NEW TECHNIQUE FOR MEASURING THERMAL CONDUCTIVITY OF ICY MATERIALS UNDER PRESSURE. F. Zhong[1], M. Barmatz[1], H. Englehardt[2], [1]Jet Propulsion Laboratory, California Institute of Technology, M/S 79-24, 4800 Oak Grove Drive, Pasadena, CA, 91109, E-mail: Fang.Zhong@jpl.nasa.gov, [2]Department of Geology and Planetary Sciences, California Institute of Technology, MC 100-23, Pasadena, CA, 91125.

Introduction: Thermal conductivity plays an important role in geological and geophysical modeling of planetary objects. This is especially the case for outer planet satellites whose material thermal conductivity can vary by up to two orders of magnitude depending on temperature, composition, structure, and pressure. Because of lack of experimental measurements, earlier models have been forced to use the published data for ordinary ice Ih. The more recent Galileo mission to Jupiter and Cassini mission to Saturn have been able to obtain spectral information of icy satellite surfaces that suggest the surfaces are composed of impure ice compositions. Candidate compositions include salt hydrates, clathrate hydrates, and ammonia water compounds. We plan to perform thermal conductivity measurements on relevant icy satellite analogs that can be used in models to obtain a better understanding of the geological development of these satellites.

Experimental technique: We have developed a method for measuring the thermal conductivity of icy compositions over a broad range of cryogenic temperatures and elevated pressures along the same heat flow direction. The innovation of this measurement approach is that it has been coupled with a high precision Instron Materials Measurement System to permit the simultaneous measurement of thermal conductivity during various compression (higher pressure) studies (Young's modulus, creep, and relaxation). A cryogenic chamber was incorporated around the Instron compression platens to permit measurements over the temperature range 90 – 270 K. With this system, we can directly measure the thermal conductivity of a given sample over the entire temperature range or can perform measurements on a sample at a given temperature, before and during various axial compression studies that may ultimately lead to the sample destruction.

For compression studies, a cylindrical sample is placed between two platens. The bottom platen is fixed while the top platen can be moved down to produce a given stress or stress rate, or a given strain or strain rate. We have mounted a calibrated silicon diode thermometer and heater on each platen that allow us to control the temperature of either platen to within ± 0.004 K. A schematic of the inside of the chamber is shown in Fig. 1. The samples will be 1″ in diameter by 0.25″ long. They will be grown and characterized in the Mars Simulation and Ice Laboratory at Caltech. Using a single crystal seed, the water is frozen from the bottom to the top of a cylindric mold in a cold room at -15 ºC at a rate slower than 10^{-6} m/s with air constantly flowing at a slow rate in the remaining water. This method excludes bubbles and cracks during freezing and leads to the production of perfect single ice crystals.

The sample thermal conductivity is determined by increasing the bottom platen temperature by a known amount, ΔT. This temperature change causes the PID temperature control of the top platen to change its control heat current to maintain its same initial temperature. The foam insulator ensures that the sample sidewall heat loss is reduced. It also minimizes any heat transfer between the platens via the surrounding nitrogen gas. The Instron rods just outside the cryochamber and the copper shield are controlled at constant temperatures. Because these temperature differences remain the same between the top platen and its surroundings, the measured change in heat current at the top platen is the heat current that comes directly from the sample. Knowing the temperature change at the sample bottom and the heat current change at the top, the sample thermal conductivity can ideally be calculated.

The above measurement is the total thermal resistance that includes the sample and the platens. By replacing the ice sample with a 1″ diameter by 0.002″ thick copper shim stock and repeating the same procedure as outlined above, the thermal resistance due to the platens is obtained. Then the thermal resistance from the ice sample can be calculated by subtracting the platen resistance from the total thermal resistance.

The uncertainty associated with the radial heat loss at the sample surface is estimated to be less than 2% from a computer simulation using the 3-D Finite Element Model (FEM) software by Comsol. The simulation includes the feedback temperature control loop, used the same geometry as shown in Fig. 1 and the thermal conductivities of specified materials including 2.8 W/cm-K for the ice and 0.02 W/cm-K for the foam.

Thermal conductivity measurements: At this time, we are performing measurements on single crystal ice samples. The thermal conductivity of single crystal ice has been measured previously [1-6]. Our new initial measurements will be compared to the most recent study by Waite *et al*. [6]. To validate the technique described above, we placed a stainless steel 304 sample of height L = 2″ and diameter D = 1″ in between the platens and applied 40 N load force to ensure good thermal contacts at both interfaces. Figure 2 shows the temporal profiles of the temperature and heat current measurements. With the system in thermal equilibrium, the temperature of the bottom platen was increased by 1 °C (at time t = 0). The system reached equilibrium within ~ 20 minutes. Given the change in heat current at the top platen, the total thermal resistance including the contribution by the platens can then be calculated. For this test case we obtained 0.176 W/cm-K for the sample thermal conductivity consistent with literature values.

One of the unique capability of this approach is that it can measure the heat flux as a function of the applied stress while keeping the temperature gradient constant. These measurements will be a sensitive indicator of structural defect changes within the sample.

Once this technique is validated using single crystal ice samples, it will be used to study other important icy compositions simultaneously with Instron compression studies.

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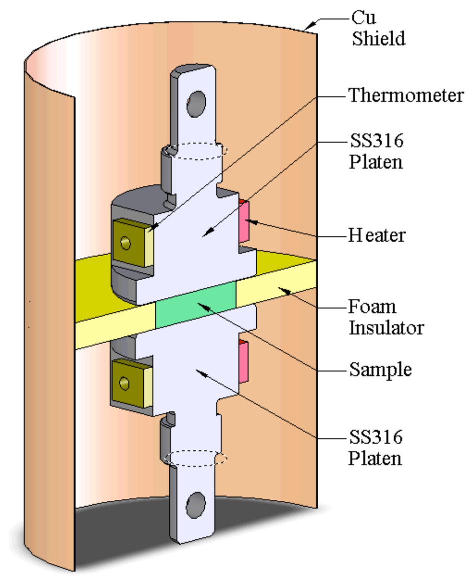

Fig. 1. The thermal conductivity experimental setup. The ice sample will be 1″ in diameter and 0.25″ high. The remaining items in the drawing are scaled to the sample size.

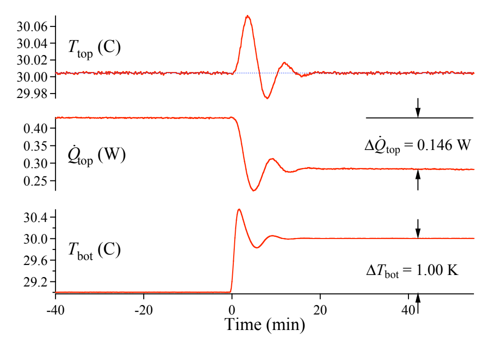

Fig. 2. Test measurement of the thermal conductivity using a stainless steel 304 sample.