PHYSICAL REVIEW B VOLUME 18, NUMBER 6 15 SEPTEMBER 1978

# Absolute thermoelectric power of amorphous metallic glass $Fe_{80}B_{20}$ between 300 and 1000 K

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(Received 16 March 1978)

The absolute thermoelectric power ($S$) for amorphous $Fe_{80}B_{20}$ has been measured in the temperature range from 300 to 1000 K. $S$ is nearly independent of temperature in this range and, in contrast to the electrical resistivity, shows no structure at either the crystallization temperature ($\sim 620$ K) or the glass temperature ($\sim 714$ K). These results can be understood in terms of the Evans, Greenwood, and Lloyd modification of the Ziman theory for liquid metals.

## INTRODUCTION

Some recent studies[1-3] of electrical resistivity ($\rho$) on amorphous metallic glasses at elevated temperatures have clearly indicated that the quantity $\rho$ is a sensitive probe for investigations of crystallization processes. This results from drastic changes in the electrical resistivity when crystallization takes place. Another transport property which, in principle, could be of interest to study in amorphous metallic systems as a function of temperature is the absolute thermoelectric power ($S$). Very little experimental work has been done in this area at elevated temperatures. Therefore, we decided to explore the quantity $S$ between 300 and 1000 K for amorphous $Fe_{80}B_{20}$ whose electric and magnetic properties in the above temperature range are reasonably well known.[1,4,5] The results of this investigation are briefly presented in this paper.

## EXPERIMENTAL CONSIDERATIONS

The amorphous $Fe_{80}B_{20}$ (Metglas 2065) was purchased from Allied Chemical Corporation. This material is a flexible ribbon of thickness $4.2 \times 10^{-3}$ cm and width 0.18 cm. The samples for the thermoelectric power measurements were cut from the same spool used for the $\rho$ studies described elsewhere.[1]

The thermoelectric power relative to Pt was determined by spotwelding two Pt and Pt + 10-at.%- Rh thermocouples to a 2-cm strip of amorphous $Fe_{80}B_{20}$. The temperature gradient of few K was obtained by selective positioning of the sample holder in a Pt furnace. The electrical potential between Pt leads was determined using the experimental facilities described before.[1] The absolute thermopower of amorphous $Fe_{80}B_{20}$ was calculated from the relative thermopower with respect to Pt by using the absolute thermopower of Pt reported by Cusack *et al.*[6] Their data were fitted to a fifth-order polynomial which permitted us to generate a table of absolute thermopower for Pt as a function of the absolute termperature in steps of 0.1 K. The maximum deviation of the fitted values from the actual data was no greater than 0.09%.

## RESULTS AND DISCUSSION

The quantity $S$ as a function of $T$ for $Fe_{80}B_{20}$, obtained with increasing $T$, is shown in Fig. 1. The experimental points (full dots and crosses) represent two separate runs using different samples cut from the same spool. The results of these two runs are practically indistinguishable from each other. The measurements between 300 and 1000 K were carried out continuously using a heating rate of about 20 K h$^{-1}$.

A striking feature of Fig. 1, compared to the corresponding $\rho$ vs $T$ curve,[1] is the absence of any anomalies at the Curie temperature $T_C = 685$ K,[5] or the crystallization temperature $T_X$. According to our resistivity studies, the latter occurs at ~620 K with a heating rate of 12 K h$^{-1}$, well below the glass temperature $T_G = 714$ K.[7] These temperatures are indicated by arrows in Fig. 1. It is not surprising that no anomalous behavior in the thermopower is seen at $T_C$ since the resistivity also behaves regularly here. However, $\rho$ under-

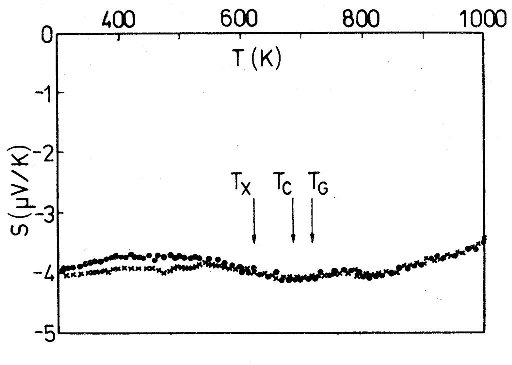

FIG. 1. Absolute thermoelectric power of glassy $Fe_{80}B_{20}$ between 300 and 1000 K.

goes dramatic changes at $T_X$, while $S$ does not. This can be understood as follows. In the modified Ziman theory[8] $\rho$ is given by

$$\rho = \frac{3\pi\Omega_0 m^2}{4e^2\hbar^3 K_F^6}\int_0^{2K_F} dq\, q^3 a(q)\,|t(K_F,q)|^2\,, \tag{1}$$

where $\Omega_0$ is the atomic volume, $K_F$ the Fermi radius, $a(q)$ the interference function, and $t(K_F,q)$ the $t$ matrix for scattering on the Fermi sphere with momentum transfer $q$. The integrand in Eq. (1) is heavily weighted toward large-angle scattering, so that the interference function may be replaced by its value at $2K_F$. Moreover, the $d$-phase shift $\eta_2$ dominates at the Fermi energy in transition metals, so to a reasonable approximation

$$\rho \approx (30\pi^3\hbar^3/me^2\Omega_0 K_F^2 E_F)\,\sin^2\eta_2(E_F)\,a(2K_F)\,. \tag{2}$$

The temperature dependence of $\rho$ and its variation from one phase to another are both attributed to corresponding changes in the interference function $a(2K_F)$. On the other hand, the thermopower $S$, given as

$$S = \frac{\pi^2 k_B^2 T}{3e}\left(\frac{\partial \ln\rho}{\partial E}\right)_{E_F}, \tag{3}$$

where $k_B$ is Boltzmann's constant and $T$ the absolute temperature, is relatively insensitive to the interference function. Using Eq. (1) we find

$$\frac{\hbar^2 K_F}{m}\left(\frac{\partial \ln\rho}{\partial E}\right)_{E_F} = -\frac{6}{K_F} + \frac{2(2K_F)^3 a(2K_F)\,|t(K_F,2K_F)|^2}{\int_0^{2K_F} dq\,q^3 a(q)\,|t(K_F,q)|^2} + \frac{\int_0^{2K_F} dq\,q^3 a(q)\,|t(K_F,q)|^2 \frac{\partial}{\partial K}\ln|t(K,q)|^2\big|_{K_F}}{\int_0^{2K_F} dq\,q^3 a(q)\,|t(K_F,q)|^2}\,. \tag{4}$$

Again, if the integrals are dominated by the backscattering contribution, we can replace $a(q)$ by $a(2K_F)$, whereupon the interference function cancels out of the expression for $S$! In transition metals the formula for $S$ analogous to Eq. (2) become simply

$$S \approx \frac{2\pi^2 k_B^2}{3e}\,T\left(\cot\eta_2(E)\frac{\partial\eta_2}{\partial E}\right)_{E_F} \tag{5}$$

provided the $d$ resonance is sufficiently sharp. Thus $S$ should vary linearly with temperature.

Writing

$$\tan\eta_2(E) = \Gamma/(E_0 - E) \quad \text{for } E \sim E_0\,,$$

where $E_0$ and $\Gamma$ are the position and width of the scattering resonance, respectively, shows that the slope of $S$ vs $T$ depends upon the position of the Fermi energy relative to $E_0$. For iron, $E_F - E_0$ is 0.12 Ry,[8] giving a negative slope. These considerations likely are altered by the $B$ component, which is known to affect the glass structure.[9] Nevertheless, the insensitivity of $S$ to crystallization, as predicted here, is expected to persist.

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