

MEASUREMENTS OF THERMAL DIFFUSIVITIES UNDER PLANETARY INTERIORS PRESSURE AND TEMPERATURE CONDITIONS

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Introduction: At the macroscopic level, diffusive heat transport is usually characterized by thermal conductivity parameter k (m^2s^{-1}). Within a crystal structure, heat transport is a second order process that requires multiple phonon interactions and then, can be hardly predicted theoretically. Measurements of the thermal diffusivity usually involve determination of the temperature gradient across the sample which is subjected to a steady heat flow [1-2]. More recently a pulsed plane-wave technique [3] has been designed, which improves the accuracy. Nevertheless, there are strong limitations because of geometrical constrains and the presence of materials with P , T dependent thermophysical properties, which reduce the accuracy of the measurements. These constraints become even more severe when working at higher pressures, because of increased spatial limitations and problems with temperature determination. Currently, only measurements of the thermophysical properties to a few GPa have been reported [3-4] using these conventional methods. Simple theories describing P - T dependence of the thermal diffusivity [4] are often satisfactory, but predictions related to changes in crystal structure [5], spin transition, or disorder need to be better developed. Static experiments at substantially higher pressure require the use of the diamond anvil cell (DAC). Here, we report on a new flash-heating method designed to measure k within the DAC.

Experimental Methods: Similarly to flash-heating systems, the experiment we present here is a non steady state method, in which the temperature history of a sample is resolved in the time domain. This technique is derived of the plane wave technique and has been adapted to match the size constraints required by diamond-anvil cell (DAC) studies. A commercially purchased thin Ir foil ($10 \times 10 \times 0.1 \mu m$) was loaded in the DAC. The pressure transmitting medium is chosen as material of study, in our case NaCl. The Ir ribbon is heated by absorption of 8 ns IR laser pulse (1064 nm, YAG, $80 \mu m^2$). Thermal emission of the Ir surface is then collected through a gated spectrometer (ANDOR). Though minimum gate available is 5 ns, the gate used during this experiment was 10 ns to improve the signal/noise ratio. Thermal emission spectra are then corrected from spectrometer transfer function and converted into absolute temperature using Wien's law. Varying detector delay enables to study the foil surface temperature in the time domain. Since the Ir foil is thin

(100 nm), its temperature will equilibrate in a short time scale and heat loss will then be only controlled by diffusive exchange with the surrounding media.

Results: Preliminary experiments have been carried out on NaCl, for which measurements at moderate pressure and temperature have been previously reported [6]. Typical results of the experiments are presented in figure 1. The cooling curves of the iridium foil are presented for pressures of 4.5 and 14.2 GPa (Fig. 1). We were able to measure temperature down to 1700 K during 10 ns gates. In those two experiments, one can remark that the temperature relaxation time significantly decreases with pressure by a factor of 3. This observation testifies of an increase in k with compression. For the two curves presented, we did not observe a significant change of slope upon crossing the melting/crystallization point (Fig. 1). From these curves, the pressure medium (NaCl) thermal diffusivity was estimated by solving the diffusion equation using a 1-D finite difference method [7] and our geometric parameters.

P and T dependence of k : Our current dataset includes measurements at pressures up to 17 GPa ($\rho/\rho_0 \sim 1.25$) and temperatures of 3500 K. All these results are plotted in figure 2. They show a significant effect of P on the thermal diffusivity, but a smaller dependence on T . For instance, at $T=2500$ K, k increases by a factor of 2 from 4.5 to 14.2 GPa.

These results can be compared with theoretical predictions. According to [4], the thermal conductivity λ (with $k=\lambda/\rho C_p$) can be given by:

$$(d\ln\lambda/d\ln p)_T = 3\gamma + 2q - 1/3 \quad (\text{eq. 1})$$

Where γ is the thermodynamic Grüneisen parameter and q is its isothermal density derivative ($q = -(d\ln\gamma/d\ln\rho)_T$). We used here a simplified version of equation 1, which neglects anharmonic effects ($q=0$).

The high-temperature measurements of k for NaCl [6] at 4.7 GPa were used to calculate the temperature dependence of k at 10, 15 and 20 GPa using equation 1 (Fig. 2). One should remark that this model enables to calculate the lattice contributions to k_L and does not take into account the radiative contribution k_R (with $k=k_R+k_L$).

The values we measured for NaCl thermal conductivity are in fair agreement with this model for our range of P - T conditions (Fig. 2). These experiments can be refined by combining our measurements with optical ab-

sorption measurements at high pressure and temperature in the diamond anvil cell [8]. The latter will enable to measure k_R and then estimate both radiative and lattice contributions.

Conclusions: We have described here a new technique for measuring thermal diffusivity at high-pressures and temperatures using a flash heating method in the diamond anvil cell. This method can be applied to any transparent or semi-transparent material, in principle to megabar pressures. Preliminary results show good agreement with existing theory, and open interesting perspectives for measuring heat transport properties under planetary interiors conditions.

References: [1] Bridgman P.W. (1922) *Proc. Am. Ac. Arts Sci* 57, 77-127. [2] Andersson P. and Bäckström G. (1976) *Rev. Sci. Instrum.* 47, 205-209. [3] Pierrus J. and Sigulas I. (1985) *J. Phys. E.: Sci Instrum.* 18, 307-313. [4] Ross R.G.P. et al. (1984) *Rep. Prog. Phys.* 47, 1347-1402. [5] Roufosse M.C. and Jeanloz R. (1983) *JGR* 88, 7399-7409. [6] Fujisawa et al. (1968) *JGR* 73, 4727-4733. [7] Crank J. (1967) *The Mathematics of Diffusion*, Oxford Univ. Press 414 p. [8] Goncharov et al. (2006) *Science* 312, 1205-1208. [9] Boehler et al. (1997) *Phys. Rev. Lett.* 78, 4589-4592.

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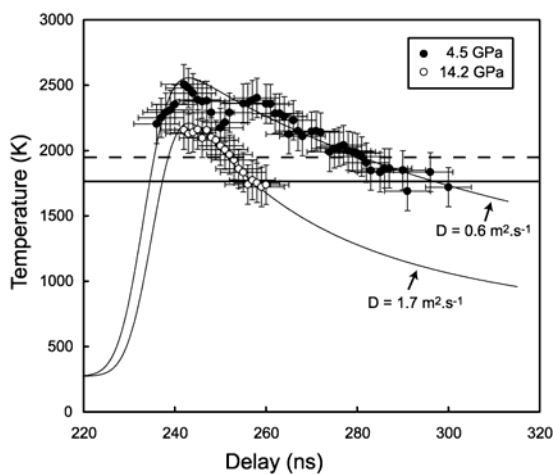


Figure 1: Temperature history of the Ir foil in NaCl pressure media as a function of delay. Two dataset are presented corresponding to pressures of 14.2 and 4.5 GPa. The cooling time of the foil significantly decrease with pressure suggesting an increase in thermal conductivity of NaCl. The solid curves correspond to our best fit using thermal diffusion model. Horizontal lines correspond to melting point at 4.5 GPa (solid line) and 14.2 GPa (dashed line) from [9].

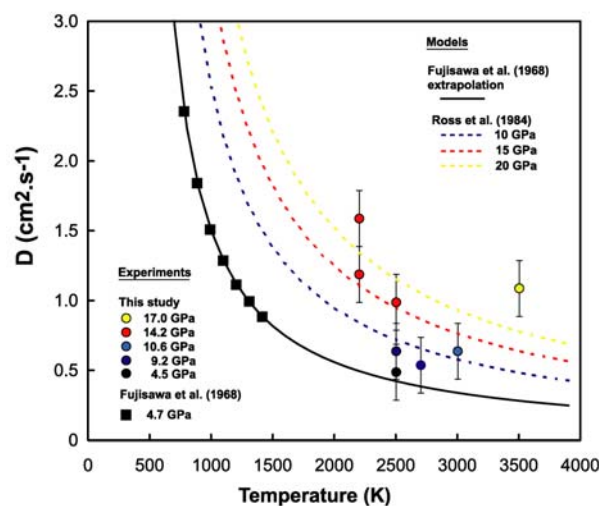


Figure 2: Thermal diffusivities of NaCl as a function of temperature, for different pressures. Our dataset (plain circles) are compared to previous measurements at 4.7 GPa [6]. The dashed curves correspond to the model described in the text, which is a simplification of [4].