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Thermoelectric behaviour of amorphous magnetic alloys

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Abstract. The Thermoelectric emfs of thermocouples formed by amorphous METGLAS 2826 ($Fe_{40}Ni_{40}P_{14}B_6$) and METGLAS 2826B ($Fe_{28}Ni_{49}P_{14}B_6Si_2$) with standard thermocouple wires like copper, chromel, alumel, etc., were measured as a function of temperature between −196° C and 30° C to assess their suitability as thermoelectric temperature sensors. Thermoelectric emfs generated by METGLAS 2826/Cu and METGLAS 2826B/Cu thermocouples at −196° C are about an order of magnitude smaller when compared to thermal emfs of a standard copper/constantan thermocouple at the same temperature.

Keywords. Thermoelectric behaviour; amorphous alloys; magnetic glassy alloys; Seebeck effect.

1. Introduction

Preparation of a large variety of amorphous/glassy solids by the rapid quenching from the melt (Duwez 1967, 1976) has provided scientific workers opportunities to study effects of the structural disorder on the properties of solids. Some of these glassy materials have been prepared in the ribbon form by Allied Chemicals (USA) under the trade name of METGLAS (Gilman 1975, 1980). Among these are METGLAS 2826 and 2826B which have nominal compositions $Fe_{40}Ni_{40}P_{14}B_6$ and $Fe_{29}Ni_{49}P_{14}B_6Si_2$ respectively. These are ferromagnetic at room temperature and have crystallization temperatures around 400° C. We report here results on the thermoelectric emfs generated by thermocouples consisting of METGLAS ribbons and standard thermocouple wires like copper, iron, chromel, etc to examine the possibility of using these materials as thermocouple materials. Measurements were carried out in the temperature range of − 196° C to 30° C. A detailed report on our work on the thermoelectric power will be published separately.

2. Experimental

Samples were in the form of flexible ribbons. The x-ray pattern on these samples showed no diffraction lines confirming the glassy structure of these alloys. To measure thermoelectric emfs a thermocouple wire (copper, chromel, etc) of 0·010″

diameter, obtained from Omega International (USA), was formed. In earlier transport measurements (Malmhall *et al* 1978a, b) either soldered connection or spot welded connections were used and it was reported that no adverse effect was observed on the measured electronic properties of amorphous samples. However we preferred thermocouple junctions using pressure contacts with indium metal instead of soldering or spot welding to avoid local heating effects near the junctions. The reference junction was maintained at the ice point while the temperature of the other junction was varied from liquid nitrogen temperature to room temperature. Thermoelectric emfs, so generated, were measured to an accuracy of 0·1 μV with a Keithley digital microvoltmeter. The temperature of the other junction was measured to an accuracy of 0·01° C. The sample side of the thermocouple, which was at the ice point, was always connected to the positive terminal of the microvoltmeter. The measurements were found to be reproducible within experimental accuracy of 0·2 μV in the temperature range studied.

3. Results and discussions

The thermoelectric voltages generated by the METGLAS 2826 and 2826B when coupled with other standard thermocouple wires are plotted as a function of temperature in figures 1 and 2. Measurements were confined to temperatures below room temperature for two reasons : (i) thermal cycling between 30° C and − 196° C was not expected to affect the amorphous structure; and (ii) to check the utility of these thermocouples at low temperature sensors. It is observed from data that the thermoelectric emf for 2826B/copper thermocouple varies linearly with

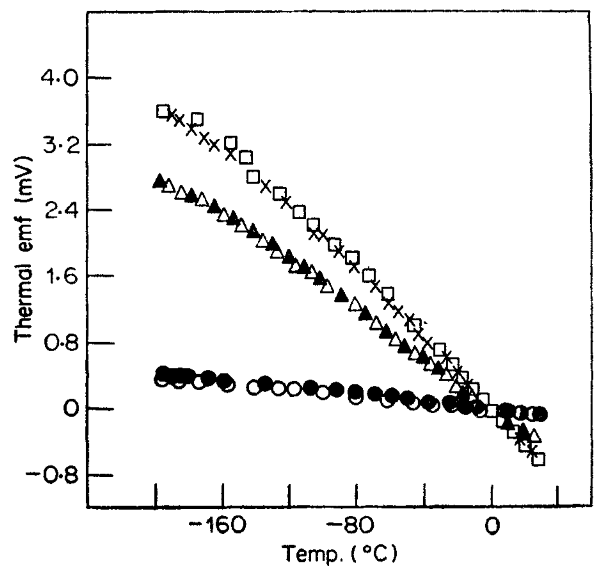

Figure 1. Thermal emf versus temperature of various thermocouples studied ; □ METGLAS 2826B/chromel, × METGLAS 2826/chromel, △ METGLAS 2826B/Fe, ▲ METGLAS 2826/Fe, ○ METGLAS 2826B/Cu and ● METGLAS 2826/Cu. Only few data points are shown.

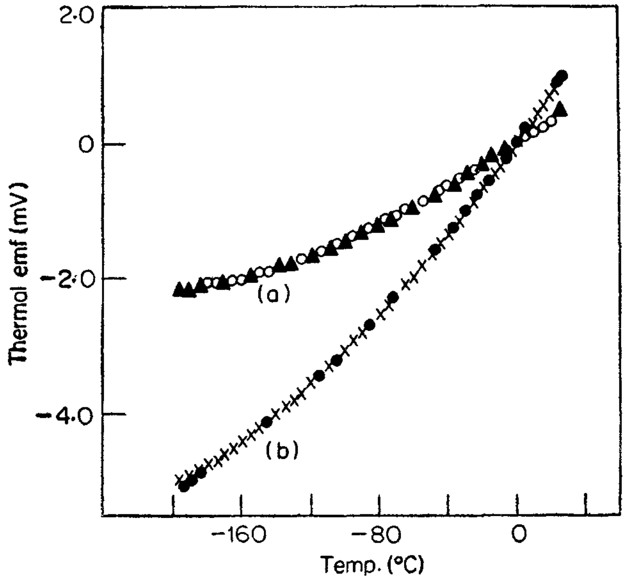

Figure 2. Thermal emf versus temperature of various thermocouples studied; ▲ METGLAS 2826B/alumel, ○ METGLAS 2826/alumel, ● METGLAS 2826B/constantan, and × METGLAS 2826/constantan. Only few data points are shown.

the temperature in the temperature range investigated. On the other hand the thermocouple 2826/copper shows linear behaviour upto approximately − 50° C and then shows nonlinear behaviour at lower temperatures. The magnitudes of the thermoelectric emfs developed are approximately 0·42 mV for 2826/copper and 0·38 mV for 2826B/copper thermocouples, respectively, when the variable temperature junction is at about − 196° C. These values are approximately an order of magnitude smaller than the values for other standard thermocouples like copper/constantan, (ASTM 1974) hence indicating a small thermoelectric power of these METGLAS materials as observed by Baibich *et al* (1979), Prasad and Bhatnagar (1980) and Basak *et al* (1980). When these ribbons are coupled with other standard thermocouple wires like chromel and alumel, the induced thermoelectric emf at − 196° C is of the order of 3·6 mV and 2·2 mV respectively, which is an order of magnitude higher than that of METGLAS 2826 or 2826B/copper. Thus, these magnitudes of thermoelectric emfs in these METGLAS ribbons, when coupled with chromel or alumel, are solely due to large absolute thermoelectric powers of these transition metal alloys. This also explains why the data for METGLAS 2826/chromel and METGLAS 2826B/chromel and other standard thermocouple materials other than copper overlap with each other. These thermocouples show linear behaviour from room temperature to about − 50° C and start showing nonlinear behaviour at lower temperatures.

We have carried out least square fitting of the thermoelectric emf versus temperature data for all the thermocouples to the expression

$$\mathrm{EMF} = a + bt + ct^2, \quad (1)$$

Table 1. Least square fit of thermal emf vs temperature data to the expression emf $= a + bt + ct^2$.

Thermocouple used	$a \times 10^3$ (mV)	$b \times 10^3$ (mV/°C)	$c \times 10^6$ (mV/° C^2)
METGLAS* —Standard wire			
2826B —Copper	-2.917×10^{-3}	-1.969	-0.1725
2826B —Chromel	$+9.837$	-23.40	-23.89
2826B —Alumel	-6.253×10^{-1}	$+18.30$	$+35.31$
2826B —Iron	$+9.757$	-16.20	-10.83
2826B —Constantan	$+8.384$	$+36.00$	$+52.37$
2826 —Copper	-6.209	-2.737	-2.836
2826 —Chromel	-9.137	-23.60	-24.91
2826 —Alumel	-14.60	$+17.30$	$+31.40$
2826 —Iron	$+9.908$	-16.30	-10.36
2826 —Constantan	$+1.208$	$+35.90$	$+52.57$

* METGLAS ribbon side was always connected to the positive terminal of the microvoltmeter.

where t is in ° C, to obtain coefficients a, b and c. These coefficients are listed in table 1. It is seen that the main contribution comes from the linear term for $-50°\text{C} < t < 30°\text{C}$. The coefficient a is not as small as one would have expected. This is due to the nonlinearity in the curve at low temperatures since we have used the complete range of temperatures (− 196° C to 30° C) in fitting the data to expression (1). The third coefficient c is found to be three orders of magnitude smaller than the second coefficient b therefore its contribution to the thermoelectric emf except at temperatures lower than − 50° C is unimportant.

From these results it is clear that METGLAS 2826 and 2826B have small thermoelectric powers compared to non-glassy transition metal alloys like chromel and alumel. Hence their application as thermocouple wires for temperature measurement is not very encouraging. Since these METGLAS ribbons are amorphous alloys of transition metals and metalloids, our results indicate that the small thermoelectric emf generated by the METGLAS/Cu thermocouples can either be attributed to (i) the amorphous or glassy structure of these materials, or (ii) presence of metalloids in the alloys or (iii) both of these factors. We believe it is the metalloid content of these alloys which is largely responsible for the small thermoelectric power of METGLAS ribbons. It will be worthwhile to investigate the thermoelectric power of glassy metallic alloys as a function of the content of a given metalloid in order to clarify this point.

4. Conclusions

Thermal emfs generated by amorphous magnetic alloys METGLAS 2826 and 2826B when coupled by various standard thermocouple wires have been measured in the temperature range − 196° C to 30° C. It has been found that thermal emfs are directly proportional to the temperature in the range − 50° C to 30° C but show nonlinear behaviour at lower temperatures. From measurements it is concluded that the absolute thermoelectric powers of METGLAS 2826 and 2826B are small, hence the usefulness of these materials as temperature sensors may not be encouraging.

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References

American Society for Testing and Materials 1974 *Manual on the use of thermocouples in temperature measurement*

Baibich M N, Muir W B, Belanger G, Destry J, Elzinga H S and Schroeder 1979 *Phys. Lett.* **A73** 328

Basak S, Nagel S R and Giessen B C 1980 *Phys. Rev. B***21** 4049

Duwez P 1967 *Am. Soc. Mat. Trans. Q.* **60** 607

Duwez P 1976 *Ann. Rev. Mater. Sci.* **6** 83

Gilman J J 1975 *Phys. Today* **28** 46

Gilman J J 1980 *Science* **208** 856

Malmhall R, Backstrom G, Rao K V, Bhagat S M, Meichle M and Solomon M B 1978a *J. Appl. Phys.* **49** 1727 and references therein.

Malmhall R, Backstrom G, Bhagat S M and Rao K V 1978b *J. Noncryst. Solids* **28** 159 and references therein.

Prasad B B and Bhatnagar A K, to be communicated.