CARBON SOLUBILITY IN Si-Fe-BEARING METALS DURING CORE FORMATION ON MERCURY.

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Introduction: Recent results obtained from the MErcury **S**urface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft showed the surface of Mercury has high S abundances (~4 wt%) and low FeO abundances (<2 wt%) [*1–3*]. Based on these extreme values, the oxygen fugacity of Mercury's surface materials was estimated to be approximately 3 to 7 $\log_{10}$ units below the IW buffer (ΔIW-3 to ΔIW-7) [*4*, *5*]. This highly reducing nature of the planet has resulted in a large core and relatively thin mantle, extending to only ~420 km depth (corresponding to a core-mantle boundary pressure of ~4–7 GPa) within the planet [*6*]. Furthermore, MESSENGER results have suggested the presence of carbon on the surface of the planet [*7*, *8*]. Previous experimental results from [*9*] have also suggested the possibility of a primary floatation crust on Mercury composed of graphite, produced after a global magma ocean event. With these exotic conditions of this compositional end-member planet, it begs the question, what is the core composition of Mercury?

Although no definitive conclusion has been reached, previous studies have made advances towards answering this question. Riner et al. [*10*] and Chen et al. [*11*] looked at Fe-S systems and implemented various crystallization and layered core scenarios to try and determine the composition and structure of Mercury's core. Malavergne et al. [*12*] examined core crystallization scenarios in the presence of S and Si. Hauck et al. [*6*] used the most recent geophysical constraints from the MESSENGER spacecraft to model the internal structure of Mercury, including the core, in a Fe-S-Si system. More recently, Chabot et al. [*13*] conducted a series of metal-silicate partitioning experiments in a Fe-S-Si system. These results showed the core of Mercury has the potential to contain more than 15 wt% Si. However, with the newest results from MESSENGER's low altitude campaign, carbon is another potential light element that could be incorporated into Mercury's core. The goal of this study is to determine the carbon concentration at graphite saturation in various Si-Fe bearing metals (Table 1) relevant to possible mercurian core compositions. Future experiments will include the addition of S into these metals.

Methods: Experiments were conducted at 1.0 GPa and 1300 °C using a salt-pyrex cell and a 13 mm piston cylinder apparatus housed in the Institute of Meteoritics at the University of New Mexico. All experiments were run in graphite capsules to ensure the starting materials

Table 1. Composition of the metal starting materials used in this study. All values are in wt%.

	Low Si	Low-Intermediate Si	Intermediate-High Si	High Si
Si	5	10	22	35
Fe	95	90	78	65
Total	100	100	100	100

(Table 1) became graphite saturated throughout the duration of the experiment. The Low Si and Intermediate-High Si compositions were chosen based on the thermal minima on the liquidus temperatures along the Fe-Si metallic-binary join. The Low-Intermediate Si and High Si compositions were chosen to examine a wider range in possible Si abundances in the core of Mercury. Each capsule was set up by completely filling the interior with the desired, pre-mixed, metal mixture. All run products were polished using hexagonal boron nitride powder instead of water to ensure no carbon was lost from the experimental charges [*14*]. All phases, were analyzed using a JEOL 8530F microprobe at NASA's Johnson Space Center (JSC). Each sample was painted with Pelco® colloidal silver liquid from the capsule to the edge of the 1-inch round to ensure contact with the sample holder. Since each experiment only contained metal, there was no need to coat the samples with a conductive material. All

Table 2. Resulting compositions from experiments run at 1 GPa and 1300 °C in wt%. N is the total number of analyses taken on the experimental charge.

	Final Compositions		
Initial Comp	**Si**	**C**	**Fe**
Si_5Fe_{95} N=13	4.07 4.50	4.95 1.32	90.98 94.18
$Si_{10}Fe_{90}$ N=10	5.20 9.78	3.37 0.40	91.41 89.81
$Si_{22}Fe_{78}$ N=9	18.23	0.40	81.37
$Si_{35}Fe_{65}$ N=21	19.46 31.80 69.27	0.47 0.47 30.28	80.06 67.73 0.45

analyses were collected at 15 keV and 30 nA, while using the cold finger on the microprobe to minimize carbon contamination. Si, Fe, and C were analyzed in each experiment. Carbon was analyzed using the LDE2 crystal and was standardized using a synthetic cohenite

(Fe_3C) standard made in the piston cylinder apparatus at JSC and verified by electron diffraction in a transmission electron microscope. Due to the wide peaks on the LDE2 spectrometer crystal as well as an interference between the backgrounds of C and Si, an optimal background was chosen to ensure this overlap was avoided. All data was corrected using the phi-rho-z matrix correction method, which is ideal when analyzing light elements.

Results: All experiments, with the exception of the one containing $Si_{22}Fe_{78}$, resulted in at least two compositions in the final quenched experiments (Table 2). The experiment containing $Si_{22}Fe_{78}$ did have a carbon dominated phase that was most likely exsolved during quenching of the experiment, however all grains were too small to analyze using the electron microprobe. Silicon carbide, with a minor iron impurity, was produced in the experiment with the highest Si content ($Si_{35}Fe_{65}$). The experiment with the lowest Si content (Si_5Fe_{95}) resulted in grains of metal containing ~1.3 wt% carbon surrounded by a quenched metallic melt containing ~5 wt% C (Figure 1).

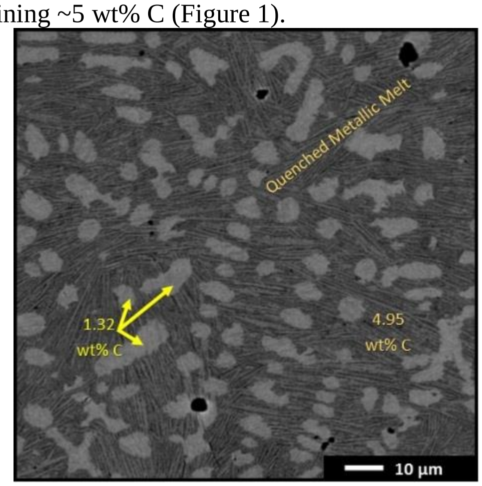

Figure 1. BSE image of an experiment that initially contained Si_5Fe_{95}. Resulting composition of the dark quenched melt is 4.07 wt% Si, 4.95 wt% C, 90.98 wt% Fe and the brighter metal grains are 4.50 wt% Si, 1.32 wt% C, and 94.18 wt% Fe.

Discussion: Although preliminary, the results of our experiments conducted at 1 GPa and 1300 °C have explored a wide range of possible Si-Fe compositions of Mercury's core. Our experiments show that in an iron dominated system, somewhere between 5 and 10 wt% Si, the metal preferentially excludes carbon over silicon. Figure 2 shows a Fe-C-Si ternary diagram including all analyses from the four experiments, excluding the analyses of silicon carbide present in a single experimental charge. From this figure, it can be inferred that the addition of Si into a Fe-dominated metal, preferentially excludes carbon from that metal phase, which has also been observed in other experimental studies [15]. These results have important implications for the thermal and magmatic evolution of Mercury.

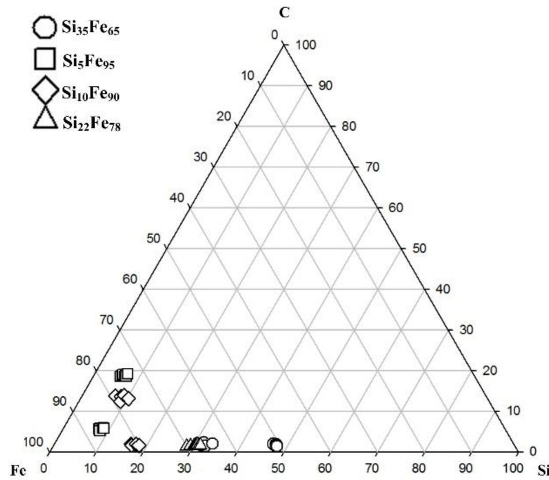

Figure 2. Fe-C-Si ternary diagram (atom %). Each symbol represents an analysis of metal within a given experiment.

Our experiments indicate that if Mercury has a Si-rich core (having more than ~5 wt% silicon), it would have saturated in carbon at low C abundances. If Mercury's volatile-rich nature [*16*, *17*] also holds true for carbon, a substantial proportion of the carbon in Mercury would have been excluded from the metallic portion of the planet. Additionally, carbon solubility in silicate melts is exceptionally low under highly reducing conditions, so it would have been excluded from the silicate portion of the planet as well [18]. These two factors would have led to the early saturation in graphite within a mercurian magma ocean at 4–7 GPa. Following the results of Vander Kaaden and McCubbin [*9*], this graphite would have been less dense than the surrounding materials and would have floated toward the surface, possibly forming a primary graphite floatation crust. The presence of this floatation crust is consistent with current observations from the MESSENGER spacecraft of darkened low-reflectance materials on the surface [*7*, *8*].

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