

**Compositions and Mobility of Metallic Immiscible Liquids at High Pressure and Temperature: Implications for Differentiation of Small Planetary Bodies.** Yingwei Fei<sup>1</sup>, and Yuki Shibazaki<sup>1,2</sup>, <sup>1</sup>Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Road, N.W., Washington, DC 20015, USA (fei@gl.ciw.edu); <sup>2</sup>Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 6-3 Aoba, Aramaki, Aoba-ku, Sendai 980-8578, Japan

**Introduction:** Differentiation of planetesimals and small bodies at early stage of the planet formation is an important process to redistribute materials and energy in the interiors, leading to metallic cores. The metallic core usually contains iron-nickel (Fe-Ni) alloy with light elements such as sulfur (S), oxygen (O), and carbon (C), based on cosmochemical constraints and element solubility in metallic liquid. Its final chemical composition depends on the bulk composition, core formation environments, and element partitioning during metal and silicate separation. The liquid core could be further chemically stratified by formation of immiscible liquids or crystallization of an inner core.

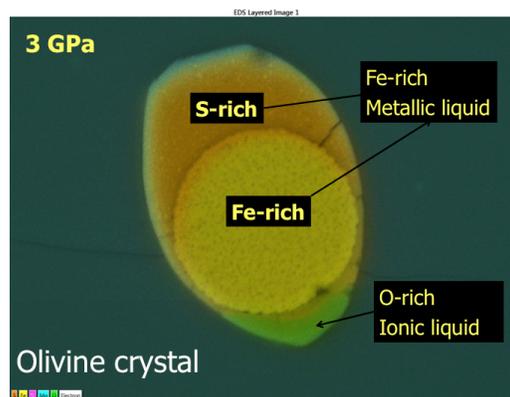
In order to understand the compositional variation of iron meteorites and the cores of small planetary bodies, it is essential to determine the melting relations in the multi-component systems containing core-forming elements and the percolative behavior of molten metal alloys including immiscible metallic liquids. In this study, we examine melting behavior and composition of immiscible liquids in the Fe-Ni-S-O-Si system. We have also investigated the percolative behavior of immiscible Fe-Ni-S-O-Si metallic liquids in San Carlos olivine matrix up to 6 GPa.

**Experimental Procedure:** A series of experiments were performed in the pressure range of 1-6 GPa at 1873 K, using mixtures of Fe, FeS, FeO, and San Carlos olivine. The contents of S and O in the metals were varied from O-rich and S-poor metal to S-rich and O-poor metal with a total light elements in the metals at about 11-17 wt%. Experiments at 3-6 GPa were conducted in the multi-anvil device with an 18/11 cell assembly [1], whereas the experiments below 3 GPa were performed in the piston-cylinder apparatus. The recovered samples were mounted in epoxy resin and polished for compositional mapping and quantitative chemical analysis. All experimental charges contain liquid metal and crystal olivine.

The chemical compositions of the liquid metal and silicate were determined with both electron microprobe and scanning electron microscopy equipped with silicon drift detector for EDS measurements. The texture and liquid metal distribution in silicate matrix were mapped with 3D imaging, using a slice-view capability on a cross-beam FIB/SEM (focused ion beam-scanning electron microscopy) system [2]. The 3D imaging provides information of connectivity of metallic liquid in

the silicate matrix and precise measurements of the true dihedral angle.

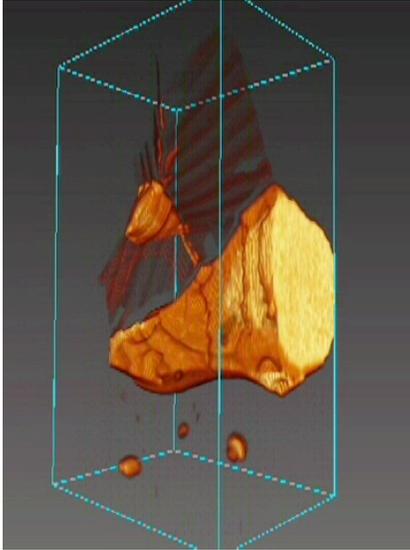
**Results:** The metallic liquids in the run products are either trapped as inclusions in the olivine or collected at the triple junctions of the olivine crystal grains. The metal liquid contains some Ni and Si in addition to the Fe-S-O starting composition. The contents of Ni, Si, and O in the liquid metal are controlled by element partitioning between metal and olivine. The olivine in equilibrium with metal has lower Fe and Ni contents compared with the initial crystals. The quenched melts show immiscible liquids (Figure 1).



**Fig. 1.** Image of immiscible liquids trapped in olivine crystal. The sample was quenched from 3 GPa and 1873 K. The melt inclusion is about 5- $\mu$ m across.

The quenched texture and composition of the metal liquid are complex. For example, at 3 GPa and 1873K, it is clear that there are at least two immiscible liquids, a S-rich liquid (~24.5 wt% S and 4.1 wt% O) in contact with the silicate, and a Fe-rich liquid (~2.7 wt% S and 1.5 wt% O) in the core. There is a third distinct composition close to FeO. It is not clear if this O-rich component is a result of quenching effect or represents an O-rich ionic liquid.

Previous study has reported immiscible liquid gap between metallic (O-poor) and ionic (O-rich) liquids in the Fe-S-O system [3]. The immiscible liquids observed in this study are more similar to those reported in the Fe-S-C-O system [4] with a S-rich liquid. For all the quenched samples, the Fe-rich liquid is always located in the core surrounded by the S-rich liquid. Only the S-rich liquid is wetting the olivine grains.



**Fig. 2.** 3D view of Fe-Ni-S-O-Si melt in an olivine matrix. The two melt pockets were connected by S-rich liquid (brown) through grain boundaries. The Fe-rich liquid is shown as yellow.

The wetting ability of metallic liquid is strongly depended on pressure and composition. We examined the effect of pressure on the dihedral angle which decreases with decreasing pressure. At pressures above 3 GPa, melt forms isolated pockets, whereas interconnected melt network was observed at 3 GPa, as illustrated by the 3D volume rendering (Fig. 2). The melt percolating in the grain boundaries is limited to the S-rich liquid.

**Discussion:** The compositions of immiscible liquids have been only investigated in relatively simple systems such as the Fe-S-O, Fe-S-Si, and Fe-S-C systems, at high pressure [e.g., 3-6]. The composition of the metallic liquid in this study is more complex because the metallic liquid is in equilibrium with the co-existing silicate, representing the natural process. The formation of a S-rich liquid at temperature significantly higher than that of solidus provides a new path to generate metal with high S content. It may have important implications for the origin of sulfide-rich iron meteorite [7].

In addition to study the effect of pressure and composition on the wetting ability of metallic liquid in silicate matrix, we are investigating a new mechanism for compositional separation through immiscible liquids. Two immiscible liquids could potentially separated through percolation if one liquid forms smaller dihedral angle than  $60^\circ$  whereas the wetting angle of the second liquid is larger than the critical angle. This mechanism could provide non-conventional compositional separation during core formation for small planetary bodies, leading to more diverse compositions of iron meteorites and planetary cores.

**References:** [1] Bertka C. M. and Fei Y. (1997) *JGR* 102, 5251-5264. [2] Fei Y. (2013) *JoVE* 81, e50778. [3] Tsuno K. et al. (2007) *PEPI* 160, 75-85. [4] Corgne A. et al. (2008) *GCA* 72, 2409-2416. [5] Deng, L. et al. (2013) *GCA* 114, 220-233. [6] Sanloup C., and Fei Y. (2004) *PEPI* 147, 57-65. [7] D'Orazio M. et al. (2009) *MPS* 44, 221-231.