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 were 2.54 cm in diameter by 0.63 cm long. They were grown and characterized in the Mars Simulation and Ice Laboratory at Caltech. Using a single crystal seed, the water was 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_{bot}. This temperature change causes the PID temperature control of the top platen to change its control heat power, $\dot{Q}_{top}$, 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 cryo-chamber 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 $\Delta\dot{Q}_{top}$ is the heat current that comes directly from the sample. Knowing ΔT_{bot} and $\Delta\dot{Q}_{top}$, the sample thermal conductivity can ideally be calculated.

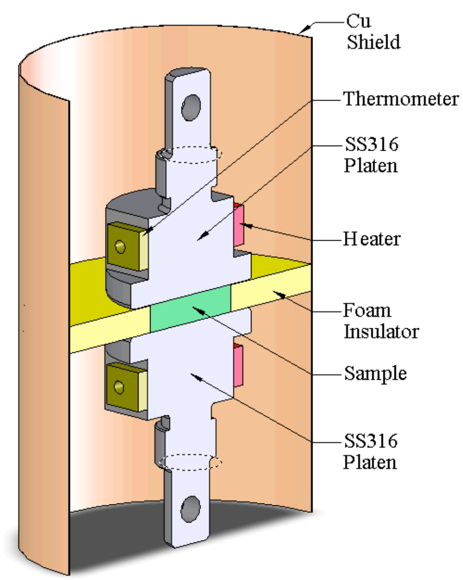

Fig. 1. The thermal conductivity experimental setup. The ice sample was 2.54 cm in diameter and 0.63 cm high. The remaining items in the drawing are scaled to the sample size.

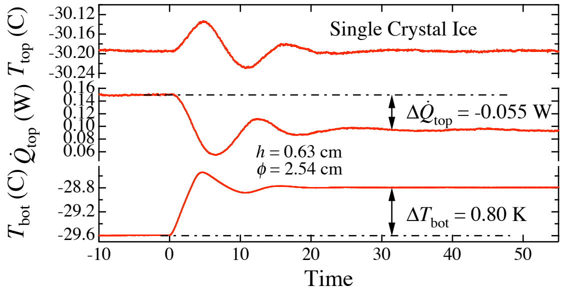

Fig. 2. Measurement of the thermal conductivity of single crystal ice at ~ -29.7 C.

Thermal conductivity measurements: At this time, we are evaluating this technique using single crystal ice samples. Figure 2 shows the temporal profiles of temperatures and heat current measurements with 40 N load force applied on the sample. With the system in thermal equilibrium, the temperature of the bottom platen was increased by 0.8 °C (at time t = 0). The system reached equilibrium after ~ 33 minutes. Given the change in heat current at the top platen, the total thermal resistance including the contribution by the platens is calculated to be 14.5 K/W. By replacing the ice sample with a pure copper disk of identical geometry and repeating the same procedure as outlined above, the thermal resistance just due to the platens was determined to be 3.33 K/W. Thus, we obtained 1.11 W/m-K for the ice sample thermal conductivity by subtracting the platen resistance from the total thermal resistance. The thermal conductivity of single crystal ice has been measured previously [1-6]. Our newly measured value is smaller than the most recent study by Waite *et al*. [6]. The difference between the two is outside the uncertainties in the measurements. We are in the process of determining the source of this inconsistency.

One of the unique capability of this approach is that it can measure the heat flux through a sample as a function of an applied stress while keeping a constant temperature gradient. These measurements are a sensitive indicator of structural defect changes within the sample. Figure 3 shows the temporal profiles of the control heat powers during the creep of the same ice sample under constant loads. Since T_{top} = -30.2 C and T_{bot} = -28.8 C remained constant, the heat exchanges from the platens to the surroundings should remain unchanged. Thus, the non-zero net heat power change $\Delta\dot{Q}$ shown in Fig. 3 directly indicates the change in thermal conductivity. The response of the control heat power and thus the thermal conductivity to the sample creep was found to be linear as shown in Fig. 4.

Once this technique is validated using single crystal ice samples, it will be used to study other important icy

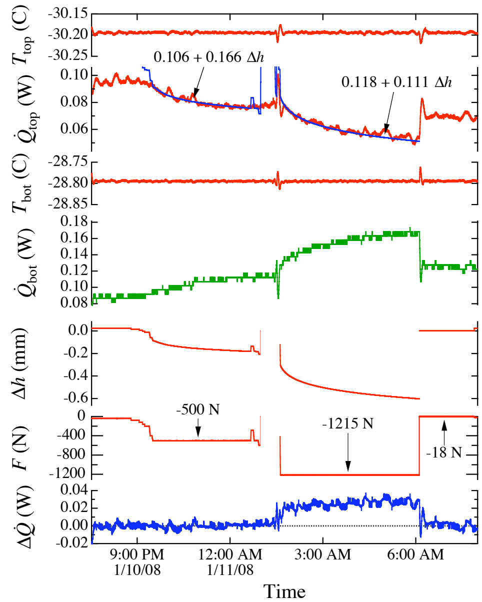

Fig. 3. Responses of the control heat powers to the ice sample creep.

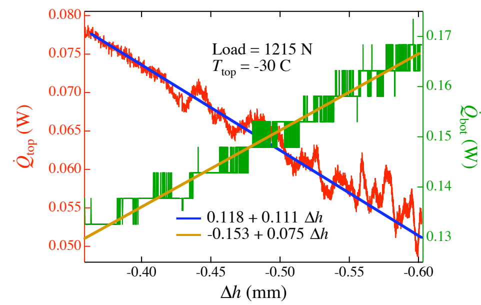

Fig. 4. Measured control heat powers versus ice sample creep. The dependence is linear.

compositions simultaneously with Instron compression studies.

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