Thermoelectric Power of Glassy Carbon

Yutaka Kaburagi, Yoshihiro Hishiyama, Denis F. Baker* and Robert H.Bragg*

Musashi Institute of Technology
Tamazutsumi, Setagaya-ku, Tokyo, 158, Japan

*University of California
Department of Materials Science and Mineral Engineering
Berkeley, CA 94720, USA

Abstract. A systematic study of thermoelectric power in glassy carbon was carried out by a differential method in the temperature range between 1.5 and 280°K. The thermoelectric power for glassy carbons heat-treated at temperatures ranging from 1200 to 2700°C can be divided into two classes according to the behavior of the dependence on temperature.

A glassy carbon had been prepared for the present study by thermal decomposition of a thermosetting resin, a mixture of phenol formaldehide and furfuryl alcohol. The as-received material had been given a final one hour processing at 1000°C in inert atmosphere. It was heat-treated further for three hours in a graphite furnace under an inert gas at temperatures ranging from 1200 to 2700°C. Specimens were ground, polished to uniform thickness and ultrasonically cut to proper size for measurements. Each specimen was 1 mm long, 0.5 mm thick and 1.5 mm wide. The specimens are designated by GC followed by the heat treatment temperature (HTT). The thermoelectric power measurements were made in the temperature range between 1.5 and 280°K by the method given in reference 1.

Experimental results of the absolute thermoelectric power for the specimens are plotted as a function of temperature in Fig. 1. Low temperature details of the thermoelectric power are shown in Fig. 2.

Isotherms of the dependence of the thermoelectric power on HTT at 4.2, 80 and 280°K can be compared with that for PAN based carbon fiber measured by Robson et al. (2), plotted as a dashed curve in Fig. 3.

The present results for the thermoelectric power for glassy carbons can be divided into two classes according to the dependence on measurement temperature.

(I) HTT ≤ 1400°C

In this class, the thermoelectric power is positive at 1.5°K, increases with temperature up to about 25°K, passes through a maximum and decreases. The rate of decrease for GC1200 is larger than that for GC1400 and the change of sign of the thermoelectric power for GC1200 occurs at about 200°K. At temperatures below 25°K, the value of the
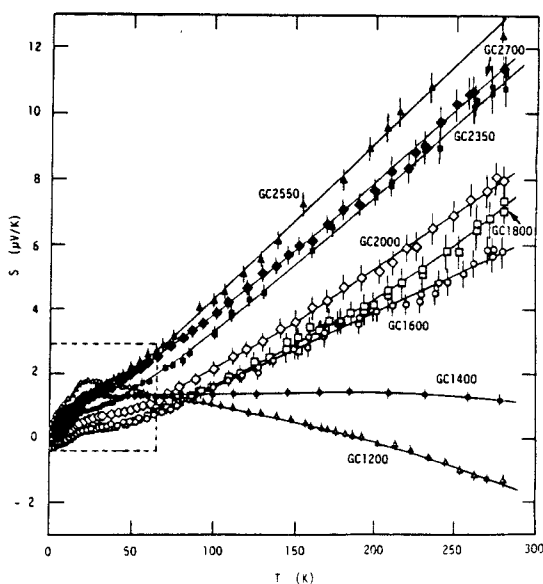

Figure 1. Absolute thermoelectric power S for GC specimens plotted as a function of temperature T.

thermoelectric power for GC1200 at a constant temperature is larger than that for GC1400.

(II) HTT ≥ 1600°C

The specimens of this class can be characterized by the monotonically increasing positive thermoelectric power with temperature and a shoulder at temperatures between 10 and 40°K. However, for the specimens heat-treated below 2000°C the thermoelectric power is negative at low temperatures. In these specimens the thermoelectric power is negative at 1.5°K, decreases at first, passes through a minimum at around 3 to 5°K, increases,
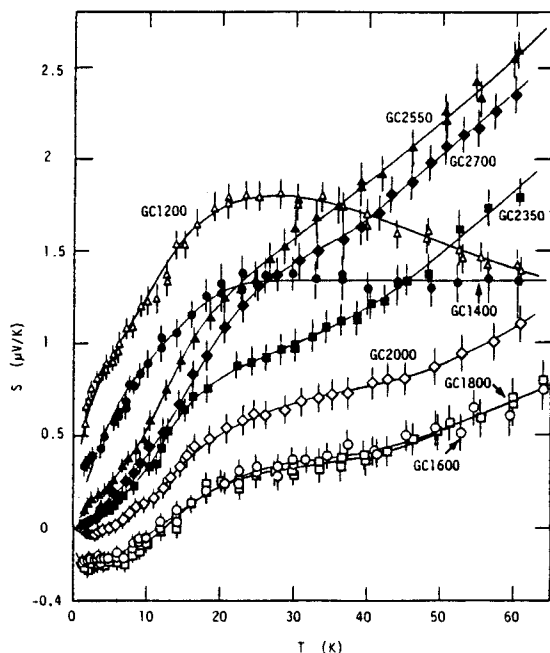
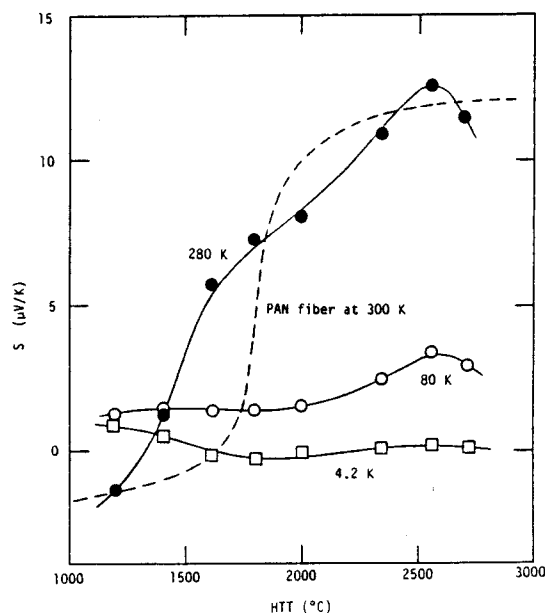Figure 2. Low temperature details of the thermo-
electric power.

Figure 3. Isotherms of the dependence of the
thermoelectric power S on heat treat-
ment temperature HTT at 4.2°K, 80°K
and 280°K. (--- : PAN based carbon
fiber at 280°K by Robson et al. (2))

changes its sign, passes through a shoulder men-
tioned above and increases further, as the tempera-
ture is increased. The value of the minimum of the
thermoelectric power increases with HTT and the
minimum disappears at HTT's above 2350°C. At a
constant temperature the thermoelectric power in-
creases with HTT up to 2550°C and then decreases.

Baker and Bragg measured the Hall coefficient
at temperatures between 2.8 and 100°K for the same
glassy carbon specimens used in the present study
and found almost temperature-independent Hall
coefficient in the temperature range investigated
(3). They also found a negative Hall coefficient
for the class I specimens and zero or monotonically
increasing positive Hall coefficient with HTT for
the class II specimens. The sign reversal between
the Hall coefficient (-) and the thermoelectric (+)
occurs at low temperatures for the class II speci-
mens heat-treated below 2000°C. A sign reversal
has also been reported for amorphous semiconductors
such as amorphous materials of chalcogenide, Ge,
Si, and As (4).

Baker and Bragg (3) measured the temperature
dependence of the electrical conductivity for the
same specimens used in the present study and
reported that a conductivity component due to
variable range hopping conduction and a component
due to metallic conduction are involved in the
conductivity for all specimens. Mott and Davis (5)
pointed out that at low temperatures the thermo-
electric power due to the variable range hopping
conduction is proportional to square root of
temperature ($\propto T^{1/2}$). Therefore, the shoulder of
the thermoelectric power measured for the class II
specimens may be due to the variable range hopping
conduction. The monotonically increasing positive
thermoelectric power with temperature for the class
II specimens may be due to the metallic conduction.

No explanations for the negative thermoelec-
tric power with a minimum for the class II
specimens, and the temperature dependence of the
thermoelectric power for the class I specimens can
be made at present.

References

1. Y. Hishiyama and A. Ono, Carbon, 19, 441 (1981).

2. D. Robson, F. Y. I. Assabghy and D. J. E.
   Ingram, J. Phys., D5, 169 (1972).

3. D. F. Baker and R. H. Bragg, J. Non-Cryst.
   Solids, 58, 57 (1983).

4. M. Roilos, Phil. Mag., 38, 477 (1978).

5. N. F. Mott and E. A. Davis, "Electronic
   Processes in Non-Crystalline Materials,"
   2nd ed., p. 56, Clarendon Press, Oxford, 1979.