Ionization of Sublimated Water Vapor for Lunar Cold Trap

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LuSTR Project Overview

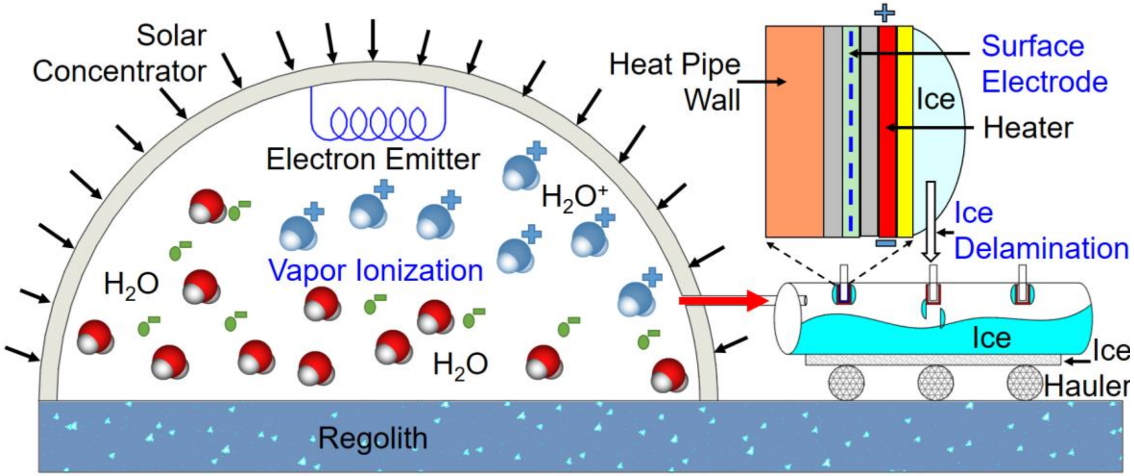
Research Goal: To develop and demonstrate an advanced thermal mining technology of 1 kg ice collection prototype in approximately 11 hours from icy lunar regolith that integrates engineered

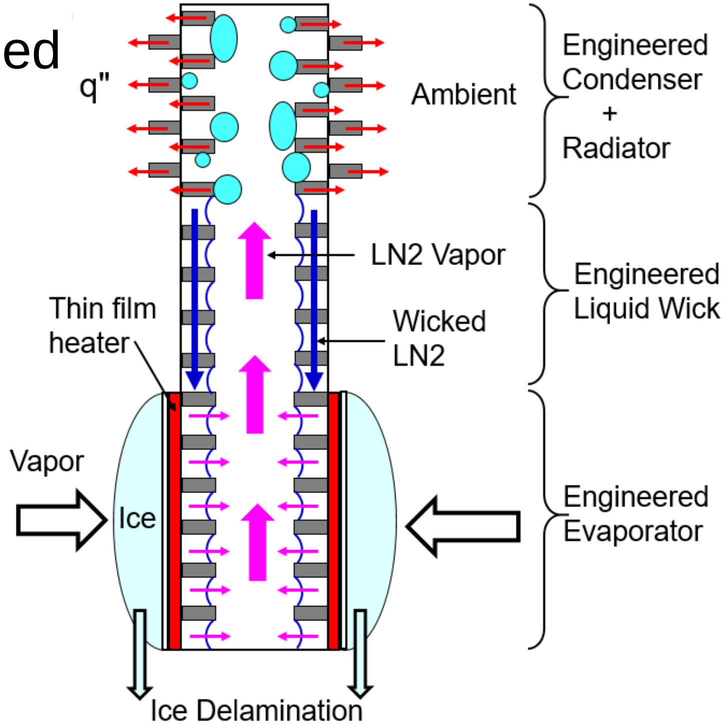
i. Extraction (thermal drill and capture tent)

ii. Vapor ionization and transportation

iii. Re-collection of water vapor using pulsed delamination of ice on an engineered cryogenic heat pipe

iv. System-level scale-up analysis of the proposed thermal mining technology





Ionization Methods

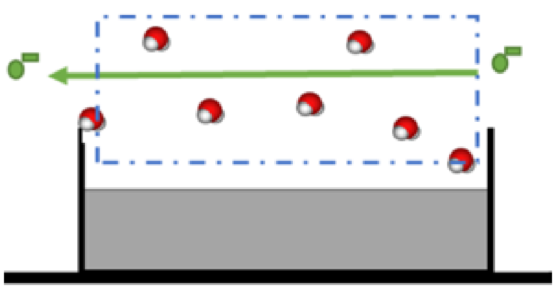
- DC Hollow Cathode Ionization: Utilizes a Direct Current Hollow Cathode (DC) to ionize sublimated water vapor through electron impact ionization.

- RF Ionization: Utilizes Radio Frequency (RF) excitation with Alternating Current (AC) to ionize water vapor through resonant excitation.

- Magnetic Trap with Hollow Cathode Ionization: Combines a Magnetic Trap (MT) with DC hollow cathode techniques using magnetic fields to enhance water vapor ionization.

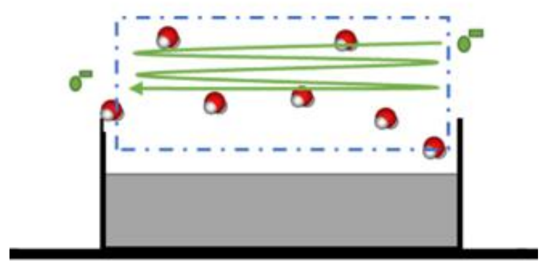
<u>DC electron source</u>

- High energy electrons
- One pass through sublimating vapor



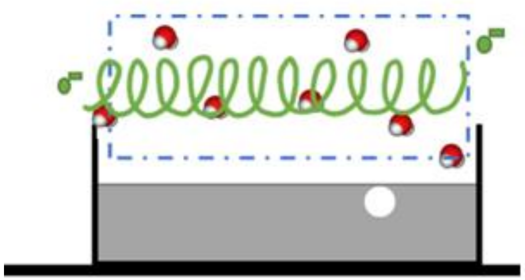
<u>RF electron source</u>

- Low energy electrons
- Multiple passes through sublimating vapor



<u>DC with Magnetic Trapping</u>

- High energy electrons
- Multiple passes through sublimating vapor



DC Hollow Cathode Schematic

- Liquid Nitrogen (LN2) is used to cool the chamber (-120 K).
- DC Hollow Cathode to ionize sublimated water vapor
- Argon gas used to create plasma for ionization
- Langmuir probes used to measure electron temperature
- Positive and Negatively charged copper plates to repel and attract ions
- Thin film heater to simulate sublimation method

Langmuir Probes

Negative Plate

Hollow Cathode Electron Emitter

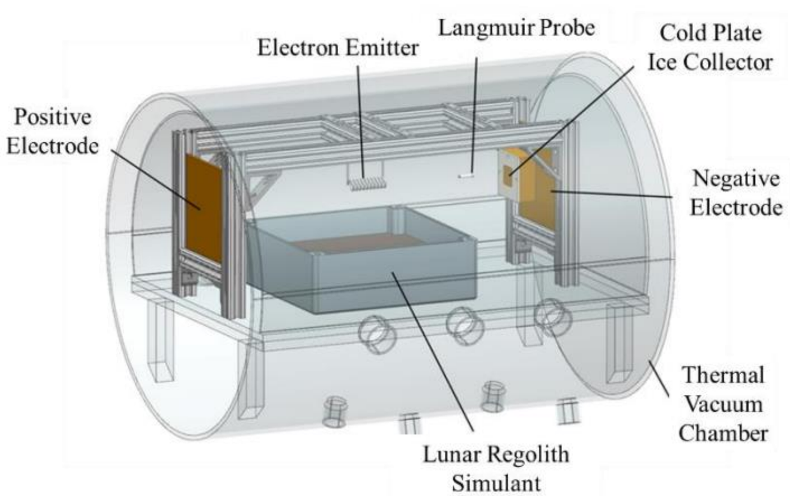
Regolith Heater

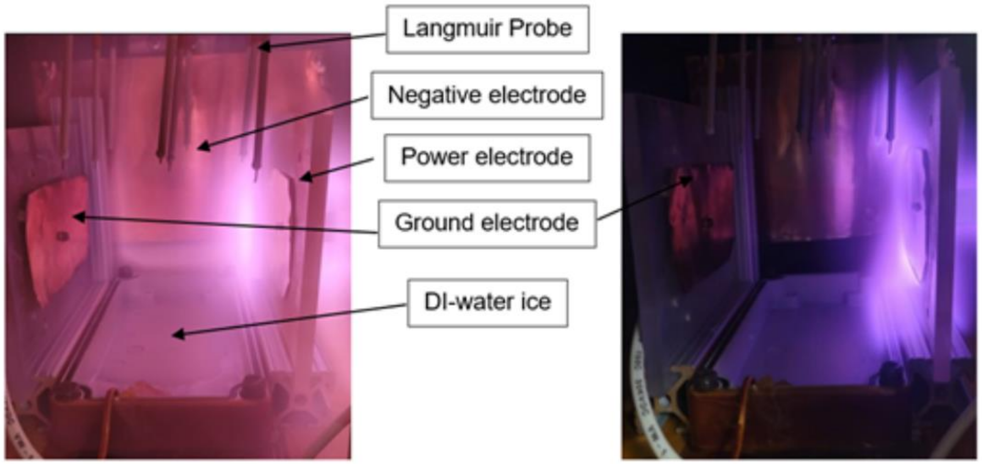
Hollow Cathode Electron Emitter Front View

Hollow Cathode Electron Emitter Rear View

Radio Frequency Schematic

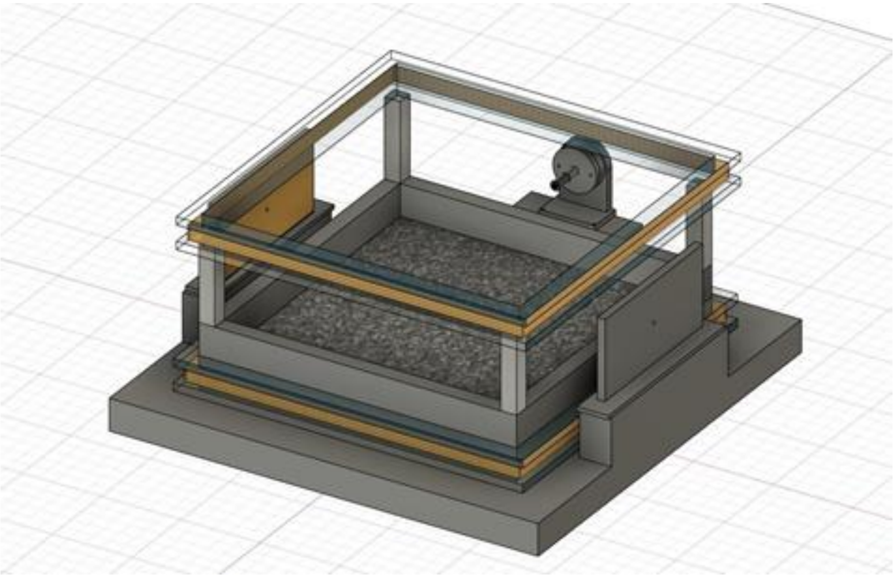
- Liquid Nitrogen (LN2) is used to cool the chamber (-120 K).
- Tungsten electron emitter is used for electron impact ionization of sublimated water vapor
- Alternating Current (AC) to excite the water vapor molecules and initiate ionization resonantly.
- Langmuir probes used to measure electron temperature
- Positive and Negatively charged copper plates to repel and attract ions
- Thin film heater to simulate sublimation method

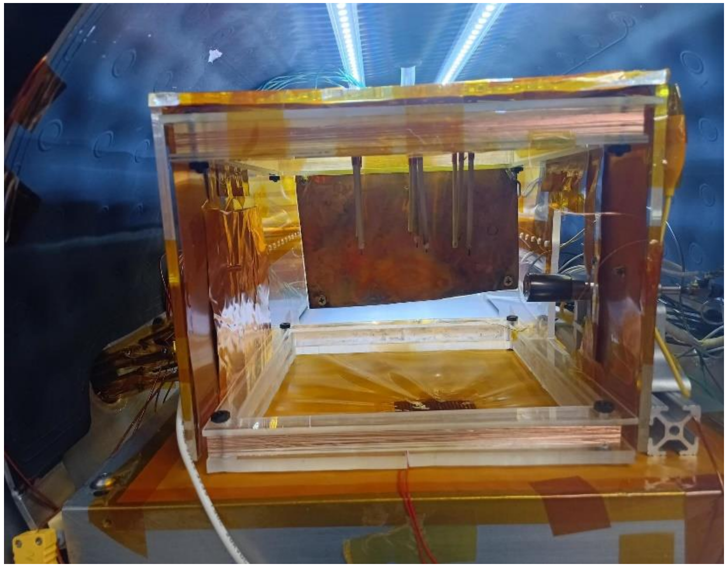




MT Hollow Cathode Schematic

- Liquid Nitrogen (LN2) is used to cool the chamber (-120 K).
- DC Hollow Cathode to ionize sublimated water vapor
- Argon gas used to create plasma for ionization
- Helmholtz magnetic Coils used to create magnetic field
- Langmuir probes used to measure electron temperature
- Positive and Negatively charged copper plates to repel and attract ions
- Thin film heater to simulate sublimation method





Data Analysis

Calculations for %ionization

1. $T_e = \frac{V_1 - V_2}{ln\frac{I_1}{I_2}}$

2. $V_e = (\frac{2eT_e}{m_e})^{1/2}$

3. $J = A_G * T^2 * e^{\left(\frac{-W}{k*T}\right)}$

4. $n_e = \frac{J}{e(v_e)}$

5. $n_v = \frac{G}{V_v m_v}$

6. $\lambda_{mfp} = \frac{1}{\sigma(n_v)}$

7. $N_p = \frac{l_r}{2r_{le}}$

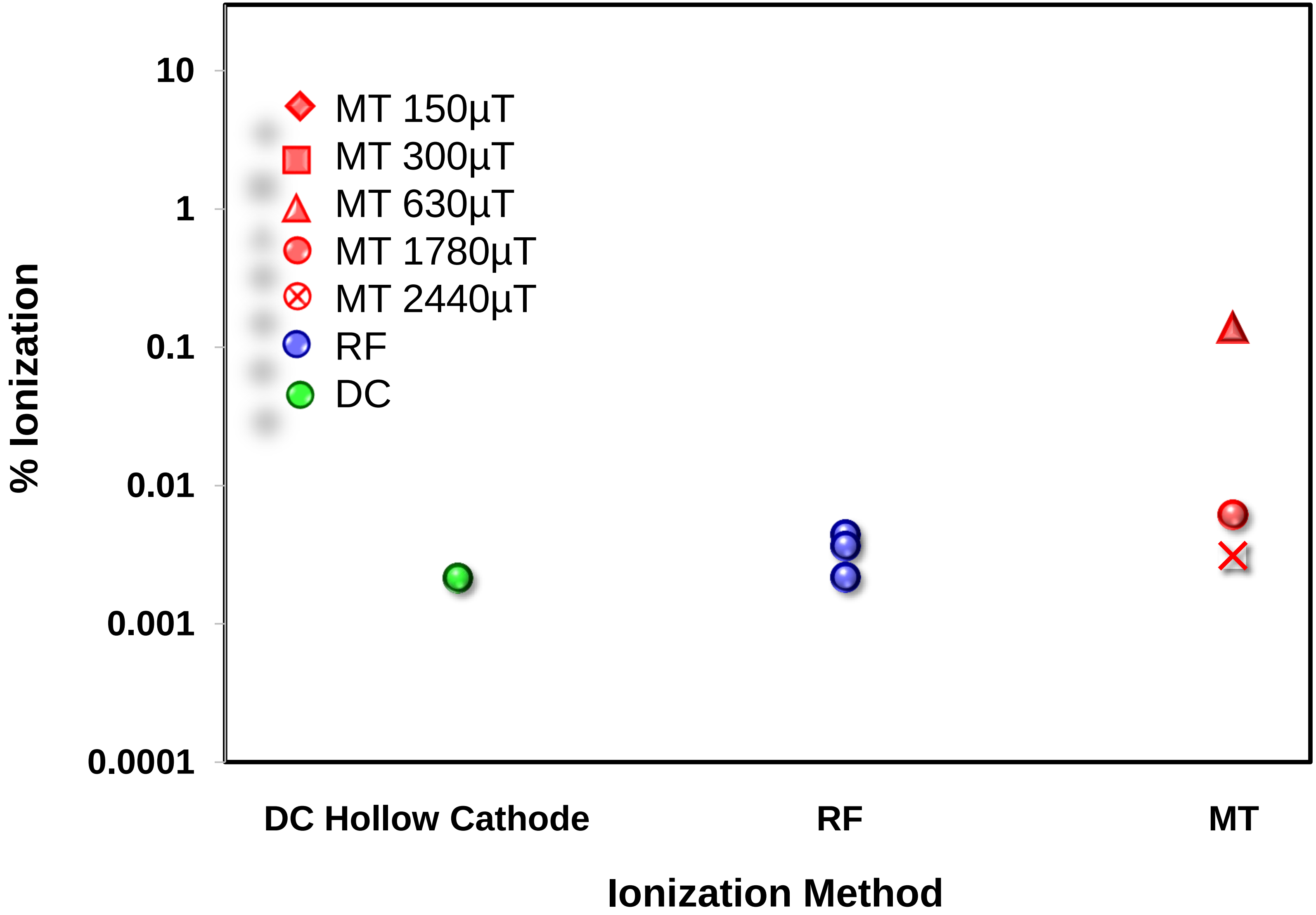
8. $n_{i,MT} = \frac{N_p n_e l_r}{\lambda_{mfp}}$

9. $\%_{ion} = \frac{n_i}{n_v}(100)$

Nomenclature:

1. Electron Temperature (taken from graph)
2. Electron Velocity(derived from Te)
3. Current Density
4. Electron Density
5. Water Vapor Density
6. Mean Free Pass
7. Number of Passes
8. Water Ion Density
9. Percent Ionization

Results



10
1
0.1
0.01
0.001
0.0001
% Ionization
MT 150µT
MT 300µT
MT 630µT
MT 1780µT
MT 2440µT
RF
DC
DC Hollow Cathode
RF
MT
Ionization Method

Conclusions

- The Magnetic Trap method, utilizing the hollow cathode in conjunction with magnetic fields, demonstrated superior ionization efficiency compared to the RF and DC methods. This suggests that combining magnetic fields with the hollow cathode technique enhances the probability of ionizing more sublimated water vapor particles.

- The Magnetic Trap method displayed an increased ionization rate due to the ability of magnetic fields to control the movement and confinement of ionized vapor. This interaction between the magnetic field and the electrons within the trap contributed to a more efficient ionization process, resulting in higher percent ionization.

- The experimental data revealed varying percent ionization rates for each method, with the Magnetic Trap exhibiting the highest efficiency in ionizing sublimated water vapor. The RF method followed closely, while the DC Hollow Cathode method showed slightly lower ionization rates.

Acknowledgement

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References

- Kornuta, D., et al., "Commercial Lunar Propellant Architecture – A Collaborative Study of Lunar Propellant Production," 2018, published online,
- Frias, J., Shafirovich, E., and Van Woerkom, M., "Extraction of Volatiles from Lunar Regolith Using Solar Power," Journal of Thermophysics and Heat Transfer, Vol.28, No. 2, April - June 2014.
- Sowers, G., Dreyer, C., and Williams, H., "Ice Mining in Lunar Permanently Shadowed Regions," Colorado School of Mines, NIAC Phase I Final Report, 2019.
- Hedge, U. et al., "Analysis of Water Extraction from Lunar Regolith," NASA/TM-2012-217441, May 2012.
- K. Zacny, P. Morrison, V. Vendiola, A. Paz, “Volatile Extractor (Pvex) for Planetary In Situ Resource Utilization (ISRU)”, Planetary Science Vision 2050 Workshop 2017 (LPI Contrib. No. 1989)
- Email Communication, John Scott, Chief Technologist, Power and Propulsion Division, NASA JSC, August 21, 2019.
- Julie E. Kleinhenz and Aaron Paz. "Case Studies for Lunar ISRU Systems Utilizing Polar Water," AIAA 2020-4042. ASCEND 2020. November 2020.
- Ethridge, E., W. Kaukler, and M.S. El-Genk, Microwave Extraction of Water from Lunar Regolith Simulant. AIP Conference Proceedings, 880 (1), p. 830-837., 2007,
- Inan, U., & Gołkowski, M., “Principles of Plasma Physics for Engineers and Scientists”, Cambridge University Press, 2010, doi:10.1017/CBO9780511761621
- N. I. Jurado, A. D. Amato, P. A. Mendoza, E. Negron, I. Torres, A. Amador, M. M. Rahman, A. D. Greig, and A. R. Choudhuri, “Increasing Ice Collection Rates on Engineered Cold Plate under Cryogenic Vacuum Conditions”, Accelerating Space Commerce, Exploration, and New Discovery (ASCEND), November 15-17, 2021
- O. W. Richardson, "On the negative radiation from hot platinum," Philosophical of the Cambridge Philosophical Society, 11: 286-295, 1901
- Dan M. Goebel and Ira Katz, “Fundamentals of Electric Propulsion: Ion and Hall Thrusters”, John Wiley & Sons, Inc., 2008, ISBN:9780470429273,