Silicon isotope constraints on the formation of silicates and metal in EH chondrites

Y. Kadlag[1], M. Tatzel[1, 2], D. A. Frick[3] and H. Becker[1], [1]Freie Universität Berlin, Institut für Geologische Wissenschaften, Malteserstraβe 74-100, 12249 Berlin, Germany, [2]Bundesanstalt für Materialforschung und –prüfung, Richard-Willstätter-Straβe 11, 12489 Berlin, Germany, [3]Helmholtz-Zentrum Potsdam, GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany (Contact: yogita@zedat.fu-berlin.de)

Introduction: Bulk enstatite chondrites (EC) and their achondritic counterpart, the aubrites, have the lightest measured Si isotope composition of all rocks in the solar system [1, 2, 3]. Some authors proposed that the enrichment of ^{28}Si in EC metal by equilibrium or kinetic isotope fractionation processes in the solar nebula may have led to the negative $\delta^{30/28}Si$ of bulk EC [4, 5]. Because EC are also depleted in refractory elements [6], loss of a heavy Si component with refractory elements might be an alternative explanation [5, 7, 8]. To further constrain their genesis, we analysed for the first time *in situ* Si-isotope ratios simultaneously with major- and trace element abundances in silicate and metal phases of Sahara 97072 (EH3) and Indarch (EH4).

Sample preparation and method: Thick sections of Sahara 97072 and Indarch were embedded in epoxy resin. The chemical composition of silicate- and metal phases of matrix, metal-troilite spherule (MTS) and chondrules were analyzed prior to laser ablation analysis using a JEOL JXA 8200 Superprobe at Freie Universität Berlin. Simultaneous determination of Si isotope ratios and the chemical composition of silicate phases (mostly enstatite, plagioclase and plagioclase + enstatite mixtures) and Fe-Ni metal were determined using a femtosecond laser ablation split stream (LASS) [9, 10]. Silicon isotope ratios in mineral phases were normalised to the NBS-28 standard that was used as bracketing standard. The long term reproducibility of $\delta^{30/28}Si$ is < 0.23 ‰ (2 SD). Major- and trace element abundances (Si, Mg, Fe, Al, V, Cr, Co and Ni) were quantified by 100 wt-% oxide normalization. Quantification limits were as low as 1 µg/g and combined uncertainties were typically <10 %, as determined by analysis of a range of reference materials.

Results and Discussion: Metal phases in the matrix show average $\delta^{30/28}Si$ values of -6.0 ± 0.6 ‰, similar to metal from aubrites [3]. The $\delta^{30/28}Si$ of metal grains in a MTS of Sahara 97072 ranges from -7.09 ± 0.19 ‰ (2 SE) to -8.24 ± 0.12 ‰, which is lower than the $\delta^{30/28}Si$ value of matrix metals. The difference between matrix metal and MTS metal were likely inherited from different nebular settings at which these metals formed. If equilibrium metal-silicate fractionation caused the isotopic differences between metal and silicates, formation temperatures of matrix metal may have been 1204 ± 43 K [calculated using equations from 3] and MTS metal may have formed at slightly lower temperatures of 1044 ± 86 K. These temperatures may reflect the conditions of the last pre-accretionary thermal processing events. Alternatively, the different metals originally may have equilibrated with silicates with variable $\delta^{30/28}Si$. Another alternative origin of the variable Si isotope ratios of the metals is variable extents of kinetic isotope fractionation between gas and solids during the incorporation of Si in condensed metal grains. At present it is difficult to distinguish between these different processes.

Silicates in chondrules show $\delta^{30/28}Si$ variations from -1.06 ± 0.13‰ to -0.38 ± 0.11 ‰. $\delta^{30/28}Si$ in matrix silicates ranges from -0.96 ± 0.18 ‰ to -0.22 ± 0.12 ‰. Thus, Si isotope ratios of silicates in both EH chondrites range from values similar to CI chondrites ($\delta^{30/28}Si_{CI}$ = -0.440 ± 0.112 ‰) to more ^{30}Si-depleted compositions. The occurrence of ^{30}Si-depleted silicates shows that the low $\delta^{30/28}Si$ of bulk EH chondrites not only reflects the presence of isotopically light metal, but also the loss of an isotopically heavy silicate component. Loss of 'isotopically heavy' Si from EH chondrite precursors may have occurred together with the loss of refractory elements [5]. The variation of $\delta^{30/28}Si$ in enstatite reflects Si isotopic heterogeneity in precursor silicates. The removal of refractory element and ^{30}Si-enriched phases from EH chondrite precursor materials was likely caused by open system solid-gas separation processes in the solar nebula [7].

In spite of the different metamorphic grades of Sahara 97072 and Indarch, the Si isotope fractionation between metal and silicates is not systematically different in two meteorites, and thus there is no evidence for diffusive re-equilibration of Si isotopes between silicates and metal phases in the parent body at these metamorphic conditions.

References: [1] Georg et al. (2007) *Nature* 447: 1102-1106. [2] Fitoussi and Bourdon (2012) *Science* 335: 1477-1480. [3] Ziegler et al. (2010) *Earth and Planetary Science Letters* 295: 487-496. [4] Javoy et al. (2012) *Earth and Planetary Science Letters* 319: 1186-127. [5] Savage and Moynier (2013) *Earth and Planetary Science Letters* 361: 487-496. [6] Wasson and Kallemeyn (1988) *Philosophical Transactions of the Royal Society of London* 325: 535-544. [7] Dauphas et al. (2015) *Earth and Planetary Science Letters* 427: 236-248. [8] Fitoussi et al. (2009) *Earth and Planetary Science Letters* 287: 77-85. [9] Frick D. et al. (2016) *Analytica Chimica Acta* 938: 33-43. [10] Schuessler and Blanckenburg (2014) *Spectrochimica Acta Part B: Atomic Spectroscopy* 98: 1-18.