クライオプラズマによる極低温環境に特有な赤色物質の生成（Ⅱ）：定性的評価および太陽系外縁天体との類似性

Cryogenic specific reddish coloration with cryoplasma (II): Qualitative characterization and analogy to Trans-Neptunian objects

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[Background] Trans-Neptunian objects (TNOs; 太陽系外縁天体) are exposed to various sources of radiation, which can cause physical and chemical changes, often creating reddish regions on their surfaces, such as that observed on Pluto (冥王星) [1]. In astrochemistry, many laboratory experiments simulating the chemical processing of molecules in planetary environments have been conducted, with plasma discharge commonly used as an energetic activation source to replicate the radiation in space that induces chemistry [2]. In experiments using plasma discharges, the reactors are frequently cooled with liquid N_2 to simulate the low temperature conditions of the planetary environment [2]. However, this method does not allow for good control of gas temperature. In this study, we utilized cryoplasma where the gas temperature can be controlled continuously between 273-5 K [3], to investigate cryogenic specific chemistry on TNOs, in order to shed light on the origin of their reddish coloration.

[Methods] Pluto, one of the largest TNOs, has an atmospheric temperature of 40- 110 K and a surface which is covered by N_2 and hydrocarbon ice [1]. In this experiment, to provide source of N atoms, He-3% N_2 was introduced and 1.75 kV_{pp} sinusoidal A.C. voltage was applied at 10 kHz to generate cryoplasma (Fig. 1A) in a dielectric barrier discharge configuration. CH_3OH/H_2O ice sample was used as the dielectric barrier and source of C and H. The ice sample was irradiated by cryoplasma for 12 hours at 85 K (Fig. 1B). Post-irradiation temperature-programmed desorption (TPD) spectra were obtained below 230 K with a quadrupole mass spectrometer at 10^{-1} Pa to analyze the volatile products formed at the plasma-ice interface. After heating the post plasma-irradiated CH_3OH/H_2O ice to room temperature, the residue was analyzed by liquid chromatograph mass spectroscopy (LC-MS).

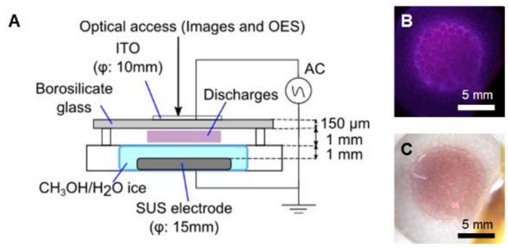

Fig. 1 (A) Setup and (B) top view of cryoplasma in contact with ice. (C) Obtained reddish coloration [3, 4].

[Results and discussion] Reddish coloration of the ice, similar in appearance to the surface of Pluto, was observed (Fig. 1C). Optical emission spectroscopy showed decreasing transmittance of the ice at UV and visible wavelengths, indicating that the reddish color was due to the absorption by the products synthesized.

Synthesis of various organic compounds with larger masses than the original CH_3OH/H_2O ice, such as glycols, carboxylic acids, and amides were confirmed by LC-MS. The presence of compounds containing C=C and C=N bonds could also be inferred from TPD analyses. The reddish coloration can thus be explained by these UV- and visible- absorbing conjugated systems. Such functional groups are significant in astrobiology as building blocks of prebiotic organic molecules such as proteins [5], so the observed reddish color could imply the possible existence of prebiotic organic compounds on TNOs. In addition, the presence of reddish coloration at cryogenic temperatures only could also be used to probe the temperature history of the environments of TNOs. Further, the temperature range of cryoplasma can replicate the temperature conditions of various solar system bodies [6]. Therefore, the results of this study could open new avenues for plasma science to contribute to astromaterials science.

References

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