Sound velocities of an Fe-Si alloy at high pressure and high temperature conditions: Implications to lunar and Mercurian cores

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Introduction:

Sound wave velocity of Fe alloys is critical in constraining the compositions and the evolutions of planetary bodies. We have determined sound velocities of an $Fe_{0.8}Si_{0.2}$ (9 wt% Si) alloy in body centered cubic (bcc) structure by combining an ultrasonic technique with synchrotron X-ray radiography at pressure-temperature conditions of 2.6-7.5 GPa and 300-1173 K, respectively. It is found that adding Si to bcc-Fe at 300 K increases the compressional velocity (V_P) but decreases the shear velocity (V_S) with increasing pressures. Compared to the behavior of bcc-Fe, our results show a pronounced effect of pressure on the V_S-T relations in the $Fe_{0.8}Si_{0.2}$ alloy. The V_P-density (ρ) relation of the $Fe_{0.8}Si_{0.2}$alloy is found to follow the Birch's law in our studied P-T range, whereas the V_S-ρ relation exhibits complex behavior.

We present ρ, V_P and V_S profiles of the Fe-Si alloy at high P-T conditions corresponding to the lunar core. If Si alone exists as the minor element in the lunar core, our results suggest that a Si-rich lunar core would have the following comparisons, relative to a pure Fe or a S-rich lunar core: V_P and ρ of a Si-rich core are both comparable to those of a pure Fe core, but display much higher and moderately smaller, respectively, than their counterparts in a S-rich core, while V_S of a Si-rich core is smaller than that of a pure Fe core. This observation demonstrates the importance of simultaneous constraints of V_P and V_S when comparing seismograms data to laboratory experimental results. It should be noted that our proposed models were based on a composition with 9 wt% Si content. If 1-3wt% Si content in Enstatite chondrite is taken as a light element concentration, then our density and sound velocity models provide lower and upper limits for a Si-bearing lunar core, respectively.

For the Mercury, considering the average core density of Mercury constrained by polar moment of inertia (C/MR^2) and fraction of polar moment of outer solid shell (*Cm/C*) from the MESSENGER spacecraft [1], our results show that a Si content in the Mercurian core should be higher than 16 wt% based on the density dataset analysis of $Fe_{0.75}Si_{0.25}$ [2] and $Fe_{0.8}Si_{0.2}$ (9 wt%, this work) samples.

References:

[1]Stark, A. et al. (2015) First MESSENGER orbital observations of Mercury's librations. *Geophys. Res. Lett.* 42 (19), 7881-7889.
[2]Fischer, R. A. et al. (2013) Phase relations in the Fe-FeSi system at high pressures and temperatures. *Earth Planet. Sc. Lett.* 373, 54-64.