CORONAL MASS EJECTION ATOMS RECORDED IN ILMENITE GRAIN FROM LUNAR SOIL 71501.

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Introduction: Our Sun often generates big solar flare events. The Carrington event occurred in 1859 is the largest solar flare ever observed. Solar-type stars have generated superflares with energies several thousand times larger than the Carrington event [1]. Such extreme solar flare events are often accompanied by coronal mass ejections (CMEs), with large number of energetic particles reaching Earth's orbit without decreasing their speed (Solar storm). The energetic particles are implanted into surfaces of soil on airless celestial bodies. The implantation range increases with increasing the particle speed. Therefore, we can estimate an energy distribution of the implanted atoms by depth profiling of the solar wind components [2]. High energy components related to CMEs would appear as a tail of normal solar wind implantation profile [3].

Lunar soil samples have recorded the antiquities of solar winds [4]. Compared to other minerals in the soil, ilmenite have high retentivity of solar wind noble gases [5]. The lunar soil sample 71501 collected by Apollo 17 is estimated to have been exposed to solar wind from ~100 Ma to present [6, 7]. To explore a record of past solar high energy events, we performed noble gas depth profiling for the 71501 ilmenite grain.

Samples and Methods: We used an ilmenite grain from Apollo 17 lunar soil 71501 of which diameter was about 100 μm. The grain was mounted on an indium metal to expose a flat surface on the top.

Noble gas analysis was carried out using laser ionization mass nanoscope (LIMAS). LIMAS is a time-of-flight (TOF) secondary neutral mass spectrometer that can measure noble gases with high spatial resolution using Ga focused ion beam. Ionization of sputtered noble gases are performed by strong field of focused femtosecond laser [8]. Depth profiling was performed by the analytical procedure similar to [2]. Primary beam pulse of $^{69}Ga^{+}$ (30 nA for the beam current, ~1 μm ϕ , and 500 ns for the pulse width) was scanned on the sample surface for an area of 10×16 μm^2 with 0.5 μm step interval. For each step, 200 primary beam pulses were irradiated. Post ionized ions of each beam pulse were introduced into multi-turn TOF mass spectrometer MULTUM II [9] with an acceleration voltage of -5 kV. We measured $^{4}He^{+}$, $^{20}Ne^{+}$, and major element ions of ilmenite, $^{56}Fe^{2+}$, $^{24}Mg^{2+}$, $^{16}O^{2+}$. TOFs for these ions were set to ~455 μs to separate interference peaks from target ions. This TOF corresponds to flight pass lengths of 224 m and 101 m for $^{4}He^{+}$ and $^{20}Ne^{+}$, respectively. These ions were detected using microchannel plates [10].

A terrestrial ilmenite polished section implanted with ^{4}He and ^{20}Ne was used as a standard to calibrate the concentrations of samples. The implantation energies of ^{4}He and ^{20}Ne were set to 20 and 100 keV with fluences of 3×10^{15} and 1×10^{14} atoms cm^{-2}, respectively. Samples and standard were measured in the same analytical session under the same analytical condition.

Results and Discussion: The depth profile of implanted ^{4}He into the 71501 ilmenite shows a plateau-like shape at 15–35 nm depth with a peak concentration of 7×10^{21} atoms cm^{-3}. The helium concentration decreases with increasing depth after the plateau until 1×10^{21} atoms cm^{-3} at 75 nm depth. Thereafter, decreasing slope becomes gentle. On the other hand, the depth profile of implanted ^{20}Ne into the 71501 ilmenite shows a Gaussian-like peak with a peak concentration of 5×10^{19} atoms cm^{-3} at 20 nm depth. The neon concentration decreases sharply after the peak until 9×10^{17} atoms cm^{-3} at 100 nm depth, and then the decreasing slope turns gentle.

Fluences of ^{4}He and ^{20}Ne into the ilmenite are calculated to be 4×10^{16} and 2×10^{14} atoms cm^{-2}, respectively. The ^{4}He/^{20}Ne ratio was ~230, which is similar to the value of previous study (~221 [6]), that measured by conventional noble gas analysis of several ilmenite grains separated from the same soil sample. This ^{4}He/^{20}Ne ratio is lower than the present ^{4}He/^{20}Ne ratio of solar wind (~656 [11]). This indicates that ^{4}He losses from ilmenite grains. The plateau-like depth profile for ^{4}He in this study supports the He loss.

The gentle slope (tailing) of the depth profiles deeper than 100 nm found in ^{4}He and ^{20}Ne should correspond to high energy solar wind components implanted in speeds more than 1000 km s^{-1}. Therefore, the tailing is evidence of the Solar storms by antique CMEs that have occurred over past 100 Ma.

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