Al-Mg dating of a meteorite by using NanoSIMS

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In order to study the formation interval between Ca-Al-rich inclusions (CAI) and chondrules in carbonaceous chondrites, extinct nuclides such as ^{26}Al and ^{41}Ca are useful. There are principally two analytical methods to detect their decay products such as ^{26}Mg and ^{41}K. The first one is in situ analysis by using SIMS and the second is MC-ICP-MS together with a successive procedures of micro-drilling, chemical digestion and separation. The former has an advantage of high spatial resolution down to 5 micro-meter but the analytical precision is not generally as good as that of TIMS. The latter shows a high precision equivalent with TIMS but the spatial resolution is significantly poor. Recently a NanoSIMS NS50 ion microprobe with a supreme lateral resolution has been developed by Cameca and applied to the field of cosmochemistry. Here we report ^{26}Al-^{26}Mg dating of a single anorthite grain located in a chondrule by using the NanoSIMS. It is noted that a CAI of the CV chondrite, Efremovka shows the oldest Pb-Pb age (4567.2 Ma) but its chondrule age is not well documented. A thin section of Efremovka was set in a sample holder together with standard anorthite (Miyake-jima) and olivine (San Carlos) and carbon coated to dissipate charge during analysis. The positions of anorthite grains in the chondrule are determined by using a scanning electron microprobe before SIMS analysis. Using a critical illumination mode, a ~500 pA mass filtered O^- primary beam was used in the case of anorthite grains to sputter a 3~4 micro-meter diameter crater and secondary positive beams were extracted for mass analysis using a Mattauch-Herzog geometry. We detected $^{27}Al^{++}$ (a secondary electron multiplier detector called EM#1) at mass 13.5, $^{24}Mg^+$ (EM#2) at 24, $^{25}Mg^+$ (EM#3) at 25 and $^{26}Mg^+$ (EM#4) at 26 at the same time under a static magnetic field. A mass resolution of 7000 (Cameca definition) was attained for separating $^{24}Mg^+$ from $^{48}Ca^{++}$ with adequate flat topped peaks. The Mg sensitivity of 100 cps/1 nA/ppm was obtained by an intensity of ^{24}Mg ion beam and abundance of Mg in the standard anorthite. In the case of olivine samples, at first, we used a primary of 1 pA and detected Mg isotopes by the same multi-collection system. However we have observed undesirable isotope fractionations probably due to Quasi Simultaneous Arrival (QSA) effect. In order to avoid the effect, we used a primary of 10 nA and detected Mg isotopes by a single Faraday cup with a magnetic scanning mode. Abundance of ^{27}Al in olivine samples was less than the detection limit of the Faraday cup. The d^{25}Mg values of Miyake-jima anorthite (^{25}Mg/^{24}Mg ratios in delta notation) ranged from -24permil to -30permil, while the d^{26}Mg values ranged from -48permil to -60permil, suggesting a typical mass dependent fractionation with a slope 2. On the other hand, 5 spots in a single anorthite grain (about 25 x 10 micro-meter) in an Efremovka chondrule showed apparent excess ^{26}Mg. The d^{25}Mg values of San Carlos olivine and Efremovka chondrule olivine ranged from -3permil to +8permil, though they are located on the mass dependent fractionation line in a three isotope plot. Thus there is no excess ^{26}Mg in both terrestrial and extraterrestrial olivine samples. In the diagram between Al/Mg ratio and excess ^{26}Mg, 5 spots data of Efremovka anorthite are located along a line with a positive inclination. If the excess ^{26}Mg is attributable to the extinct ^{26}Al, an inferred ^{26}Al/^{27}Al ratio becomes 5.3×10^{-6} based on the slope. This ratio suggests that the formation interval between CAIs and this chondrule is about 2.4 Ma. In conclusion we have developed an Al-Mg dating method of a single anorthite grain by using NanoSIMS. The formation interval of 2.4 Ma between CAIs and a chondrule in Efremovka was estimated. This method may be applicable to various kinds of primitive meteorites in future.