Thermal Convection in Water under Strong Gradient Magnetic Fields

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Strong gradient magnetic fields in a hybrid magnet enable levitation of diamagnetic materials against the gravity. This levitation state is considered to be equivalent to the microgravity because the magnetic force acting on the material counterbalances the gravity and such counterbalance holds for the molecules constituting the levitating material. The magnetic levitation is thus expected to provide a novel technique for materials processing. One of advantages under the microgravity condition is the repression of thermal convections that must be crucial for chemical reactions and materials synthesis. A similar effect can be expected under the magnetic levitation condition. However, the behavior of the thermal convections in diamagnetic liquids has not yet been studied under the magnetic levitation condition. We made attempts at the observation of heat transfer in water under the strong gradient magnetic field whose magnetic force balances the gravity [1].

Heat transfer in water was visually observed in a plastic optical cell placed in a hybrid magnet, using a thermochromatic liquid crystal sheet (Fig. 1). The upward thermal convections around a heater were drastically suppressed by the magnetic force, however, the residual upward convection existed even under the levitation condition with the gradient field BdB/dz = 1360 T^2m^{-1} (Fig. 2(a)). The temperature dependence of the magnetic susceptibility is responsible for the convection behavior in the gradient fields. A thermal conduction state without the convection was realized in the stronger gradient fields $B(dB/dz)$ =2880 T^2m^{-1} at temperatures 35-40ºC (Fig. 2(b)). Furthermore, the downward magnetic convection was observed in the same gradient field at higher temperatures 40-45ºC (Fig. 2(c)).

[1] I. Mogi, C. Umeki, K. Takahashi, S. Awaji, K. Watanabe, M. Motokawa, Jpn. J. Appl. Phys. 42 (2003) L715.

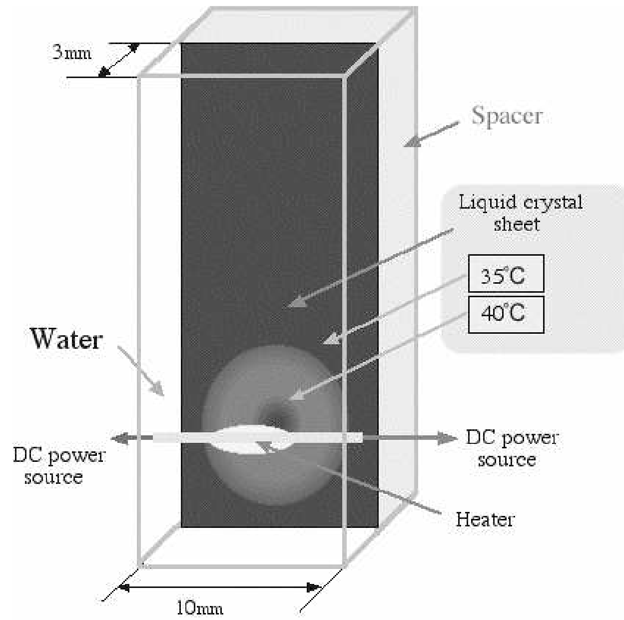

Fig. 1 Schematic view of heat transfer in water in the sample cell, which was placed in the magnet bore and the position of the heater was adjusted to z = 89 mm. The heat transfer was visualized by the color change of a liquid-crystal sheet in a particular temperature range. Three kinds of the sheet were used, which represents temperatures 20-25, 35-40, and 40-45ºC.

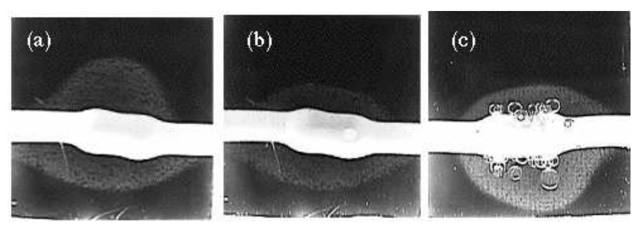

Fig. 2 Heat transfer in water (a) under the gradient field $B(dB/dz)$ = 1360 $T^2 m^{-1}$ in a temperature range 35-40ºC, (b) under the gradient field $B(dB/dz)$ = 2880 $T^2 m^{-1}$ in a temperature range 35-40ºC, and (c) under the gradient field $B(dB/dz)$ = 2880 $T^2 m^{-1}$ in a temperature range 40-45ºC.