The Hall Effect Measurement of the Polymer–Filler Composition

The authors have studied the electrical conduction mechanism of polymer–filler particles using polymer-grafted carbon black (GC).[1,2] In the previous paper,[1] it has been demonstrated that the electrical conduction is due to thermally activated electron hopping at low field strength, while tunneling conduction is predominant at high field strength. It is also important to know the number density of charge carriers and their mobility. But, for composite materials, these values have not still been measured accurately, because conductive fillers in conductive composite materials are liable to shift one another due to electrical field or magnetic field.

Conductive materials made from GC are comparatively stable even at high electrical field or high magnetic field.[1] In this note, we present measurements of the Hall coefficient and resistivity, from which the number density of charge carriers as well as their mobility were determined.

The GC samples were prepared according to the procedure described previously.[1,2] The preparation conditions of both GC and resistors are given in Tables I and II, respectively. The shape of samples for the Hall effect measurements is shown in Figure 1. The resistivities were measured between the point *a* and the point *b* with a digital multimeter (Takeda Riken Industrial Co., Ltd., TR 6853). To obtain the Hall voltage, a given current was flown into the sample with a electric source (Metronix Model 691 A), and, at the same time, a given magnetic field was applied at right angle to the direction of the current. Then, the Hall voltage between point *c* and point *d* was recorded.

The current take off in the sample was also determined from the voltage between point *a* and point *b* using the resistance between the two points. The Hall voltages of the samples T_1–T_4

TABLE I
Preparation Conditions[a] of Polymer-Grafted Carbon Black (GC)

GC designation	Monomers MMA used[b] (g)	GMA used[c] (g)	Conversion (%)
G_1	2.34	0.64	96.5
G_2	7.01	1.99	94.8

[a] 3.0 g of carbon black (Philblack O treated with benzoyl peroxide) was used.
[b] MMA, methyl methacrylate.
[c] GMA, glycidyl methacrylate.

TABLE II
Preparation Conditions of GC Resistors

Sample designation	GC used	Cured conditions[a] Temperature (°C)	Time (h)	Carbon black content (wt %)	Resistivity R_s (Ω cm)
T_1	G_1	No cure		50	3.00
T_2	G_1	150	10	50	0.73
T_3	G_1	200	10	50	0.40
T_4	G_2	200	10	25	540

[a] All samples were precured for 10 h at 100°C.

Journal of Applied Polymer Science, Vol. 32, 4299–4301 (1986)

CCC 0021-8995/86/034299-03$04.00

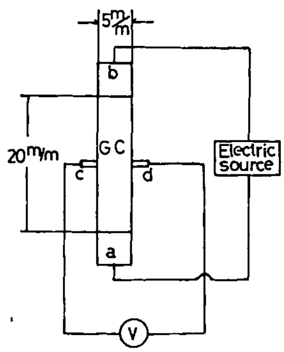

Fig. 1. The shape of the sample used in the measurement of Hall effect: (a,b,c,d) electrodes made from silver paste.

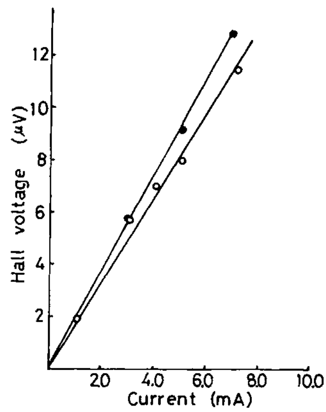

Fig. 2. Hall voltage–current relationship: (●) T_2; magnetic field, 9.3 kgauss; (○) T_3; magnetic field, 9.3 kgauss.

is plotted against the current in Figures 2 and 3. The relationships were found to be linear. The equations for Hall effect are

$$R_H = 1/n \times e = 10^8 \times d \times V_H/I \times B \quad (\mathrm{cm^3/coulomb}) \tag{1}$$

$$\mu = 10^8 \times V_H \times d/I \times B \times R_s \quad (\mathrm{cm^2/V\ s}) \tag{2}$$

where R_H is the Hall coefficient, n is the number density of charge carriers, e is the charge of electron, d is the thickness of the sample, V_H is the Hall voltage, I is the electrical current, μ is the mobility of carriers, R_s is the resistivity of the sample, and B is the magnetic field.

The carriers of the conduction are found to be electrons from the Hall coefficient. The Hall coefficient R_H was calculated from eq. (1) for each sample by substituting for V_H/I with the slope determined by a method of least squares in Figures 2 and 3. Using the above two equations, the number density of electrons (n) and their mobility (μ) were then estimated with results given in Table III. The order of the number density of carriers is ca. 10^{18}–10^{19} near that of grafite material.[3] The mobility of carriers is 0.32 $\mathrm{cm^2/V\ s}$ at most, and decreases rapidly with the decrease of conductivity. This value is smaller than 1 $\mathrm{cm^2/V\ s}$, which is considered as a minimum at the band conduction.[4] These facts suggest that the conduction of GC is due to thermally activated electron hopping. Seebeck effect for T_3 was also examined in the range of 298–563 K and was found to be negative in the lower temperature side. From the results of both R_H and Seebeck coefficient, it was assured that the dominant carriers in the conduction is electrons, particularly at room temperature.

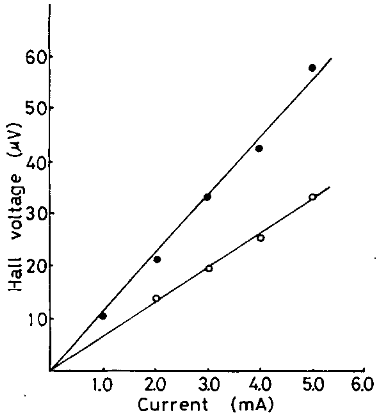

Fig. 3. Hall voltage–current relationship: (○) T_1; magnetic field, 9.3 kgauss; (●) T_4; magnetic field, 10 kgauss.

TABLE III
Hall Coefficient, Numbers of Carriers, and Mobility of GC

Sample designation	Hall coefficient R_H (cm^3/coulomb)	Number of carriers, n (cm^{-3})	Mobility μ (cm^2/V s)
T_1	−0.50	1.2×10^{19}	0.16
T_2	−0.14	4.5×10^{19}	0.19
T_3	−0.13	4.8×10^{19}	0.32
T_4	−1.34	4.7×10^{18}	2.48×10^{-3}

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Received July 3, 1985
Accepted December 5, 1985