Development of Permittivity Sensors for Lunar Water Prospecting. C. Gscheidle[1], and P. Reiss[1], [1]Technical University of Munich (Boltzmannstr. 15, 85748 Garching, Germany, c.gscheidle@tum.de)

Introduction: Precise knowledge of the distribution, abundance and physical state of lunar volatiles is crucial for planning future missions. The data from numerous remote sensing missions around the Moon has provided a strong basis for such analyses, however ground truth data for verification and model correlation is still lacking especially from the lunar poles. Although upcoming exploration missions, such as NASA's VIPER and ESA's PROSPECT, will hopefully improve the ground truth data availability, broader coverage and finer spatial resolution is necessary.

Measuring the regolith's electrical permittivity is a technically feasible and scientifically meaningful technique to quickly determine the state and abundance of water in lunar regolith. Multiples missions to the Moon and other celestial bodies have used or intend to use permittivity sensors [1,2,3] and the Technical University of Munich (TUM) is currently developing this measurement technique for multiple additional instruments [4].

Electrical Permittivity of Lunar Regolith: The electrical permittivity (or dielectric constant), describes a material's ability to store energy in an electric field. Any mixture of materials between two electrodes and their respective relative permittivity influences the system's electric capacitance. In the context of lunar exploration, this phenomenon can be exploited as the relative permittivity of vacuum (=1), dry regolith (~5-8), and water (liquid and ice, ~80-100) differ significantly in both magnitude and behaviour in the frequency domain [6]. Measuring the capacitance of a calibrated system thus allows for deduction of the material's permittivity and subsequently the water content.

Permittivity Sensors exhibit several advantages for usage on spacecraft: They are lightweight, require very low power and can cope with harsh environments while providing scientifically meaningful data. Based on a basic RC-circuit, the measurement principle is based on applying a square wave excitation potential with given switching frequency and measuring the transient charging process. This characteristic time series yields frequency domain information when being Fourier transformed.

Besides the (relative) electrical permittivity, such sensors can also provide information on the material's electric conductivity and magnetic properties over frequency.

Currently, TUM is involved in multiple permittivity sensor development activities:

- The Lunar Volatiles Scout (LVS) is a drilling instrument designed for exploring the lunar poles by characterizing thermally extracted volatiles with an integrated mass spectrometer and pressure sensors [5]. Its drill shell geometry forms a cylindrical capacitive system with the central heating element, which can be employed to perform permittivity measurements to extend the LVS capabilities. An analog LVS setup for testing with representative dimensions is shown in Figure 2.
- The instrument package PROSPECT, developed by ESA, includes a permittivity sensor integrated into its drill to measure the subsurface regolith properties and detect water ice, as well as determine the geometry of the borehole [1].
- Drawing from the above involvements, we are currently investigating different forms of patch electrodes for permittivity sensors. These flat and light electrodes could be attached to otherwise

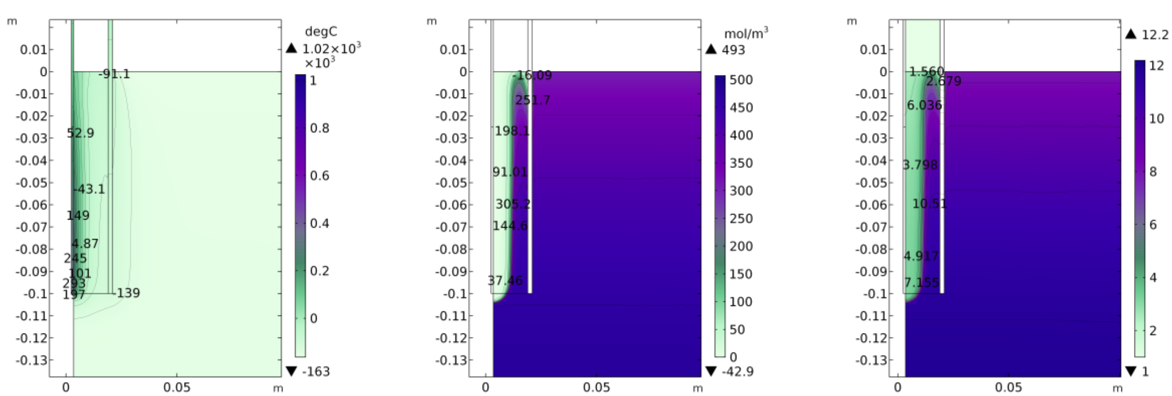

Figure 1: Exemplary result fields from the LVS simulations after 400 s heating: (left) Temperature; (middle) Adsorbed water concentation; (right) Electrical relative permittivity. The modeled domain is rotationally symetric around the instrument's central axis.

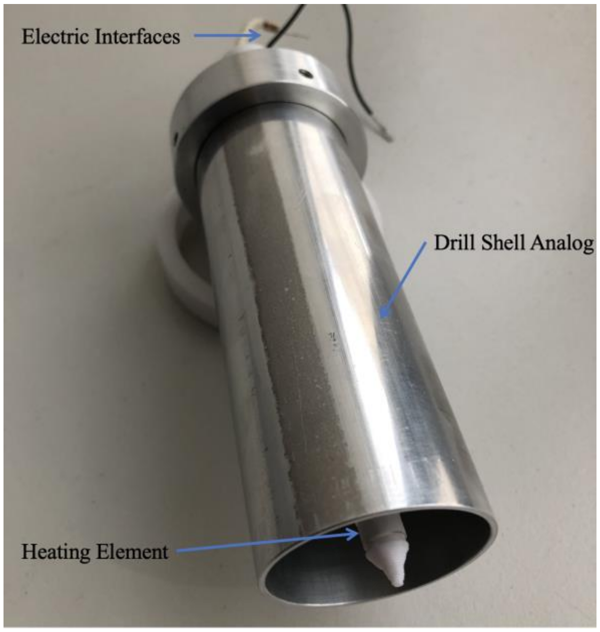

Figure 2: LVS Analog for testing.

unused surfaces of exploration systems, such as wheels of rovers or pads of lander foots. Valuable data on the subsurface can be acquired herby using only minimal resources.

Simulations of the physical system are crucial both for developing an optimized sensor configuration and for interpretation and correlation of the sensor data. However, as permittivity is dependent on material mixtures, temperatures, and frequencies, sophisticated multi-physics simulations are required. Based on the heat and mass transfer model for the lunar surface by Reiss [7] and Smolka [8], we extended the model into the electrical domain to simulate the electrical fields and resulting capacitances. Exemplary results from the simulations for our LVS system are presented in Figure 1. The simulation shows a clear dependence between the different physical parameters, where heating causes a decrease in the adsorbed water concentration, which in turn leads to a decrease of the relative permittivity.

The simulations predict that the system is able to detect different amounts of water in the regolith. A permittivity measurement before and after heating thus allows estimating the initial hydrated and final dry concentration of water in the sample volume, providing an important reference for the correlation with other instrument data on gas pressure and composition, as well as temperature.

As the model is sensitive to material composition and the respective mixing rules, further tests will be performed in a relevant environment to verify the results of the multiphysics simulations.

Conclusion: Prospecting for water on the surface of the Moon (and volatiles on other celestial bodies) benefits from the availability of rapid surveying techniques. Especially for mobile prospecting and exploration platforms, compact and simple instruments are advantageous. The proposed permittivity sensor technology offers scientific instrumentation for the in-situ characterization of volatile water in a small and simple package that can be integrated in existing designs with little additional effort.

Preliminary coupled multiphysics simulation confirm the feasibility of such measurements. Nevertheless, further experiments are necessary to determine mixing laws and for model correlation and verification.

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