Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS23-P06 Room:Convention Hall Time:May 24 17:15-18:30

Development of an in-situ K-Ar dating instrument for landing planetary missions

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We propose an instrument that conducts the in-situ age measurement of rocks during landing missions. The absolute age of a geological unit is one of the most important information for the planetary science. However, the absolute chronology of Mars is poorly constrained due to the lack of directly dated samples. The uncertainty is as large as 1 billion years, preventing us from quantitative understandings of the Martian history. In order to obtain accurate and precise age, sample return missions are of course ideal but such a mission must face many technical challenges and huge budget as compared to sending a robot to the planet. Additionally, sampling place will be limited because of the cost. Therefore the main goal on Mars mission is to the calibrate absolute chronology by in-situ age measurement on Mars.

Our interest also includes future lunar landing missions. One of the most important objectives is that contribution to the sample-return mission from the Moon because such a mission is more realistic than that of Mars. Our instrument will be able to provide information whether a rock underwent resetting event after its formation. We can choose primitive rock samples on the Moon, maximizing the scientific value of the sample return mission.

The instrument determines the K-Ar age of rock samples on a rover in the following way. Laser-induced breakdown spectroscopy (LIBS) and quadrupole mass spectrometry (QMS) are coupled with each other to measure K and Ar, respectively, and it is named LIBS-QMS system. The instrument consists of a vacuum chamber, pulsed laser, an X-Y stage, a CCD camera to observe the measured site, a spectrograph, a QMS, a getter to purify the extracted gas, and a vacuum pump, which is unnecessary for lunar missions. An outstanding feature is that the spot analyses using laser beam enable isochron measurements, which improves the accuracy and precision of age determination.

In order to establish the K-Ar in-situ dating instrument, the following items need to be achieved: (1) improving the accuracy of K measurement by overcoming the matrix effect, (2) improving the detection limit for both K(~1000 ppm) and Ar(^{40}Ar~10^{-11} cc, ^{36}Ar~2x10^{-11} cc) by an order of magnitude, and (3) inventing proper sample handling system, that is, how to pick up rocks, put them into the vacuum chamber, and how to measure them.

We show the current strategy to resolve such issues. First, the matrix effects are shown to be removed to some extent by the multivariate analytical techniques (e.g., partial least squares regression method, neural network analysis). Such statistical techniques will be introduced to our signal processing method. Secondly, we have improved the experimental conditions by optimizing the light collection system in order to enhance the observed intensity of K emission lines. We also replaced our previous detector system, which consisted of a 75 cm spectrograph and an ICCD camera, to a compact spectrograph (~ 500 g in weight) equipped with an ordinary CCD detector. Our preliminary experimental results show that the K emission lines from ~4000 ppm K2O sample are detected by such spectrographs. Improving the limit of detection by an order of magnitude seems to be possible. To improve the detection limit of Ar, the conditions of laser beam (e.g., beam diameter, pulse energy, and beam profile) are required to be optimized. Reducing the blank level of QMS is essential as well. We are now building an oil-free exhaust system. The sensitivity of QMS will be enhanced by reducing the volume of the vacuum system. Finally, the sample handling procedures will be considered with some experts in this area. We are going to establish our method in 2012 and build a compact breadboard model by the end of 2013.

Keywords: In-situ dating, K-Ar dating, Landing mission, LIBS-QMS