Thermodynamic Calculation and Spectroscopic Observation of SiO2 Dissociation in Impact Induced Vapor Plume

Masanori Fuyuki[1], Seiji Sugita[2], Toshihiko Kadono[3], Sunao Hasegawa[4], Takafumi Matsui[5]

[1] Complexity Science and Engineering,Frontier Sciences,University of Tokyo, [2] Earth and Planet. Sci., Univ. of Tokyo, [3] ERI, [4] ISAS, [5] Dept. of Earth and Planetary Phys., Univ. of Tokyo

In our solar system, the impact of planetesimals affects the origin and evolution of life and atmosphere [1,2]. Impact induced vapor plume expands so rapidly that chemical reactions quench at a certain temperature (quench temperature). At the quench temperature thermodynamic equilibrium determines chemical composition of materials supplied to planets and satellites. Some authors have done indirect observations of vapor plume and made it clear that molecular Oxygen induced by the thermal dissociation of SiO2 plays an important role in the whole chemical reaction in the plume [3]. Unfortunately we can not observe SiO2 dissociation at the quench temperature of planetesimal-size vapor plume (QTPS) in laboratory. As scale of vapor plume becomes larger, the quench temperature becomes lower [4](table 1). It remains in dark.

Recently our team have developed a new method for getting over this problem. This method consists of two parts. One part is thermodynamic equilibrium calculation. The other is making an equation of relationship between pressure and temperature for vapor plume by spectroscopic observation.

The calculation system is composed entirely of SiO2. In the system we assume gas-phase reaction only, because It is often said that the impact vapor plume supercools and gas phase does not condense even at low temperature. The calculation result shows that SiO2 dissociation at QTPS strongly depends on the pressure. As the pressure is lower, more SiO2 dissociates (figure 1).

To discuss more quantitatively, we tried to make equation of relationship between pressure and temperature (ERTP). There are several equations of state for expressing expanding vapor plume. But none of them is probable for whole temperature-pressure range in which impact vapor plume experiences. For that, we can not perform ERTP and can assume shape of ERTP only.

For performing ERTP, we did impact experiment using laser pulse irradiation and the direct observation of the induced vapor plume with spectrometer. The target is quartz, SiO2 crystal. We calculate theoretical spectrogram of SiO, Si, O2, O (molecules induced by SiO2 dissociation)(figure 2). Using this spectrogram, we analysis the observation data. We find not only SiO and Si spectra, but also changes of individual spectra and of the ratio of their intensity, Isi/Isio (figure 3-1 & 2). These changes suggest SiO2 recombination with decrease of temperature in the vapor plume.

This analysis is first step to perform ERTP. Second step is making (T,[Si]/[SiO]) data and third step is to transform (T,[Si]/[SiO]) data to (T,P) data by thermodynamic equilibrium calculation. As the last step, we fit unperformed ERTP to the (T,P) data in the region where the vapor plume is over the quench temperature of the laboratory size vapor plume. By extending this ERTP to QTPS, we can discuss SiO2 dissociation quantitatively.

We are now in the second step. To determine temperature of the vapor plume in each snap shot, we use Si spectra peaks. As Si is optically dense, we must determine temperature, column density and Lorentz type broadening of Si at one time. By inversion analysis, we determined temperature and analytical error was 200K.

Reference:[1] Kasting,J. Origins Life Evl.Biosphere20,199-231(1990) [2] Chyba,C. and Sagan,C. Nature 355,125-132(1992) [3] Mukhin,L.M. et al. Nature 340,46-48(1989) [4] M.V.Gerasimov et al. Earth,Moon and Planets 80,209-259(1998)

Table 1: Quench temperature of vapor plume (Gerasimov et al., 1998). Their calculation is based on observation data of O3 similar to SiO2.

Vapor Plume	Giant Impact	Experiment
Quench Temperature(K)	1000～2000	3000

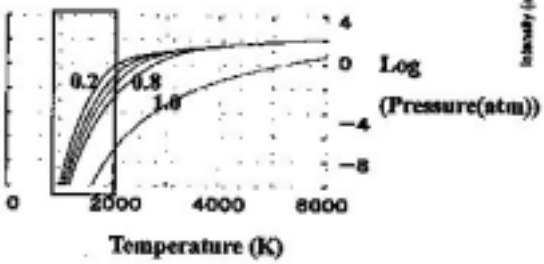

Figure 1:Degree of SiO2 dissociation. Contour '1.0' shows all SiO2 dissociate and '0' shows no SiO2 dissociates. Red box shows the range where quench temperature of Impact vapor plume exists.

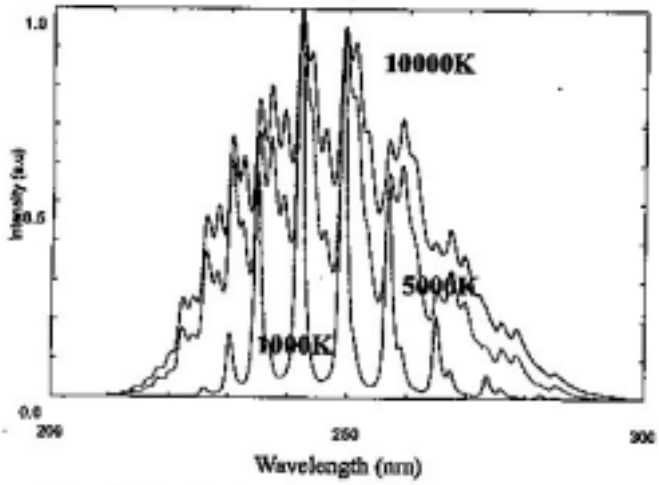

Figure 2:Theoritical spectrogram of SiO at several temperature. Instrumental function is that of the spectrometer we used.

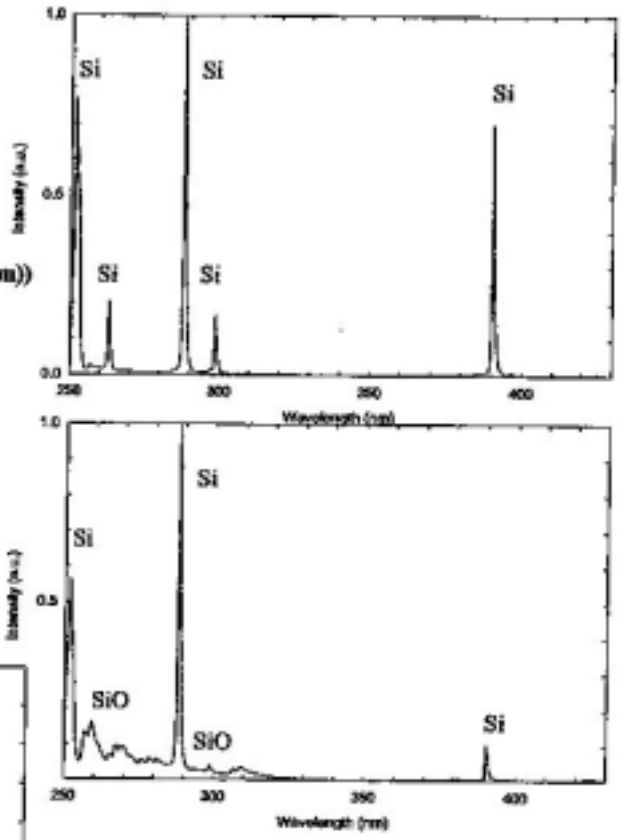

Figure 3-1&2:Spectroscopic observation data; At 10,80 μ s after Laser irradiation. Explosure times are 500ns、20 μ s.