MAGNESIUM-ISOTOPE COMPOSITIONS IN A COMPOUND AMOEBOID OLIVINE AGGREGATE – CHONDRULE OBJECT FROM ACFER 094 METEORITE. K. Nagashima1, G. Libourel2, M. Portail3, and A. N. Krot1, 1HIGP, University of Hawai’i, Honolulu HI, 96822, USA (kazu@higp.hawaii.edu), 2Observatoire de la Côte d’Azur, Nice, France. 3Centre de Recherche sur l’Hétéro-Epitaxie et ses Applications, Valbonne, France.

Introduction: The chondrule precursors include Ca,Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), chondrules of earlier generations, and fine-grained matrix-like material [e.g., 1]. As CAIs and AOAs have distinct isotope compositions, including O-isotopes, compared to those in chondrules, compound CAI/AOA/chondrule objects are suitable for investigation of gas-melt interaction including evaporation and condensation during chondrule formation. We have studied a compound AOA/chondrule object (A/Ch#1) from Acfer 094 ungrouped C3.00 chondrite [2]. The O-isotope compositions of this object suggest ~60–85% of oxygen was introduced from the gas, suggesting efficient O-isotope exchange between chondrule melt and gas [2]. In this study, we investigated Mg-isotope compositions in olivines from A/Ch#1 to understand condensation of Mg into chondrule melt as suggested by [3].

Methods: Mg-isotope compositions in olivines were measured using the UH Cameca ims-1280 SIMS. We used ~2 nA primary 16O beam produced by Hyperion-II ion source (installed in August 2019), and 4 Faraday cups (FCs) to measure simultaneously 25Mg, 26Mg, 27Al. Typical internal precision for δ25Mg is ~0.06–0.08‰ (2-standard-error) and typical external reproducibility of standard measurements is ~0.1–0.15‰ (2-standard-deviation). Since olivines in A/Ch#1 have relatively uniform composition at Fo~99, we used San Carlos olivine (Fo~90) and forsterite from Norton County aubrite (Fo~100) as standards. The Mg-isotope compositions of these olivines in DSM3 scale are reported in [4 and refs. therein]. Instrumental fractionation of Mg-isotopes in olivines changes depending on their forsterite contents [5], generally similar to the observations by [6,7]. We observed ~0.8‰ increase in δ25Mg from Fo~100 to Fo~99 and made a correction for Fo~99 by interpolating values between the two. However, more complex trend with abrupt changes around Fo~97 was found [6,7] and if we apply this trend, the δ25Mg values reported in this study are decreased by ~0.5‰.

Results and Discussion: Cathodoluminescence (CL) imaging of A/Ch#1 revealed at least 3 CL domains (CL-dark-core, CL-bright-mantle, CL-dark-rim) in olivine crystals. The O-isotope compositions are systematically different among the CL domains [2]. The CL-dark-core and CL-bright-mantle have 16O-rich compositions (Δ17O~ −24‰) similar to typical CAIs and AOAs, while CL-dark-rim region has 18O-poor, chondrule-like compositions (Δ17O~ −11 to −3‰). Thus CL-dark-core and CL-bright-mantle are relicts. δ18O-imaging shows their O-isotope boundaries are sharp, comparable to spatial resolution of the imaging (~1 μm).

We obtained 15 Mg-isotope compositions from different parts of olivine crystals revealed by CL imaging (Fig. 1). Magnesium-isotope compositions are homogeneous in both δ25Mg and δ26Mg* (excess 26Mg) within uncertainty (Fig. 2a) and no systematic differences are seen among the CL domains. The δ25Mg values are ~1−1.2‰, consistent with those for chondrule olivines [8], but inconsistent with negative δ25Mg values reported for AOA olivines [9]. All δ26Mg* values are ~0. Similarly forsterite contents (Fo) are limited to a narrow range around Fo~99, and also not correlated with their δ25Mg values (Fig. 2b).

Based on textures, minor element distributions, and O-isotope compositions, [2] concluded that original AOA materials experienced partial melting and transformation into the AOA/chondrule compound object during chondrule formation, and this transformation was accompanied by condensation of gaseous SiO into the initially 16O-rich AOA melt and O-isotopic exchange with 16O-poor gas. Magnesium-isotope compositions from 16O-rich parts of olivines might be expected to have negative δ25Mg values as all AOAs investigated by [9] have negative δ25Mg (~3.9 to −0.4‰). However, we found all olivines have δ25Mg ~1‰, consistent with those of olivines in Acfer 094 chondrules (+0.2 to +2.3‰) [8]. It seems this can be explained by homogenization of Mg-isotopes and Fo contents in olivine without significant changes in O-isotope compositions. Figure 3a shows diffusion rates of Mg, O and Fe-Mg interdiffusion in forsteritic olivine [10-12]. At high temperature, such as 1400°C, diffusion rates of Mg and Fe-Mg are comparable, but are ~4 orders of magnitude faster than that of O. Figure 3b shows calculated time required to have diffusion distances of 0.1 and 1 μm for oxygen and 50 and 100 μm for Mg in forsteritic olivine. If olivine overgrowth onto relict AOA olivines crystallized under high temperature, such as ~1600°C as [3] suggested, the object was kept for several hours to have diffusion distances of Mg and Fe-Mg of ~50–100 μm which are
comparable/smaller than the largest olivine grains, while O diffusion distance is only <0.5 μm.


Fig. 1. BSE and cathodoluminescence (CL) images of a compound AOA/chondrule object, A/Ch#1 from Acfer 094 ungrouped type 3.00 meteorite. In the CL image, Mg-isotope analysis locations are indicated by light-blue circles.

Fig. 2. $\delta^{25}$Mg values against (a) $\delta^{26}$Mg*, (b) Fo content, and (c) $\Delta^{17}$O values in olivines. Note these comparisons are made with values taken from nearest measurement locations, not always from same locations.

Fig. 3. (a) Diffusion rates of oxygen, magnesium, and Fe-Mg inter-diffusion in forsteritic olivine. The rates are from [10-12]. (b) Calculated time (hours) required to have diffusion distances of 0.1 and 1 μm for oxygen and 50 and 100 μm for Mg in olivine.