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Melting relation in the Fe-S-Si system at high pressure and temperature: Implications for the Earth's core

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The Earth's core is mainly composed of iron alloy. Its density is, however, smaller than that of pure iron. Therefore, the light elements are required in the core to account for the core density deficit (Birch, 1964). The potential light elements have been considered to be S, Si, O, C, and H (Poirier, 1994). Alloying light elements significantly affects the physical properties of iron and depresses its melting temperature (e.g., Boehler, 1996). Sulfur and silicon are considered as major light element components based on cosmochemical study (McDonough, 2003) and high pressure partitioning experiments (e.g., Sakai et al., 2006). Therefore, the melting relationship of the Fe-S-Si system is the key information to clarify the thermal and compositional structure of the Earth's core. In the case of the Fe-S-Si ternary system, there are no experimental data at high pressure and the phase and melting relations have not been clarified in detail under core conditions. In this study, the melting relationships of the Fe-S-Si system were determined up to 60 GPa using a laser-heated diamond anvil cell combined with in situ X-ray diffraction technique. Chemical analyses of the recovered samples were also carried out to determine the partitioning of the elements in the samples.

The sample composition used in this study were $Fe_{80.1}S_{12.7}Si_{7.2}$(Fe-8wt.%S-4wt.%Si) and $Fe_{74.4}S_{18.5}Si_{7.1}$(Fe-12wt.%S-4wt.%Si), which are in the range of the amounts of the light elements to explain the density deficit in the Earth's core. The sample foil was sandwiched between NaCl or Al_2O_3 pellets, which worked as the pressure medium, and the thermal insulator. An experimental pressure was determined from the pressure dependence of the edge of the T_{2g} Raman band of the culet of the diamond anvil (Akahama and Kawamura, 2004) and the lattice parameters of NaCl with using the equation of states of the NaCl B1 phase (Brown, 1999) and NaCl B2 phase (Fei et al., 2007). In situ X-ray diffraction experiments were conducted at the BL10XU beamline at the SPring-8 facility (Ohishi et al., 2008).

On the basis of diffraction patterns, Fe(hcp/fcc) which contains silicon and Fe_3S are stable phases under subsolidus conditions. First Fe_3S melts at a solidus temperature, and Fe-Si alloy coexists with partial melts above the cotectic temperature in this system. This melting sequence is consistent with the study of the Fe-Fe_3S system observed earlier by Kamada et al. (2010). The solidus temperature is significantly lower than the melting temperature of pure Fe (Ma et al., 2004) and close to the eutectic temperatures of the Fe-Fe_3S system (Morard et al., 2008), suggesting that the effect of 7.2 at.% silicon on the eutectic temperature in the Fe-Fe_3S system is minor. Based on the present results, the temperature at the core-mantle boundary should be greater than 2630(160) K and the temperature at the boundary of the inner and outer cores is estimated to be 4500(320) K, assuming that sulfur and silicon are the only light elements in the Earth's core. We also determined the elemental partitioning from chemical analyses. The results in this study provide important constraints on the chemical and thermal structure of the Earth's core.

Keywords: Earth's Core, core-mantle boundary, inner core boundary, laser-heated diamond anvil cell, Fe-S-Si system