Evaluation for multi-turn time of flight mass spectrum of laser ionization mass nanoscope

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Introduction: Laser ionization mass nanoscope (LIMAS) is a sputtered neutral mass spectrometer (SNMS) by tunneling ionization effect. This instrument was developed for measuring solar wind particles from extraterrestrial materials collected by planetary exploration missions, such as JAXA Hayabusa and NASA Genesis (Bajo et al., 2015). LIMAS consists of a Ga liquid metal ion source and an aberration corrector system for sputtering of nanometer scale area on samples, a femtosecond laser system for tunneling-ionization of the sputtered particles, and a multi-turn time-of-flight mass spectrometer (MULTUM II) for mass separation of isotope analysis. We have evaluated the performance of MULTUM II equipped with the ion injection optics of LIMAS.
Experimental procedure: We carried out numerical simulations of ion trajectories in the ion injection optics, and then load voltages for each lens were determined experimentally. As a result, Extraction lens L1 was -700 V, L2 was -3300 V. Einzel lenses 1 and 2 were set to -1260 V and -2700 V, respectively. Under these conditions, we evaluated mass resolving power and transmittance of LIMAS using $^{24}Mg^{2+}$. Data for each cycle were averaged for 1000 shots. We calculated useful yield of each cycle of LIMAS by depth profile of Si ions. The sputtered crater volume was measured by 3D laser scanning confocal microscope.
Results and Discussion: Mass-resolving power of TOF mass spectrometer is defined by time-of-flight of ion “t” and ion packet width “Δt” (R = t/2Δt). Mass-resolving power increased up to the TOF of 1000 μs (200 multi-turn cycles). After 1000 μs, mass-resolving power became saturated. Saturation of the mass-resolving power (R = ~10^5) indicates that the averaged peak width increases linearly with increasing the number of cycles. Increasing FWHM was occurred by different TOF of ion packet become large with increasing cycle. 3 factors affect by different TOF of ion packet: 1) modulation by the acceleration voltage (ΔU), 2) modulation of the injection timing for the ion injection optics (Δt_{L1}), and 3) modulation of the electric field for the electric sectors (ΔE) in MULTUM II. Modulations of ΔU and ΔE become dominant if TOF increase. The ΔE was observed at 5 ppm, corresponding to R = 10^5, which is consistent with the saturation value of R described above. In order to correct the modulation of ΔE, TOF correction among peaks must be effective. Appling TOF correction, the mass-resolving power of LIMAS increased linearly with increasing the flight path length, and reached 620,000 (FWHM) at 1,000 multi-turn cycles of MULTUM II (flight path length: 1,312 m).
The transmittance up to 20 multi-turn cycles decreased to 60–70%, compared with the transmittance on linear mode. After 20 multi-turn cycles, the transmittance per multi-turn cycle became constant (99.96%).
A useful yield of LIMAS was estimated. As a result, useful yield was 3 x 10^{-3} at 30 multi-turn cycles (R = 17,000), 2 x 10^{-3} at 1000 multi-turn cycles (R = 620,000) of MULTUM II. The calculated useful yields for LIMAS would be better than to those for Cameca ims 6f at the same R (cf. 7 x 10^{-3} at R = 4,000; Hervig et al., 2006).

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