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

PPS22-P02 Room:Convention Hall Time:May 25 11:45-12:15

Ultra-sensitive noble gas analysis system for return samples from the solar system

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Isotopic compositions of terrestrial and extraterrestrial materials are important to understand the formation and evolution of the solar system materials and bodies, since they are contributed by some processes such as radioactive decay, mass fractionation, and isotope exchange. Noble gases are most sensitive to such isotopic effects because of the extreme depletion in solid materials. In extraterrestrial materials, He and Ne are dominated by isotopes that originate from solar wind implantation, spallation/n-capture reactions, and radioactive decay ($^{235,\ 238}$U and ^{232}Th). Heavy noble gases, Ar, Kr, and Xe are mixtures of products from stellar nucleosynthesis (s-, r-, and p-processes), radioactive decay (^{40}K, $^{128,\ 130}$Te, ^{238}U, ^{232}Th, ^{244}Pu, and ^{129}I), and spallation/n-capture reactions, in addition to primordial (planetary) gas. Hence, the noble gas isotopes reflect many processes and should be a useful tool for cosmochemistry and geochemistry.

Because of their low abundances in solid planetary materials, extremely high sensitivity is necessary for a noble-gas analyzer. In order to measure microgram- or sub-microgram samples returned by space explorations, I have been constructing a new ultra-sensitive mass spectrometry system at Kyushu Univ. The system is a combination of a conventional mass spectrometer that consists of a magnetic sector-type MS with a Neir-type ion source), and a resonance ionization mass spectrometer (RIMS) that consists of a resonance ionization ion source and a time-of-flight (TOF) MS.

The conventional MS is useful to measure all noble gases (He, Ne, Ar, Kr, and Xe) with a detection limit of around 5000 atoms. Helium and Ne in Antarctic micrometeorites (around 0.5 microgram in weight) have been measured using a small resistant furnace (called Pot-pie furnace). Return samples from asteroid and lunar regolith should contain amounts of solar-wind He and Ne of which isotopic ratios and concentrations would reflect the regolith history.

The RIMS is designed to measure extremely small amounts of Kr and Xe ($>$100 atoms), referring to RELAX (Refrigerator Enhanced Laser Analyzer for Xenon) developed by Dr. J. D. Gilmour and his colleagues. The RIMS at Kyushu Univ. is equipped with a dye laser system (TII Tokyo Instruments Inc.) that generates 3.5 mJ per pulse (8 nsec of pulse width) at 216 and 256 nm of wavelengths applied for ionization of Kr and Xe, respectively. The power densities of the UV lights are probably high enough to ionize Kr and Xe with almost unit probability when focused to be $<$0.01 cm in diameter in the ion source. Ionization efficiencies and ion transmissions will be investigated. The RIMS enables to apply many radiometric dating (such as I-Xe, Te-Xe, and Pu-Xe) and Kr-Kr dating that will be very interesting for samples experienced cosmic-ray exposure.

For gas extraction from samples, the analysis system is equipped with a pulse Nd:YAG laser in addition to the furnace (Pot-pie). The Nd:YAG laser produces 200 mJ per pulse (10 nsec) at 1064 nm. The focused beam has a diameter of 50 micrometer and will create the plasma plume. The plasma lights have wavelengths that depend on the chemical composition of fused area of the sample, and are measured using a LIBS (Laser-induced Breakdown Spectroscopy) system. Using the LIBS system, the fused mass can be calculated by measuring the major element abundances. Also, potassium contents will be determined for micro-area K-Ar dating.

The RIMS and LIBS systems are now under construction, and the progress will be reported.

Keywords: return sample, noble gas