THE ELEMENTAL ABUNDANCE OF MAGNESIUM IN SOLAR WIND SAMPLES RETURNED BY GENESIS.* W. F. Calaway[1], I. V. Veryovkin[1], C. E. Tripa[1], M. R. Savina[1], M. J. Pellin[1] and D. S. Burnett[2], [1]Materials Science Division, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439 (email: WFCalaway@anl.gov) [2]Division of Geological and Planetary Sciences, Mail Code 100-23, California Institute of Technology, Pasadena, CA. 91125.

The return to Earth of solar wind samples by the Genesis Discovery Mission[1] has opened new opportunities to better understand the composition of the solar nebula and formation of our solar system. The various high purity materials which acted as collectors for solar wind were returned to Earth in September 2004 and are now available for analysis. These samples contain a record of the elemental and isotopic abundances of the solar wind implanted in the near-surface region of the collectors.

Estimates of the composition of both the photosphere and solar wind have been made through various determinations. Some solar wind abundances have been determined previously by examining foil collectors from Apollo[2] and directly from unmanned missions, including ACE, WIND and SOHO.[1] However, the sum total of all data collected lacks the completeness and accuracy needed to test current models of solar system formation. It was the goal of Genesis to return solar wind samples for terrestrial analysis in order to obtain a comprehensive set of elemental and isotopic abundances at significantly higher precision and accuracy levels than presently available.

A new secondary neutral mass spectrometry (SNMS) instrument implementing resonance enhanced multiphoton ionization (REMPI) of ion-sputtered and laser-desorbed neutral species has been developed and constructed for the specific purpose of quantitative analysis of metallic elements at ultra-trace levels in the solar wind collectors returned to Earth by the Genesis spacecraft. This resonance ionization mass spectrometry (RIMS) instrument has been described elsewhere in detail.[3] Since accurate quantitative analysis is compromised by sample contamination, several features have been built into the new RIMS instrument to mitigate this difficulty.[4] The main advantages of the RIMS instrument are its sensitivity, accuracy and selectivity. The RIMS technique has been shown to be capable of quantitative sub-parts per billion determinations while consuming little sample.[5]

The solar wind composition of the various metallic elements range from above one part per million ($>10^{-6}$) to below one part per trillion ($<10^{-12}$) and are embedded within 100 nm of the surface,[1] making analysis a challenging proposition but well suited for RIMS. The first measurements are focused on determining Mg, Ca and Cr in Genesis samples. These measurements will determine concentrations and isotopic abundances and help elucidate fractionation effects between the photosphere and the solar wind compositions due to first ionization potential fractionation. Since these elements are present in relatively high concentrations, these measurements also serve as a useful first test of the RIMS method and will help to better identify sample contamination problems. Generally, Genesis samples have been found to be contaminated by a thin film deposited during flight and by particles introduced when the Sample Return Capsule was breached during its crash landing. The ubiquitous nature of Mg makes it an ideal candidate to examine whether surface contamination will limit the accuracy or precision of the RIMS measurements.

To quantify the Mg concentration in the solar wind, measurements of composition versus depth were conducted on Genesis samples and compared to a standard. The standard consisted of a Si wafer implanted with 43 keV ^{25}Mg at a dose of 1.10×10^{13} atoms/cm^2. Two Genesis samples from the B or C collector arrays (60178 and 60179) were cleaned using a Megasonic ultra-pure water stream at Johnson Space Center (JSC) before being sent to Argonne National Laboratory (ANL). JSC has found that this cleaning procedure removes a substantial fraction of the surface particulate contamination (>50%), leaving areas as large as 500 μm in diameter particle-free at the ≥1 μm scale. Both the C and D collector arrays of Genesis were

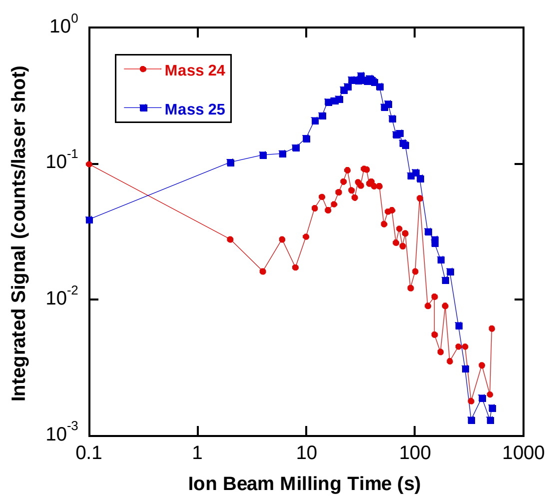

Figure 1. RIMS depth profile of implant standard.

exposed to the solar wind for the entire 27 months that the collection canister was open and thus should represent the average solar wind over that time.

Shown in Fig. 1 is the depth profile for ^{24}Mg and ^{25}Mg in the implant standard. These two isotopes as well as ^{26}Mg follow the expected shape for an implant. Small amounts of ^{24}Mg and ^{26}Mg are expected in the implant standard due to an inefficient mass filter capability of the implant tool. By integrating the three mass peaks over sputter time, it is determined that the ^{25}Mg represents 0.744 of the total dose or 8.18×10^{12} atoms/cm^2. To calibrate the depth scale, profilometry measurements performed on sputter craters produced during SIMS measurements at Arizona State University on part of the same standard were used.[6] These results determined that the peak in the depth profile is at 76 nm and allows the sputter time to be converted to depth.

Of particular interest is the Mg signal very near the surface of the implant. As can be seen from Fig. 1, the ^{24}Mg signal is much larger than the ^{25}Mg at the surface, and the ^{24}Mg decreases with depth while the ^{25}Mg increases. Since ^{24}Mg is the dominant terrestrial isotope, these data are a clear indication that the surface was contaminated by adventitious Mg from the environment at some point prior to the analysis. This result bodes well for analysis of Genesis samples, since the Mg surface contamination in the implant sample was limited to the surface (<10 atomic layers) and could clearly be separated from the implanted Mg by examining the composition versus depth profile.

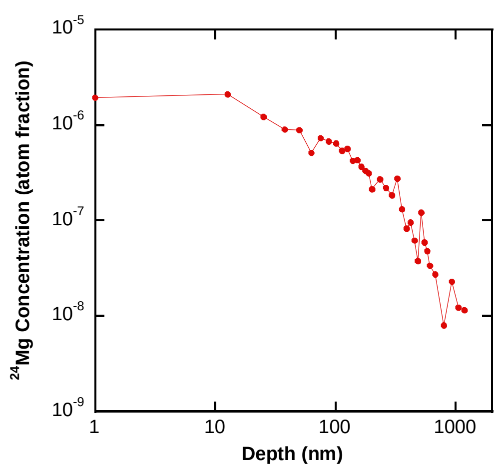

Figure 2. Concentration of ^{24}Mg versus depth in Genesis sample 60178 as determined by RIMS.

Shown in Fig. 2 is the depth profile of ^{24}Mg in Genesis sample 60178. In this plot, the depth and concentration have been determined using calibration data obtained from the implant standard shown in Fig. 1. To improve the accuracy of the calibration, both the standard and Genesis samples were measured within two hours of each other on the same day while keeping the instrument parameters exactly the same. During this time period, neither the laser intensity nor ion beam current was found to have changed significantly.

Two features of the concentration versus depth profile merit comment. First, the depth profile shows no peak as was expected for the implanted solar wind. Second, the Mg concentration near the surface shows no spike suggesting that terrestrial contamination does not dominate the Mg from the solar wind. A total of three measurements were performed on sample 60178. All three show the same qualitative behavior, namely inconsequential surface contamination and no peak in the composition versus depth profiles. For these first measurements, a 15 keV ion beam was used for both analysis and ion milling. In future experiments, a normal-incident, low-energy ion beam will be used for ion milling. It is possible that this dual beam mode of operation will improve depth resolution allowing a peak in the depth profile to be observed.

The ^{24}Mg dose in the Genesis sample was quantified by integrating the measured depth profile and scaling the result by the integrated depth profile of the implant standard and the implant dose. The measured value obtained for ^{24}Mg was 1.02×10^{12} atoms/cm^2. This value is the average of two measurements that differ by <3%. A quantitative result from the third measurement was not possible due to a large Mg signal that suddenly appears at a depth of ~300 nm, possibly due to contamination from a nearby surface particulate.

The measured dose is lower than expected for the 27 month solar wind exposure by about a factor of two.[1] Since only two measurements were made and only on a single sample, it is unclear if difference between the measured and expected fluence is significant. Measurements are currently in progress on the second sample to determine if there exist concentration variations among samples and to better assess the accuracy and precision of the RIMS measurements.

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