

DIELECTRIC CONSTANT MEASUREMENTS FOR CHARACTERIZING LUNAR SOILS,

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Introduction: The return to the Moon has ignited the need to characterize the lunar regolith using fast, reliable in-situ methods. Characterizing the physical properties of the rocks and soils can be very difficult because of the many complex parameters that influence the measurements. In particular, soil electrical property measurements are influenced by temperature, mineral type, grain size, porosity, and soil conductivity. Determining the dielectric constant of lunar materials may be very important in providing quick characterization of surface deposits, especially for the Moon. A close examination of the lunar regolith samples collected by the Apollo astronauts indicates that the rocks and soils on the Moon are dominated by silicates and oxides. In this presentation, we will show that determining the dielectric constant measurements can provide a simple, quick detection method for minerals that contain titanium, iron, and water. Their presence is manifest by an unusually large imaginary permittivity.

Background-Impedance Spectrometry (IS): The dielectric constant, ϵ , is expressed as the product of the permittivity of free space, ϵ_0 , times the relative permittivity, ϵ_r . The permittivity is further described as $\epsilon_r = \epsilon' - j\epsilon''$ where ϵ' is the real permittivity and ϵ'' is the imaginary permittivity.

Lunar Mineral IS Measurements: Figures 1 and 2 shows that the dielectric constant (real permittivity), ϵ' , can be used to determine the soil density for terrestrial and lunar minerals. The simple relationship shown in the figure holds especially true for silicates and oxides. The only major exceptions are the lunar titanates, which have abnormally high permittivity.

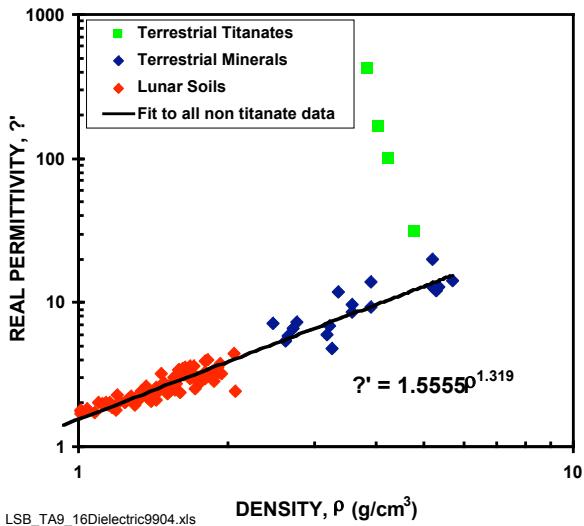


Figure 1. Dependence of the real permittivity versus solid terrestrial mineral density

In Figure 3, the imaginary permittivity, ϵ'' , is plotted against ϵ' for various lunar values of %TiO₂ + %FeO. This graph demonstrates a direct correlation in the amount of %TiO₂ +

%FeO in the lunar soil. At the measured ϵ' , the amount of

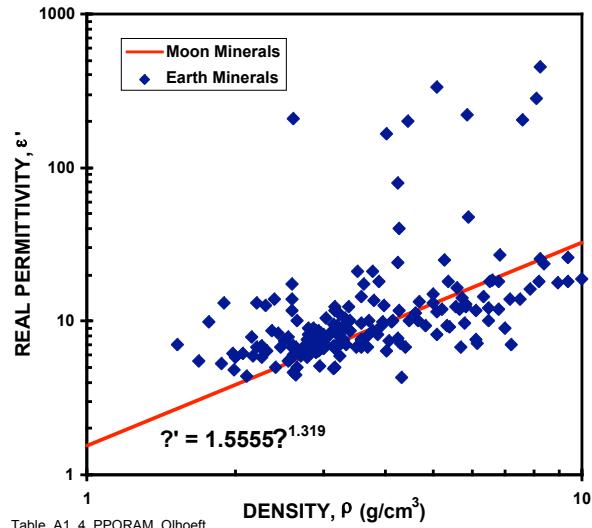


Figure 2. Dependence of the dielectric constant (real permittivity) on an assortment of Earth-based minerals. The lunar regolith fit line is shown for comparison.

%TiO₂ + %FeO is determined from ϵ'' . Four outlier data points appear at low values for %TiO₂ + %FeO.

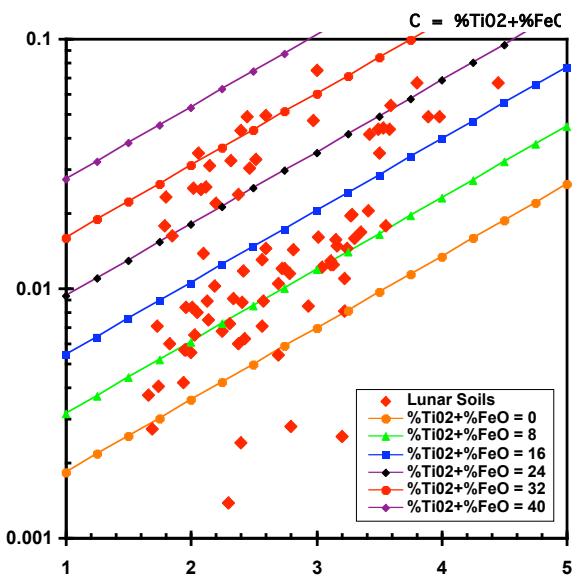


Figure 3. The percentage of TiO₂ and FeO can be determined by measuring the real and imaginary part of the permittivity. The measured data are for lunar soils returned from the Apollo missions.

Water-Ice IS Measurements: Early data returned by the Lunar Prospector spacecraft indicated the possibility of water ice being present at both the north and south lunar poles. The ice originally appeared to be mixed in with the lunar regolith

(surface rocks, soil, and dust) at low concentrations conservatively estimated at 0.3 to 1 percent buried beneath as much as 18 inches (40 centimeters) of dry regolith. Although subsequent research from Lunar Prospector spacecraft failed to prove the existence of water on the moon, the question remains on whether water, if present, could be easily detected in lunar soils at low concentrations. The dielectric constant for ice and water is shown in Figure 4. The graph reveals that at low frequencies (1 Hz), the dielectric constant of ice and water is approximately 80. At higher frequencies (100 kHz), the dielectric constant of water remains high, but the dielectric constant of ice drops to 3 depending on temperature. For this analysis, we modified a commercial, battery operated impedance spectrometer to determine the amount of water needed for detectability (Figure 5).

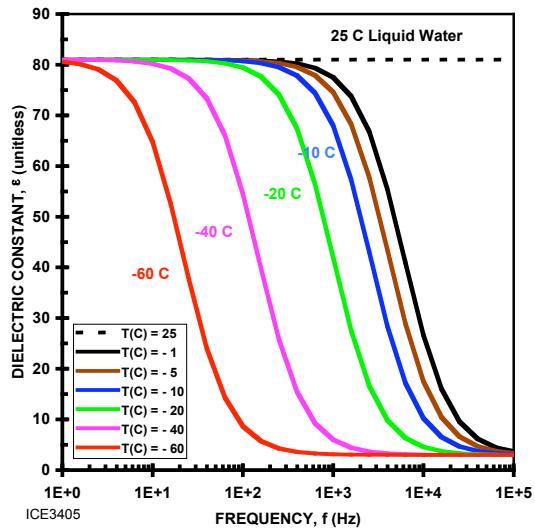


Figure 4. Dielectric constant of ice as a function of measurement frequency and temperature. Water is shown as the straight line at a dielectric constant of 80.

Preliminary Results-Lunar Minerals: The basic measurement principle used with lunar mineral dielectric constant measurements is based on the fact that (1) most lunar minerals are either silicates or oxides and (2) there is a determinable relationship between density and porosity. That is, ϵ'' directly tells the density of the mineral and or soil. The ϵ'' versus ϵ' relationship, shown in Figure 3, provides additional information about the composition of the regolith. That is, for $\%TiO_2 + \%FeO = 0$ the regolith is composed of silicates and non-Ti and Fe bearing minerals. The amount of Ti and Fe present in the regolith appears as an increase in ϵ'' . The inclusion of TiO_2 or FeO in the soil causes ϵ'' to increase above the $\%TiO_2 + \%FeO = 0$. Other minerals or water can also cause ϵ'' to be abnormally large. The deviation of the ϵ'' versus ϵ' above the $\%TiO_2 + \%FeO = 0$ line signals the detection of a mineral in the regolith that needs further identification by some other means.

Soil Moisture: For low water detection, initial results obtained from the IS are shown in Figure 6. We used coarse silica sand and added various amounts of water spiked with 100 mM KCL. The results show that we can easily detect 0.1% water in coarse sand. Preliminary estimates are that we will be able to determine the lower limit of detection to be approximately

0.001% water in coarse sand. Future test will be conducted in finer grain silt size particles.

Conclusion: Prospecting for minerals on the surface of the Moon calls for developing rapid survey techniques. We propose the use of the following techniques: impedance spectroscopy that provides dielectric constant measurements, electrostatic measurements that provide data for signature analysis techniques, and magnetic properties measurements. All of these measurements are rapid and the sensors are small and so can be incorporated into the wheel of a roving vehicle allowing rapid in situ measurements.

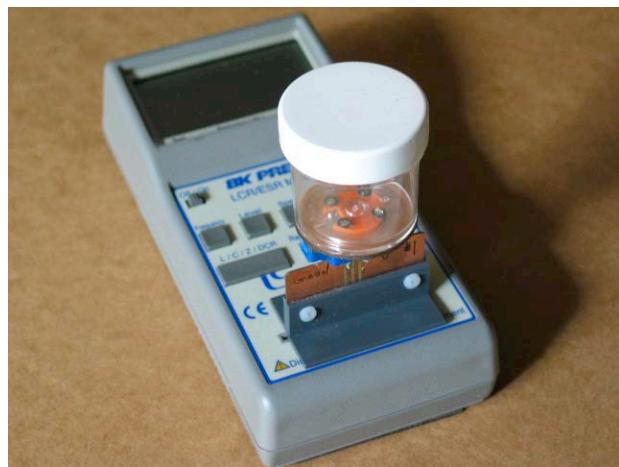


Figure 5. Impedance spectroscopy apparatus used to measure the coarse silica sand results shown in Figure 6. Four-probe located at the bottom of the polystyrene jar has a spacing of 1.12 cm.

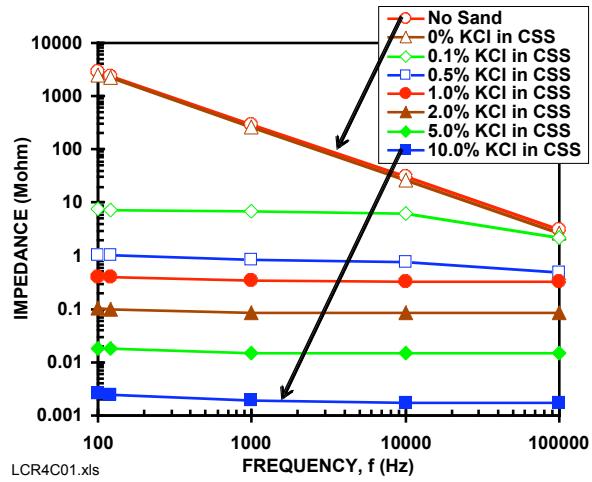


Figure 6. Impedance spectroscopy analysis of coarse silica sand measured at room temperature showing moisture detection well below 0.1%.