In-Situ Dielectric Spectroscopy (ISDS) for Water Detection on the Lunar Surface

How does dielectric spectroscopy of water ice work?

•When ice is placed in a time varying electric field, the molecules or bonds try to reorient themselves so that polarization occurs along the field lines. As the oscillation frequency increases, the reorientation begins to lag, causing molecular relaxation.

•Molecular relaxation is dependent on temperature and can be affected by impurities.

•The real (ε' blue curve) and imaginary (ε'' red curve) permittivity show the idealized relaxation for ice at around 260 K.

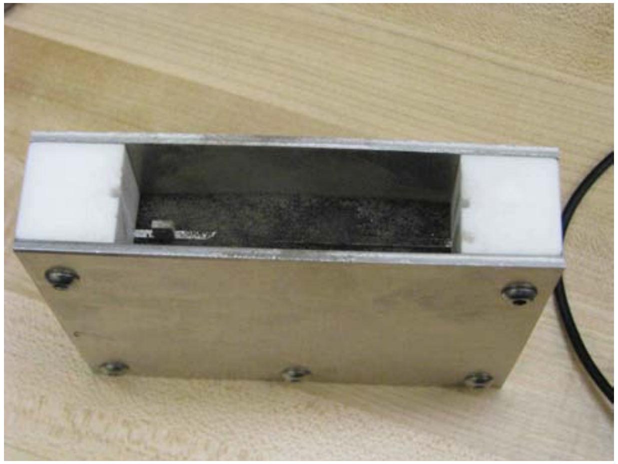
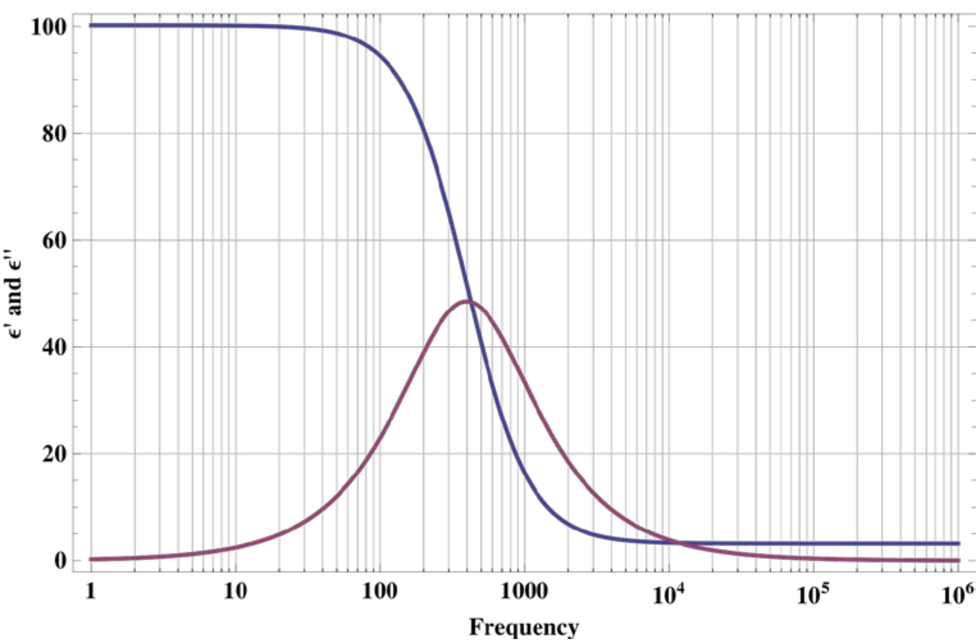


Photo of an early parallel plate sensor filled with simulant (JSC-1A)



•The results of the LCROSS mission and others suggest that substantial quantities of water ice exist (~5% by mass) in the top meter below the lunar surface.

•Dielectric spectroscopy is one technique that could be used to detect subsurface ice by mounting electrodes on a cone penetrometer or auger. The purpose of this project was to develop and test such a sensor.

•A problem with dielectric spectroscopy of ice is that the knee of the blue relaxation curve shown to the left shifts to well below 1 Hz in the colder regions of the Moon, making it difficult to measure. At higher frequencies, the ice is indistinguishable from the regolith which both have a relative permittivity of about 3.

•So a key question is: How do we make the ice stand out from the background?

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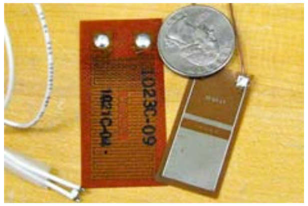


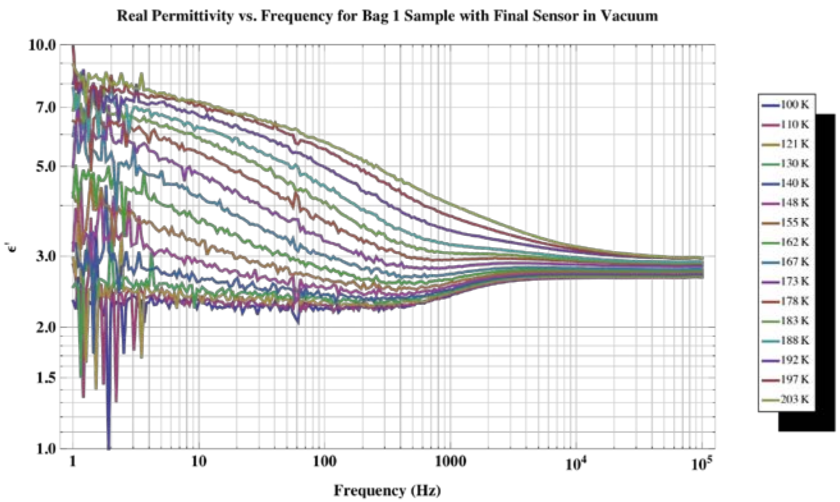
•**Answer: Heat it.**

If we warm the ice, but keep it below the freezing/ sublimation point, the knee will move up in frequency.

•**The device tested consisted of an RTD, a heater encased in polyimide, and a two electrode, inter-digital permittivity sensor.**

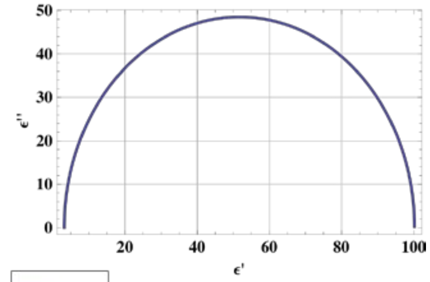
•**The sensor was mounted in a sandwich fashion on a Teflon backing with a groove cut in it for the RTD. The heater was then placed on top of Teflon followed by the inter-digital electrodes.**

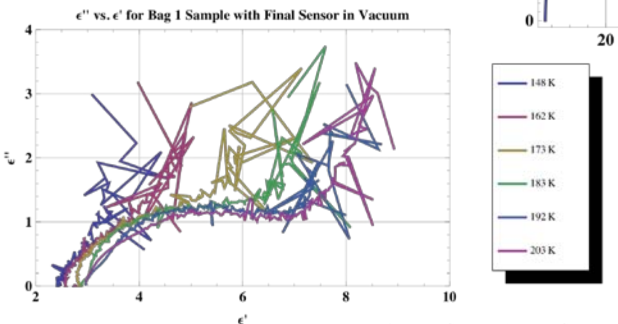
•**Adhesives that would work over the large temperature range were prohibitively expensive, so Gorilla tape was used to hold the assembly together, leaving the main sensing electrodes exposed.**

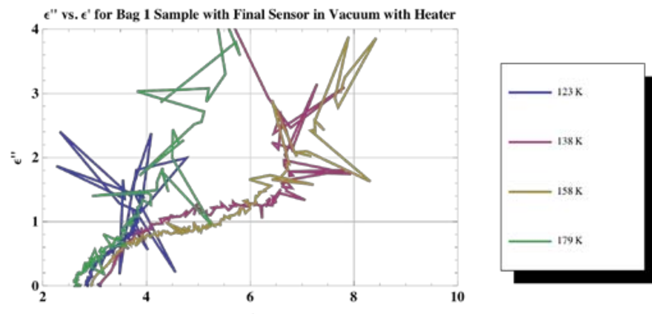


Ice relaxation measured on a sample of JSC-1A containing 5.2% water by mass

On right: Cole-Cole Plot for relaxation on previous slide







•**A different way to look at the data is via Cole-Cole plots which generally form semi-circles for relaxation phenomena (see top plot).**

•**The lower two plots above are of the data collected with the sensor on the same sample as the plot on the left. The temperature of the simulant in the middle plot was allowed to slowly rise in the vacuum chamber, whereas the lower plot used the heater to warm the ice.**

•**The deviations from the semi-circle are likely caused by static conductivity and possibly Maxwell-Wagner hydrate-silicate interface polarization.**

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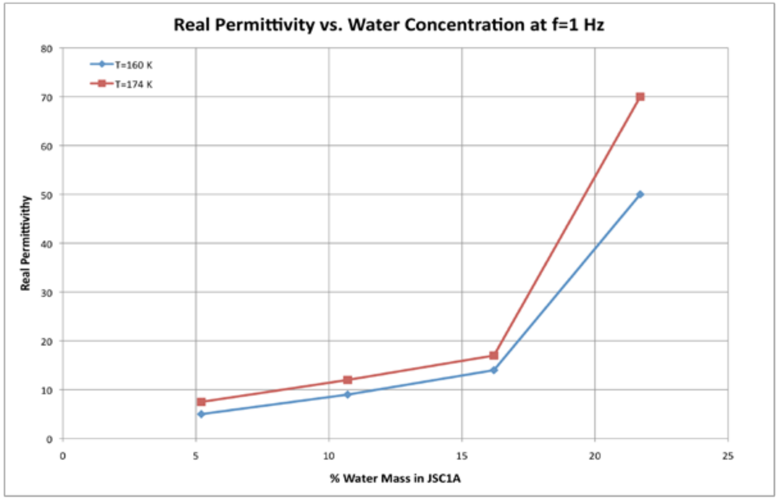
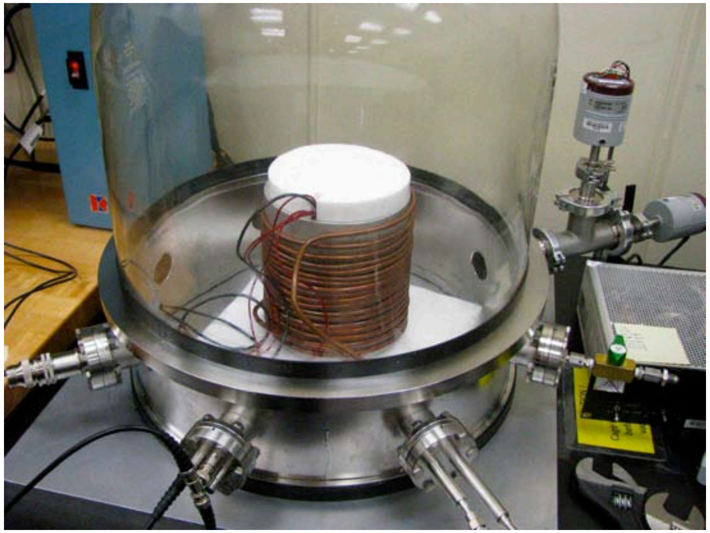
Four different ice mixtures with JSC-1A were tested: 5.2%, 10.7%, 16.2%, and a totally saturated 21.7% by weight.

By looking across the tests and examining the real permittivities at several temperatures at 1 Hz, it is seen that a fairly linear relationship exists between the real permittivity and the moisture content, across all but the fully saturated sample (see graph at right)





Vacuum chamber showing the sensor under test with cooling coils containing liquid nitrogen

<u>Conclusions</u>

The prototype sensor detected different concentrations of water ice in JSC-1A lunar simulant with small inter-digital electrodes.

- **The heater successfully raised the temperature of the sample, allowing the relaxation knee to be detected by the permittivity sensor.**
- **The response was linear for all but the fully saturated test.**
- **The sensor assembly is small and flexible enough to allow mounting on the side of a cone penetrometer.**

Quantification of ice content still requires further work

- **Salts and impurities affect the static permittivity and relaxation frequency.**
- **Linear mixing models found in literature didn't quite conform to the data sets collected.**

Further work is planned for FY11 via the RESOLVE project, but depends on the final budget resolution.

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