Ion Microprobe Measurements of Oxygen Isotope Compositions of Artificial Chondrule and CAI: Implication for Nebular Oxygen Exchange During the Formation of Chondrules and CAIs. B.-G. Choi[1], T. Nakamura[2] and M. Kusakabe[3], [1]Department of Earth Science Education, Seoul National University, Seoul, Korea 151-748 (bchoi@snu.ac.kr), [2]Department of Earth and Planetary Science, Kyushu University, Fukuoka 81-8581, Japan (tomoki@geo.kyushu-u.ac.jp), [3]Korea Polar Research Institute, Incheon, Korea 406-840 (mhk2314@hotmail.com).

Introduction: Oxygen isotopic heterogeneity preserved especially in primitive meteorites is interpreted as results of mixing between two or more oxygen reservoirs that had existed prior to or during the formation of chondritic materials [1]. Several models have been proposed for the nature of the reservoirs, including recent models of CO shelf shielding [2-4]. However, there are limited numbers of experimental and/or theoretical studies for oxygen isotope exchanges among oxygen bearing phases in the nebula [5, 6]. These studies show that, if oxygen isotopic exchange occurred during the formation of chondrules with CO gas as major gaseous species in the reaction, it would be required to have substantially longer duration times above melting temperature of chondrules and/or higher CO pressure that suspected for the solar nebula. Thus, it was suggested that oxygen isotopic exchange may be controlled by the proportion of CO to H_2O within the nebula, since H_2O dissociates much more rapidly than CO at high temperature and H_2O is able to contribute a substantially larger proportion of O_2 or O^{-2} to the nebular environment [6]. Recently Choi and Kusakabe [7] reported bulk oxygen isotope compositions of artificially recycled chondrules and Ca-Al-rich inclusion (CAI) after oxygen isotopic exchange with O_2 gas during brief (a few minutes) heating events using CO_2 laser. Here we report *in situ* oxygen isotope measurements of minerals in artificially recycled chondrules from Eagle Station olivine and Ca-Al-rich inclusion synthesized by [7]. We found that, in general, the compositions fall along new mixing lines connecting between compositions of original solids and reacted O_2 gas.

Analytical conditions: Cameca 6f at Kyushu university was used for *in situ* oxygen isotope measurements. Polished thick sections having artificially recycled chondrules and CAI along with San Carlos olivine used as oxygen isotope standard were coated with gold in order to minimize charging during the SIMS measurements. Electron flood gun was turned on for the charge compensation. Approximately 1 nA of Cs^+ beam was used that gave about 2.5 x 10^7 cps of $^{16}O^-$ at Faraday cup. Sputtered craters have about 15 μm in diameters with reasonably flat bottoms. Mass resolution of ~ 5500 was used in order to separate tail of ^{16}OH from ^{17}O peak. Masses 15.9 (back ground), ^{16}O, ^{17}O, ^{16}OH, 17.995 (tail of ^{18}O), and ^{18}O were measured for 0.5, 1, 5, 0.2, 1 and 1.5 seconds, respectively for one cycle (^{16}O on Faraday cup while the others on electron multiplier). Each measurement consists of 60 cycles. No effort was made in order to make matrix effect. Typical errors in samples are slightly larger than 1 ‰ (1 σ).

Results: Back scattered electron (BSE) images and oxygen isotope compositions of the artificial chondrule made from Eagle Station olivine and CAI from fragments of Allende CAIs are shown in figures. 1, 2, 3 and 4.

Artificial chondrule made from Eagle Station olivine. The Eagle Station olivine didn't melt completely, thus has relict grains inside (Fig. 1). The relict grains have oxygen isotope compositions of the original eagle station olivine, i.e., - 2.8 ‰ and 6.0 ‰ in $\delta^{18}O$ and $\delta^{17}O$ [8], respectively. The melted area, which formed barred olivine texture, has exchanged oxygen with gas, thus has the isotopic composition fall between those of original solid and reacted gas (Fig. 2); the red broken line is the best fit for the spot analyses and nearly identical to the line connect between original solid and reacted gas.

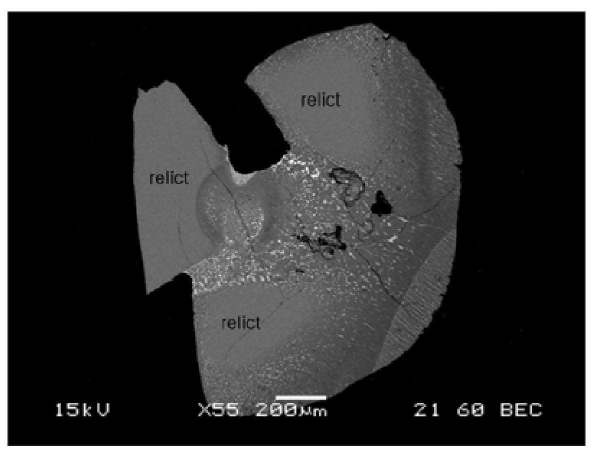

Fig. 1. BSE image of artificial chondrule from Eagle Station olivine. The right side with rounded shape was top that directly exposed to CO_2 laser. Barred olivine texture was formed at the right side. Three large relict grains are shown; they were relatively far from the CO_2 laser.

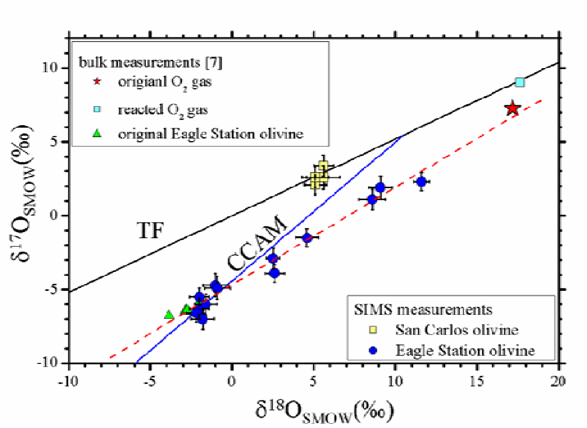

Fig. 2. Oxygen isotopic compositions of mineral phases in artificial chondrule made from Eagle Station olivine. Spot data fall along a mixing line that connects original solid and reacted gas. The red broken line is the best fit for the spot analyses.

Artificial CAI made from fragments of Allende CAIs. The artificially recycled CAI consists of spinel and plagioclase (+ minor olivine) in fassite mantle. BSE image shows that this artificial CAI was melted almost completely except some small relict spinel grains (Fig. 3).

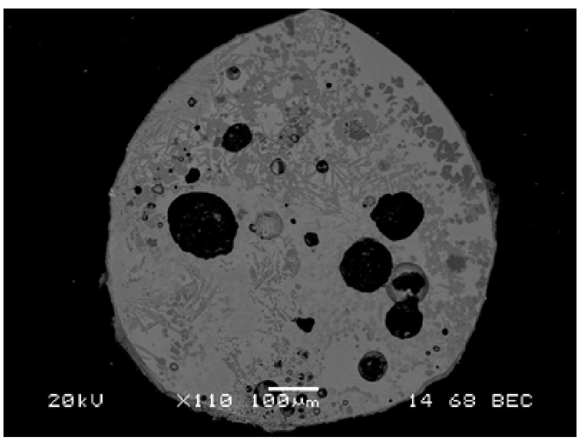

Fig. 3. BSE image of artificially recycled CAI from fragments of Allende CAIs. It was almost completely melted, thus has spherical shape. Light gray mantle is fassite, medium gray phases are either anorthite (needle shape) or FeO-rich spinel, and dark gray is mostly spinel with minor amount of olivine. Circular black areas inside are holes that probably was gas vesicles.

Relict spinel grains depleted in FeO have oxygen isotope compositions close to many natural CAI spinels, i.e., -40 ‰ in both $\delta^{18}O$ and $\delta^{17}O$ (Fig. 4). Relatively FeO-rich (up to 10 wt.%) spinel grains, anorthite and fassite mantle are more depleted in ^{16}O. The red broken line is the best fit for the spot analyses. It is not identical but very similar to the line connect between reacted gas and -40 ‰ in both $\delta^{18}O$ and $\delta^{17}O$.

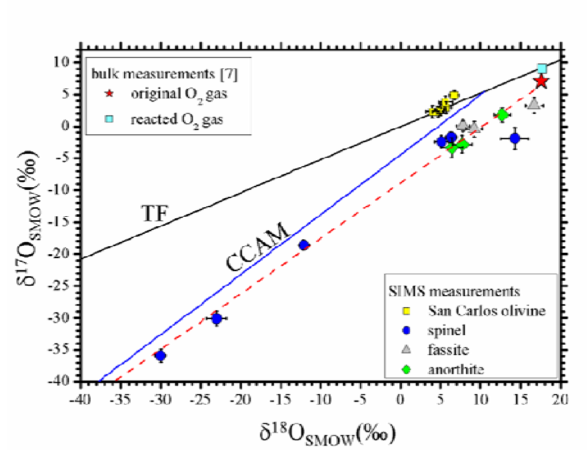

Fig. 4. Oxygen isotopic compositions of mineral phases in artificially recycled CAI. The red broken line is the best fit for the spot analyses. FeO-poor spinel has the most ^{16}O-enrich composition, while FeO-rich spinel, anorthite and fassite fall relatively close to the reacted gas.

Discussion: Our data show that the oxygen isotope mixing line of chondritic materials can be produced during brief heating and melting of chondrules and CAIs by exchanging their oxygen with surrounding gas, if O_2 partial pressure was high enough during the formation of them in the nebula. However O_2 gas is not the major oxygen-bearing gas species at the nebular condition, thus H_2O, which dissociated to form O_2, may have played important role in the oxygen isotopic exchange in the nebula as suspected by [6].

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