Journal of Thermal Analysis, Vol. 37 (1991) 1973-1977

A NEW HEAT FLUXMETER

J. L. Gaillard, F. Gallin and B. Wojtyniak

LABORATOIRE D'ELECTRICITÉ INDUSTRIELLE, CONSERVATOIRE NATIONAL DES ARTS ET MÉTIERS, 292 RUE SAINT MARTIN, 75141 PARIS, CEDEX 03, FRANCE

The dynamic measurement of heat flux gives a lagged and out of shape electrical response due to the heat transfer through the materials. So, it is necessary to use dynamic correctors to get the real response.

To reduce the length of the thermal conductors, we propose to generate the useful electric signal perpendiculary to the heat flux by means of a magnetic induction field.

We built a new heat fluxmeter, fitted to a 15 cm^3 cell and based on this thermomagnetoelectric effect. Its main intrinsic time constant is 25 seconds and its sensibility at room temperature is 0.6 μV/mW.

Thermomagnetoelectric detector advantage

With usual thermoelectric detectors, the electric voltage ΔV_x is generated by the heat power P_x, according to its direction (Fig. 1).

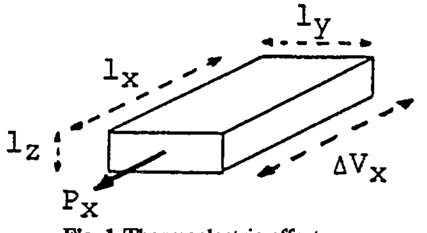

Fig. 1 Thermoelectric effect

Without thermal leakage, the sensibility is,

$$s_d = \frac{\Delta V_x}{P_x} = \frac{K l_x}{\lambda_x l_y l_z}$$

where K is the thermoelectric power, λ_x the thermal conductivity according x direction, and l_x, l_y, l_z the dimensions of the rectangular isotropic paral-

John Wiley & Sons, Limted, Chichester
Akadémiai Kiadó, Budapest

lelepiped which represents the detector. It results from an intrinsic time constant value $\tau_d = D\, l_x^2$, where D is the diffusivity of the material.

Any reduction of the length l_x involves that of τ_d, but also of s_d.

Let us consider now a thermomagnetoelectric detector, in a constant magnetic induction field B_z, perpendicularly to the heat power direction P_x. The Nernst effect, analog to the Hall effect with an electric current, generates a transverse voltage ΔV_y (Fig. 2).

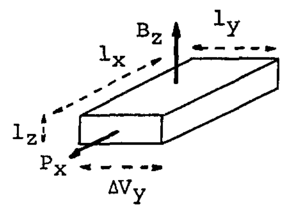

Fig. 2 Thermomagnetoelectric effect

The sensibility of this detector is:

$$s'_d = \frac{\Delta V_y}{P_x} = \frac{K_N B_z}{\lambda_x l_z}$$

where K_N is the Nernst coefficient. We see, that, theoretically, any reduction of l_x involves that of τ'_d without changing the sensibility.

Among all the elementary materials the bismuth gives the greatest Nernst effect.

We realized an experimental device to determine the value of K_N, according to the magnetic induction field and the temperature T_e at the electrodes level (Fig. 3).

We checked up on the linearity of the voltage ΔV_y *vs.* P_x for a constant temperature T_e at the electrodes level.

Principle of the thermomagnetoelectric heat fluxmeter

The setting depends on the cell shape. A radial structure, i. e. of a circular cylindrical shape, seems well appropriate for the thermal links leading to the heat sink. A bismuth detector is inserted in each thermal link. The magnetic field lines may be either vertical or circular near the detectors (Fig. 4).

For a number n of identical detectors, the sum of the n voltages is:

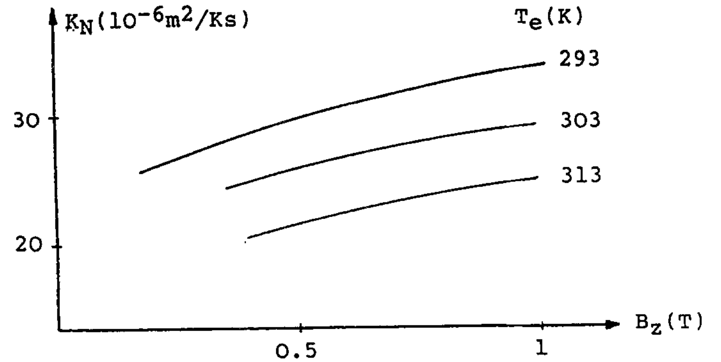

Fig. 3 Nernst coefficient *vs.* induction field B_z and T_e of a polycrystalline bismuth sample (99.99% pure)

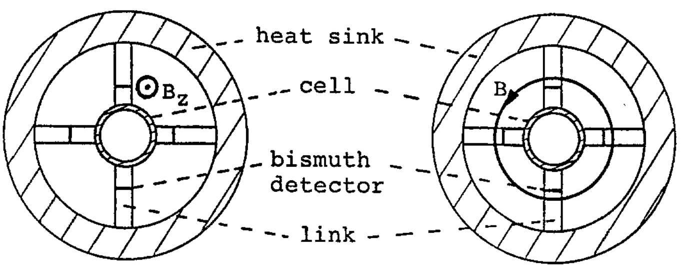

Fig. 4 Schematic dispositions of the magnetic induction field

$$\Delta V_y = \sum_{i=1}^{n} \Delta V_{y_i} = s'_d \sum_{i=1}^{n} p_{x_i} = k\, s'_d\, P$$

where P is the whole emitted power and k the leakage factor at the detectors level. The number of detectors does not increase the sensibility, but reduces the main intrinsic time constant to $\tau \approx \frac{\tau_1}{n}$, with τ_1 as the time constant of each thermal link between the cell and the heat sink.

Set up of the fluxmeter

The heat sink and the cell are copper cylinders with a diameter of 20 cm and 2 cm respectively.

The detectors and the magnets were developed as storied structures.

The inside structure of the achieved fluxmeter is depicted in Fig. 5, with a differential device.

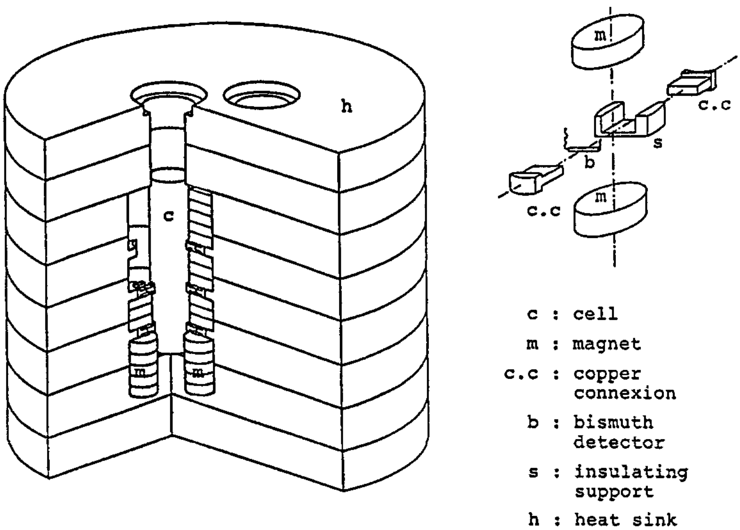

Fig. 5 Inside view of the differential heat fluxmeter and enlargement of a detector insertion

Each cell is consisting of 12 detectors with the following dimensions in millimeters: $l_x = 0.4$, $l_y = 6$, $l_z = 0.8$. These cells were cut from the same sample of polycrystalline bismuth of a purity of 99.99%.

The vertical magnetic induction field is produced by means of cylindrical anisotropic permanent magnets (15 mm in diameter, 5 mm in thickness), set in vertical piles above and below the detectors with a 4 mm gap.

The magnetic induction field near such detector is about 0.6 T and it is nearly uniform.

The detectors voltages are separately amplified and added through operational amplifiers.

Performances

The main intrinsic time constant could be reduced to 25 seconds and the sensibility, without amplification, is 0.6 μV/mW at 294 K.

We tested the dynamic range with power pulses produced by a small incandescent bulb enclosed in the cell.

Conclusion

We showed that it was possible to achieve a heat fluxmeter based on a thermomagnetoelectric effect with the goal of reduction of the intrinsic time constant.

This device is apparently the first of this kind, applied to thermal power measurement at room temperature.

The sensibility has to be increased with applying single crystalline bismuth or others alloys.

This apparatus may simplify or suppress the usual dynamic correctors.

References

1 T. C. Harman and J. M. Honig, Thermoelectric and thermomagnetic effects and applications, McGraw-Hill, New York 1967.

2 A. Von Ettinshausen and W. Nernst, Über das Auftreten electromotorischer Kräfte in Metallplatten, welche von einem Wärmestrome durchflossen werden und sich in magnetischen Felde befinden, in Annalen der Physik und Chemie, Vol. 23, G. Wiedemann Ed. Germany, Leipzig 1886.

Zusammenfassung — Die dynamische Messung eines Wärmeflusses ergibt ein zeitlich verzögertes und amplitudenmässig verändertes elektrisches Signal. Mit geeigneten dynamischen elektrischen Korrekturgliedern kann das reale Signal approximiert werden. Zur Verringerung der Länge der Messanordung wird ein neues thermomagnetoeletrisches Prinzip vorgeschlagen. Unter Verwendung eines magnetischen Induktionsfeldes senkrecht zum Wärmefluss wird ein zu diesen beiden Flüssen senkrecht stehendes elektrisches Potential erzeugt.

Die Konstruktion dieses Wärmeflussdetektors wird vorgestellt und die Charakteristik wird diskutiert.