DEVELOPMENT OF INSTRUMENTATION FOR ATMOSPHERIC NEON MEASUREMENTS ON MARS.

Y. N. Miura[1], Y. Cho[2], H. Kurokawa[3], Y. Saito[4], S. Kasahara[2], K. Yoshioka[5], H. Kumagai[6], N. Iwata[7], H. Hyuga[2], A. Yamazaki[4], K. Fujita[4], T. Usui[4], H. Yabuta[8] and S. Sugita[2], [1]Earthquake Res. Inst., Univ. of Tokyo, Yayoi, Bunkyo, Tokyo 113-0032, Japan, [2]Dept. of Earth and Planet. Sci., Univ. of Tokyo, [3]ELSI, Tokyo Inst. Tech., [4]ISAS, JAXA, [5]Dept. of Frontier Sci., Univ. of Tokyo, [6]JAMSTEC, [7]Yamagata Univ., [8]Hiroshima Univ.

Introduction: The compositions of the planetary atmospheres give insight into planetary formation and evolution of surface environments via degassing and escape processes of volatiles over 4.6 b.y. (e.g., [1]). The depletions in lighter elements/isotopes of the present Martian atmosphere suggest extensive loss of the ancient atmosphere. Neon, the second lightest noble gas, is suggested to have been continuously removed from the atmosphere by sputtering. On the basis of the model according to the observation by MAVEN [2], Kurokawa et al. (2021) [3] estimated the lifetime of atmospheric Ne to be 60−100 m.y., which is much shorter than the age of Mars. The abundance of Ne in the Martian atmosphere has been reported by Viking mission as 2.5 (+3.5, -1.5) ppm [4]. Therefore, a source continuously supplying Ne to the atmosphere is necessary. By considering the fluxes from external and internal sources, Kurokawa et al. (2021) [3] concluded that volcanic degassing of Ne in the mantle is likely the source for the present Martian atmospheric Ne, suggesting atmospheric Ne as a probe of the Martian interior. The abundance of Ne in the source magma was estimated to be 0.3–4 × 10^{-9} g/g at least. Nevertheless, there is no report for the isotopic compositions of Ne with in situ measurements, which hinders us to unveil the ultimate origin of abundant mantle Ne. This is because the interference of $^{40}Ar^{2+}$ complicates the accurate measurement of $^{20}Ne^{+}$ with mass spectrometry. In order to determine the abundance and isotopic compositions of Ne in the Martian atmosphere, we propose an instrument combining a permeable membrane that physically separates Ne from Ar based on their atomic diameters and a mass spectrometer for future Mars explorations. A small lander for the International Mars Ice Mapper mission (I-MIM) would be a possible opportunity for such measurements [5].

In a previous study, we reported the basic capabilities for the Ne-Ar separation using polyimide and Viton sheets [6] and proposed to use a polyimide sheet as the membrane for future planetary explorations. However, outgassing from the Viton O-ring used to hold the polyimide sheet between two vacuum flanges was found to be a major problem in measuring the trace amounts of noble gases. Thus, in this study, we replace the Viton O-ring with a metal O-ring and performed additional permeation experiments: the amounts of permeated He, Ne, and Ar through a polyimide sheet were measured under various conditions. We also perform environmental tests to check whether the flanges withstand mechanical and thermal loads expected in planetary missions.

Instrument configuration: A schematic drawing of the instrument for Ne measurements is shown in Fig. 1. It consists of a flange system to hold the polyimide sheet for Ne-Ar separation, getter to remove active gases, vacuum pump, and mass spectrometer.

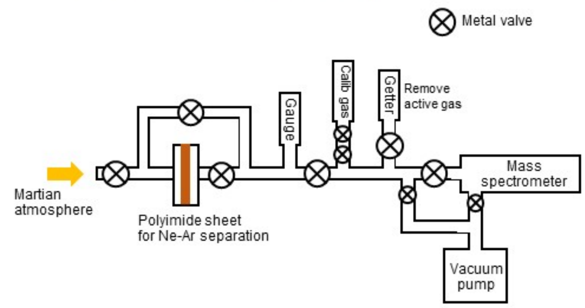

Figure 1. Schematic drawing of the instrument for Ne measurements.

Methods: The amounts of permeated He, Ne, and Ar were measured under different conditions. We examined (i) permeation of the atmosphere at low temperatures, (ii) permeation of ~590 Pa CO_2-Air mixture simulating the Martian atmosphere, and (iii) vibration test of flanges fixing a polyimide sheet.

Apparatus for measuring permeated He, Ne and Ar. A polyimide sheet was fixed between metal flanges made of stainless steel or titanium. The flange design is shown in Fig. 2. The thickness of the polyimide sheet is 100 μm, and its effective area for permeation is 28 cm^2. A set of flanges was connected to an analytical line equipped with a quadrupole mass spectrometer (QMS) at Univ. of Tokyo. Both sides of the polyimide sheet were first evacuated. To prepare ultra-high-vacuum condition, the analytical line including the flange set was baked out. Before each permeation analysis, procedural blank was measured without gas permeation. When permeation measurement started, one side of the polyimide sheet was opened to the 1 bar atmosphere. The duration of permeation was 40 minutes. The permeated ^{4}He, $^{20,22}Ne$ and ^{40}Ar were measured with the QMS. The experimental method is essentially the same as reported by [6].

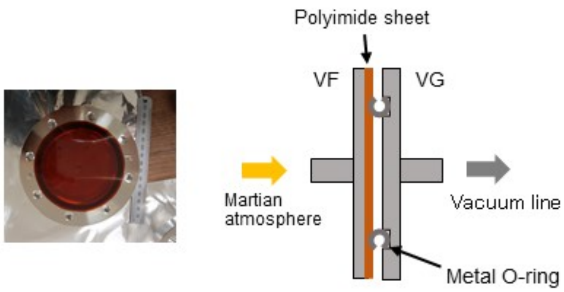

Figure 2. Flange to fix a polyimide sheet.

Permeation at low temperatures. The amounts of permeated He, Ne, and Ar through a polyimide sheet were determined under different temperatures: the room temperature (RT, ~20 °C), 6 °C, -18 °C and -37 °C (the temperatures are averages of the temperatures at the beginning and end of permeation except for RT). To keep the flanges at these temperatures except for RT, dry ice, ice and/or cold insulator were used. For the experiment at -37 °C, two permeation measurements were conducted: the 1st run started permeation when one side of the polyimide sheet was opened to the 1 bar atmosphere (the average temperature was -38 °C), while the 2nd run started 128 minutes after it was opened to the atmosphere (-36 °C).

Permeation of CO_2-Air mixed gas with the total pressure of ~590 Pa. A CO_2-Air mixed gas was prepared in a tank with the volume of 5.7 L and permeated through the polyimide sheet. The pressure of the tank during the permeation was 584 Pa. The volume ratio of CO_2/Air was estimated as 1/2.2 based on the ratio of CO_2 and ^{40}Ar measured with the QMS. We assumed that air without fractionation was contained in the prepared gas tank.

Vibration test of flanges fixing a polyimide sheet. The flanges were placed on a shaker at Dept. Aeronautics and Astronautics, Univ. of Tokyo. The random vibration of 16 Grms was applied to the flange set for 60 sec. After the vibration test, it was attached to the analytical line again, and the amounts of permeated He, Ne and Ar were measured at RT.

Results and discussion: Significant amounts of permeated He and Ne were detected in the experiments. No leakage occurred at the low temperature experiments nor after the vibration test. The permeated gas amounts were obtained after subtracting the blank. The amounts of permeated ^{4}He and ^{20}Ne at RT are consistent with the amounts obtained by theoretical calculation for a polyimide of the size used in this study (the theoretical amounts are 1.4×10^{-6} and 2.4×10^{-7} cm^{3}STP for ^{4}He and ^{20}Ne, respectively), where permeability and diffusion coefficient reported by [7] were used. For Ar, the amounts of blank ^{40}Ar and permeated ^{40}Ar were similar within the experimental uncertainty, implying that no significant amount of ^{40}Ar was permeated through the polyimide sheet. This is also consistent with the theoretical estimation, which predicts that the amount of ^{40}Ar permeation would be several orders of magnitude lower than the level of blank ^{40}Ar.

Figure 3 shows the amounts of permeated ^{4}He and ^{20}Ne as a function of invers temperature. The permeated amounts at -37 °C (the 2nd run) are approximately 1/6 and 1/8 of those at RT for ^{4}He and ^{20}Ne, respectively. The ratios of He/Ne are comparable among the data of RT, 6 °C and the 2nd run of -37 °C.

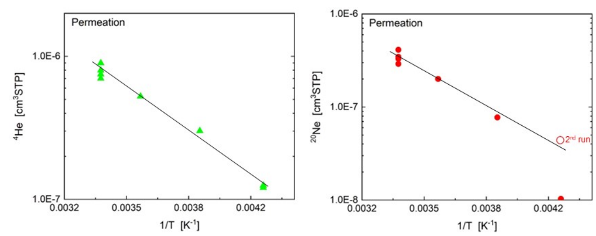

Figure 3. Amounts of permeated ^{4}He and ^{20}Ne versus invers of the temperature.

For permeation of the ~590 Pa CO_2-Air mixed gas, permeated ^{4}He and ^{20}Ne were also detected, whose amounts agree with the amounts estimated from the partial pressures of He and Ne in the prepared gas within 50%. The amount of CO_2 after the purification by the getter is similar to those observed in the permeation experiments done for the atmosphere. Permeation of gas containing abundant CO_2 (its partial pressure was about five times higher than that of the terrestrial atmosphere) did not affect Ne permeation. Our results confirmed the reasonable behaviors of permeation of the noble gases through the polyimide sheet as well as robustness of the polyimide sheet against the thermal and mechanical loads expected during planetary missions. These results strongly suggest the capability of the polyimide membrane for the Ne analysis on Mars.

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