Experimental equipment for exploring reactions of low energy ions with an ice surface as an interstellar dust analog

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An understanding of the synthesis of interstellar molecular evolution is indispensable for understanding various chemical aspects in the universe, *e.g.*, the origin of life. Various kinds of molecules have been found even in molecular clouds in the first stage of star formation, despite their very low temperature. Gas-phase ion-molecule reactions have been always considered to play an important role in the chemical evolution in molecular clouds. Reactions of neutral radicals with neutral species on an icy grain surface have been also proposed as other pathways, the importance of which has been confirmed for the production of hydrogen molecules, water molecules, methanol molecules, and so on.[1)] Recently, the reactions of very-low-energy (eV order) ions with an icy surface have been theoretically proposed to be new non-negligible reaction pathways. In most of the proposed pathways, neutral species and H_3O^+ ions are produced on the surface through reactions involving multiple water molecules.[2,3)] These reactions are extremely complicated compared with gas-phase reactions. In addition, an actual icy surface probably has more variety and complexity than the theoretical assumptions. Therefore, experimental investigations are crucial to confirm theoretical predictions and explore such reactions more deeply. However, no experiments have been reported to our knowledge. Thus, we have started developing an experimental apparatus. In this report, we will provide an overview of our apparatus under development.

Figure 1 shows a schematic of our experimental equipment. An amorphous solid water (ASW) film is made on an aluminum substrate mounted on the cold head of a He refrigerator at a low temperature (∼10–50 K) by introducing water vapor of $\sim 1 \times 10^{-5}$ Pa into the vacuum chamber. The thickness of the ASW film is estimated from its infrared absorption intensity, which is measured using Fourier-transform infrared spectroscopy (FTIR). After the introduction of water vapor is stopped, the ASW surface is irradiated with low-energy atomic/molecular ions using the ion source located at the front of the substrate (low-energy ion source in Fig. 1). This ion source consists of an electron-impact ionizer, a Wien filter in which the ions are mass-analyzed, and a deceleration lens system to decelerate and focus ions on the substrate. In the test of the ion source using a N_2^+ beam, we obtained an intensity of ∼2.8 nA with an energy of ∼3 eV and an energy spread of approximately ±2 eV on the substrate.

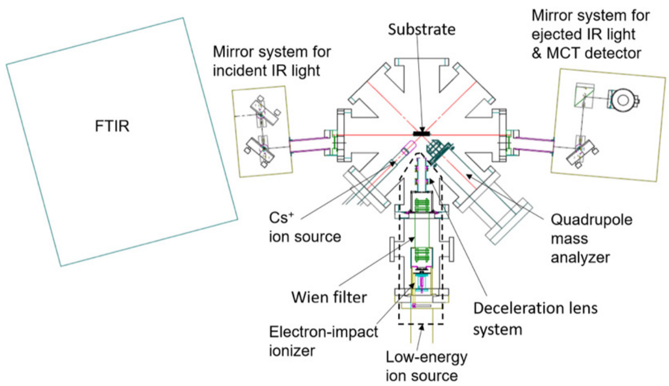

Fig. 1. Schematic drawing of the experimental setup.

Our apparatus has another ion source (Cs^+ ion source in Fig. 1) for detecting reaction products by the irradiation of low-energy atomic/molecule ions. The detection method is based on reactive ion scattering (RIS) and low-energy ion sputtering (LES) by Cs^+ ions with a kinetic energy of a few or several tens of eV, which has been mainly developed as a detection method for neutral and/or ionic species on metal and ice surfaces at temperatures higher than ∼70 K.[4)] When Cs^+ ions collide with an ice surface, a part of them pick up neutral species including water molecules on the surface and scattered composite ions of CsM^+ (RIS), where M is a picked-up neutral species. We can obtain a mass of M from the mass analysis of scattered CsM^+ ions. Moreover, we can obtain the masses of ionic species on the surface through the mass analysis of ions sputtered by Cs^+ (LES). A quadrupole mass analyzer is used for these mass analyses. At present, we performed isolated tests of the RIS method using a pristine ASW film at 30 K and could detect $Cs(H_2O)^+$ ions from the RIS process. However, the detection sensitivity will be further improved for our purpose.

We are now continuing development of the low-energy ion source and the RIS-LES method for the ASW surface at low temperature, aiming for better performances.

References

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