

X-ray diffraction as a function of temperature for $\text{Fo}_{92}\text{-Fa}_8$: implications for the hermean surface.

S. Ferrari (1), F. Nestola (1), A. Maturilli (2), M. Massironi (1, 3), J. Helbert (2), G. Redhammer (4) and SIMBIO-SYS team (1) Dipartimento di Geoscienze, Università degli studi di Padova, Italy, (2) Institute for Planetary Research, DLR, Berlin-Adlershof, Germany, (3) CISAS, Università degli studi di Padova, Italy (4) Institute for Crystallography for the RWTH, Aachen, Germany
(sabrina.ferrari@studenti.unipd.it / Fax: +39-049-8729134)

Abstract

It is well known that the surface of Mercury shows temperature variations extremely large at specific locations [1]. Such a range can cause strong crystal structure changes and, as a consequence, the detected spectral signature could be significantly affected. Here we investigated the low-high temperature behaviour of one of the olivine, which has been recently considered as a possible constituent of the Mercury surface [2]. Aim of the work is to determine which expansion the olivine undergoes within a temperature range typical of the Mercury surface in order to verify which could be the effect of thermal expansion on a spectra.

1. An *in situ* approach

The temperature on the surface of Mercury can range in 44 earth days between 70 and 725 K at different latitudes and such variation affect significantly the crystal structure and density of the minerals and rocks present on the surface of the planet [2] [3]. As a consequence, several kinds of remote information linked to mineral structures, including relative spectral signatures, are strictly dependent on the environmental conditions and vary according to the surface temperature [4] [5]. Thus, we need to investigate the behaviour of planetary geological materials *in situ*, or under extreme temperature environments, and improve the geological interpretation and compositional inferences by applying the knowledge acquired to the analysis of available remote sensing data.

The BepiColombo Mercury Planetary Orbiter (scheduled launch in 2014) will have on board the MERTIS spectrometer (Mercury Radiometer and Thermal Infrared Spectrometer) [6] allowing to obtain crucial information on the identification and mapping of silicate minerals like feldspars,

pyroxenes and olivines, that are considered among the most abundant phases for Earth planets. MERTIS will collect mineral spectral signatures in the range 7-14 μm . In fact, in such wavelength range the spectra can be used very effectively to identify the fine-scale structural properties of silicates (e.g. stretching and bending motions in the silicon-oxygen anions, metal – oxygen and lattice vibrations) and for some important mineral family, like olivine, the peak positions in this range are good indicator of their composition [7].

Here we present a new *in situ* multi-methodological laboratory approach comprehensive of high-temperature X-ray diffraction (single-crystal and powder materials) and TIR spectroscopy (in the range 7 to 14 μm). In particular, we investigated a sample of olivine with composition $\text{Mg}_{1.84}\text{Fe}_{0.16}\text{SiO}_4$ as this is among the major component of Earth's mantle, meteorites, and has been identified on the surfaces of planetary bodies, and in the spectra of astronomical targets [8]. First of all, the phase has been well characterized at room conditions by single crystal X-ray diffraction and X-ray powder diffraction, then analyzed by electron microprobe. Subsequently, each single mineral phase has been reduced in a likely grain-sizes range about the hermean surface regolith: 100-160 μm [9]. High temperature powder X-ray diffraction measurements ($5^\circ - 100^\circ$ in 2θ , continuous scan mode) were carried out in the temperature range 295 K - 1273 K at the Institute for Crystallography for the RWTH in Aachen, Germany. The results emphasize an important increase of the cell volume in the hermean surface temperature range (fig. 1).

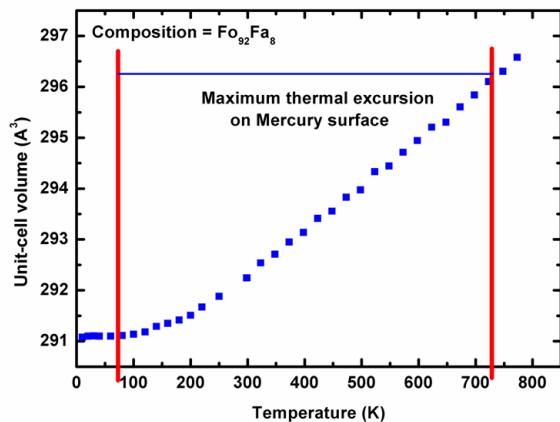


Figure 1: Cell-volume derived from high-temperature powder X-ray diffraction measurements on $\text{Fo}_{92}\text{Fa}_8$.

Comparing these results with those of Nestola et al. (2011), we could obtain the same cell variation at room conditions increasing the iron content. This means that such an increase of temperature lead to a *virtual* mineral enriched in iron content.

Concerning the TIR spectroscopy we performed laboratory measurements at the Planetary Emissivity Laboratory (PEL) at the German Aerospace Center (Deutsches Zentrum fuer Luft- und Raumfahrt in Berlin), where is available a high-temperature and vacuum spectrometer. The PEL has been build up over the last 5 years to study systematically the effect of temperature on TIR spectral signature of single mineral phases [10] and mixtures, and build up a new spectral library taking these effects into account. In our case, the sample has been investigated at four different steps and the calibrated temperatures reach 718 K. Comparing the obtained high temperature spectra with the earth-environmental spectra of ASU spectral library [11], we measure a significant shift of the major absorption features toward longer wavelength. This is in agreement with a virtual enrichment of iron in the olivine phase.

2. Conclusions

This work demonstrates that under strong temperature ranges, like the ones experienced by Mercury surface, thermal expansion is an unavoidable process and could strongly mask the actual chemistry of the mineral phases since they can appear variable through time and from place to place as a function of solar irradiation. This could drive to important misinterpretations and limit our capability of inferring compositions and rheological properties of materials from remote sensing acquisition.

References

- [1] Strom, R. G.: Mercury: the elusive planet, solar system series, Smithsonian Institution Press, Washington, D. C., 1987.
- [2] Vernazza, P., De Meo, F., Nedelcu, D. A., Birlan, M., Doressoundiram, A., Erard, S. and Volquardsen, E.: Resolved spectroscopy of Mercury in the near-IR SpeX/IRTF, *Icarus*, Vol. 209, pp. 125-137, 2010.
- [3] Warell, J., Sprague, A., Kozłowski, R., Rothery, D. A., Lewis, N., Helbert, J. and Cloutis, E.: Constraints on Mercury's surface composition from MESSENGER and ground-based spectroscopy, *Icarus*, Vol. 209, pp. 138-163, 2010.
- [4] Singer, R. B. and Roush, T. L.: Effects of Temperature on Remotely Sensed Mineral Absorption Features, *Journal of Geophysical Research*, Vol. 90, pp. 12434-12444, 1985.
- [5] Bowey, J. E., Lee, C., Tucker, C., Hofmeister, A. M., Ade, P. A. R. and Barlow, M. J.: Temperature effects on the 15-85 μm spectra of olivines and pyroxenes, *Mon. Not. R. Astron. Soc.*, Vol. 325, pp. 886-896, 2001.
- [6] Hiesinger, H., Helbert, J., MERTIS Co-I Team: The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) for the BepiColombo mission, *Planetary and Space Science*, Vol. 58, pp. 144-165, 2010.
- [7] Koike, C., Chihara, H., Tsuchiyama, A., Suto, H., Sogawa, H. and Okuda, H.: Compositional dependence of infrared absorption spectra of crystalline silicate – II Natural and synthetic olivines, *Astronomy and Astrophysics*, Vol. 399, pp. 1101-1107, 2003.
- [8] Hamilton, V. E.: Thermal infrared (vibrational) spectroscopy of Mg-Fe olivines: a review and applications to determining the composition of planetary surfaces, *Geochemistry*, Vol. 70, pp. 7-33, 2010.
- [9] Emery, J. P., Sprague, A., Witteborn, F. C., Colwell, J. E., Kozłowski, R. W. H. and Wooden, D. H.: Mercury: thermal modeling and Mid-infrared (5-12 μm) observations, *Icarus*, Vol. 136, pp. 104-123, 1998.
- [10] Helbert, J. and Maturilli, A.: The emissivity of a fine-grained labradorite sample at typical Mercury dayside temperatures, *Earth and Planetary Science Letters*, Vol. 285, pp. 347-354, 2009.
- [11] Christensen, P. R., Bandfield, J. L., Hamilton, V. E., Howard, D. A., Lane, M. D., Piatek, J. L. Ruff, S. W., Stefanov, W. L.: A thermal emission spectral library of rock-forming minerals, *Journal of Geophysical Research*, Vol. 105, pp. 9735-9739, 2000.