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A K-Ar dating instrument for future in-situ dating on planetary surfaces

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Surface retention age is one of the most fundamental observables in planetary science. Crater chronology is often used to estimate the timing of geologic events. For example, crater counting on lunar maria revealed most of the mare basalts were emplaced 3.5 Gyr ago, while the latest eruptions occurred 1-2 Gyr ago mainly in the Procellarum KREEP Terrane [Hiesinger et al., 2004; Morota et al., 2011]. The absolute age determination relies on correlation between crater number density and age (chronology function), which is calibrated with the radiometric ages of the samples due to the Apollo and Luna missions [e.g., Neukum, 1983]. Since there are no returned samples showing >3.9 Ga and 3.0-1.0 Ga, however, the chronology curve has 0.5-1 Gyr of uncertainty in this range. To determine the shape of the chronology function is important not only for accurate age determination but also for understanding the temporal variation of the impact flux to the Earth-Moon system. For example, whether or not the impact flux has a spike around 3.9 Gyr ago, namely the lunar cataclysm hypothesis, is one of the main issues regarding the uncertainties of the impact flux [e.g., Gomes et al., 2005].

In-situ age measurements and/or sample-return mission(s) are needed to resolve this problem. We have been developing an in-situ dating method using K-Ar system for future planetary landing missions on the Moon or Mars [Cho et al., 2011, 2012]. The K-Ar dating method employs radiometric decay of 40K into 40Ar with half-life of 1.25 Gyr [Steiger & Jager, 1977]. This method requires much less technological developments than other dating methods, such as Ar-Ar, U-Pb, and Sm-Nd dating, because K is relatively abundant (~100 ppm-1 wt%) in the igneous rocks and Ar can be easily extracted (i.e., simply heat the sample). This leads to a simpler instrumental configuration. Our system measures the abundance of both K and Ar at the same laser irradiation spot on a sample using with two techniques (i.e., laser-induced breakdown spectroscopy (LIBS) and quadrupole mass spectrometer (QMS)). Potassium and argon are extracted from a sample simultaneously by the laser ablation, in which the sample is vaporized by a series of intense (> 1GW/cm2) laser pulses.

Using our instrument, we measured three samples whose K concentrations and ages have been measured previously with flame photometry and a sector mass spectrometer: a hornblende (K2O=1.12 wt%, 1.75 Ga), a biotite (K2O=8.44 wt%, 1.79 Ga), and a plagioclase (K2O=1.42 wt%, 1.77 Ga) [Nagao, unpublished data]. We obtained the model ages of 2.1+/-0.3, 1.8+/-0.2, and 2.0+/-0.3 Ga, respectively. We measured K2O with a calibration curve constructed by measuring 24 geologic samples with known K2O concentration. The absolute amount of the extracted Ar is measured with the QMS. The sensitivity to Ar isotopes was calibrated by introducing the known amount of atmospheric Ar into the experimental system.

Since the three samples have similar ages and different K concentrations, we should be able to construct a "virtual" isochron by plotting the concentrations of K and $40Ar_{rad}$. The slope of the isochron simulated with our experimental data yields 1.34 Ga of age. The data with known values yields 1.79 Ga. Such underestimation probably results from both overestimation for K and underestimation for 40Ar in the biotite data, which have large weight for the regression. Nevertheless, a clear correlation between [K] and [$40Ar_{rad}$] is observed. Although further improvement in the accuracy of our measurements is necessary, the data obtained in this study demonstrate that our LIBS-QMS method can reproduce the trend essential for quantitative isochron-based age measurements.

Keywords: In-situ age measurement, K-Ar dating, Planetary explorations