, and V. Orofino, 1995, Planet. Space Sci., Vol. 43, Nos10/11, pp.1241-1246.
[4] E. Kurahashi, C. Yamanaka, K. Nakamura ,and S. Sasaki, 2003, Lunar Planet. Sci., XXXIV, #1499.
[5] S.G. Lee, H.C. Park, B.S. Kang, G.S. Seo, S.S. Hong, and S.S. Park, 2007, Mat. Sci. Engin. A, 466, 79-83.
[6] J.N. Lee , Y.W. Choi, B.J. Lee, and B.T. Ahn, 1987, J. Appl. Phys., 82, p.2918-2921.
[7] Y.L. Khait, R. Well, R. Beserman, F. Edelmen, W. Beyer, and B. Rech, 2003, J. Appl. Phys., 94, 443-453.
[8] T. Wang, Y.B. Dai, and H.-D. Lee, 2005, J. Mat. Engin. Perform., 14, 516-518.