Experimental attempts to study the solubility of Ar in molten iron at high-pressures

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Dissolution mechanism of rare gasses in silicate melt and the pressure dependence of their maximum solubility have been studied in many laboratories using various techniques over the last decade (e.g., Shibata et al., 1998; Chamorro-Perez et al., 1998; Schmidt and Keppler, 2002; Bouhifd and Jephcoat, 2006). Matsuda et al. (1993) first studied partitioning of rare gasses between basalt melt and molten Fe up to 10 GPa. Concerning the solubility of noble gasses in molten metal at high-pressures, this is the only study, so far. Unlike silicate melts which can be easily quenched as glasses, solubility of gas component in molten metal is difficult to study, because metal melt would crystallize completely during quenching. Although Matsuda et al. (1993) carefully separated the metal droplet from the basalt glass in their high-pressure run products, it is unwarranted that quenched metal melt (aggregate of fine metal crystals) retains the gas component originally dissolved in the molten metal.

In order to understand the behavior of noble gasses in early history of our planet, it is very important to understand their solubility mechanism in molten Fe (planetary core components). We started high pressure experiments with an aim to clarify the behavior of noble gas in molten Fe at high-pressure. During the course of this study, we found that Fe, that has molten and quenched under Ar-saturated conditions at high-pressures, have numerous small bubbles. We interpreted this texture as exsolution of Ar from the Fe melt during quench crystallization.

In order to study the systematic relation between bubble density, bubble size, temperature, and run duration, more than 20 experiments were carried out at 1 GPa using a non end-loaded piston-cylinder apparatus. In these experiments, Ar was supplied from SiO2 glass, that has been previously doped with Ar, to the Fe-rod (1.0 mm diam. and 2.0 mm long). The Ar-doped SiO2 glass (0.2 to 0.4 wt% of Ar was doped at 0.4 GPa and 1000-1400 degree C with an internally heated Ar-gas medium apparatus) crystallizes rapidly at temperatures above ca.1000 degree C at 1GPa (although it stays meta-stably as glass in the gas-medium apparatus at 0.4 GPa) and yielded numerous Ar-filled bubbles. Because the Fe-rod is encapsulated in the Ar-doped SiO2, it is expected that Fe was molten under Ar-saturated conditions.

Both SEI and BEI were used to identify the Ar-bubbles from other impurities (i.e., FeO and SiO2). A systematic relation has been observed between the bubble density and the melting temperatures (0.1 vol.% at 1600, 0.4 vol.% at 1700, and 0.55 vol.% at 1800 degree C, respectively). At 1700 degree C, time study revealed that the Ar-bubble density decreases after more than 10 min of heat duration probably due to Ar diffusion from the sample to ambient low temperature portion of the talc-Pyrex-graphite-MgO high pressure assembly.

Preliminary experiments were carried out at 3 GPa with a Boyd-England type piton-cylinder apparatus and at 9 GPa with a multi-anvil apparatus. When Fe-metal were partially molten (in other words, whenever liquid-solid interface can be identified in the quench texture of Fe), Ar-bubble density is always more than 5 times higher in the quench Fe-melt part than in the solid-Fe part. In quenched run product at 9 GPa, the Ar-bubbles are found to have radial cracks most probably due to the very high Ar-filling density.

We are still in the process of searching best experimental techniques to study the noble gas solubility in molten Fe, and our experimental data are presently limited only for Ar. Our reconnaissance results, however, indicate that the solubility of Ar in molten Fe is much greater than that in solid Fe and it has a positive temperature effect. Although the pressure effect on Ar solubility in molten Fe is yet unknown, it may have considerable solubility even at 10 GPa as exemplified by the presence of Ar-filled-bubbles.