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The Thermoelectric Power of Alumel at High Temperatures

[1]J. A. Trujillo, [1]Garcia Muriel and [2]Ruben-Dario Ortiz-Ortiz
[1]Department of Physics, Cartagena University, Cartagena, Colombia
[2]Department of Mathematics, Cartagena University, Cartagena, Colombia

Abstract: An ac technique for the measurement of the thermoelectric power is introduced. We have developed a high resolution experimental set-up in the temperatures range 300-600 K. The method was used to measure the thermoelectric power (and specific heat) of the alumel alloy (95% Ni-2% Mn-2% Al-1% Si). Optical radiation was used to heat the sample periodically with a frequency of $\omega_0/2\pi = 2.6$ Hz which induces temperature modulation T_{ac} in one end of the sample. The induced emf, $V_{ac}(T)$, between the illuminated and the obscure ends of the sample was then measured. The thermoelectric power S (T) was calculated from the relation V_{ac}/T_{ac} whose data points indicate an anomaly near 463 K. The temperature region of this anomaly agrees with that of the previously reported specific heat anomaly of alumel which is associated with the para-ferromagnetic phase transition in this Ni alloy.

Key words: Alumel, thermoelectric power, phase transition, para-ferromagnetic, previously

INTRODUCTION

Many experimental techniques have contributed to the present understanding of phase transitions and critical phenomena. Besides the study of equilibrium properties near the critical temperature (e.g., the heat capacity) the study of nonequilibrium properties (e.g., the electrical resistivity) provides further insight into the critical phenomena. The Thermoelectric Power (TEP) is Extremely sensitive both to changes in charge carriers structure and to mechanisms which scatter them. Some measurements of thermoelectric power of pure Ni and Ni-1.5 wt% Cu alloy were previously reported by Papp (1983).

In this study we describe an ac method for the measurement of the thermoelectric power which can be combined with the ac heat capacity measurements on the same specimen. The temperature variation of the thermoelectric power of alumel is analyzed and compared with the heat capacity of alumel and pure Ni (Ortiz *et al*., 1996) near the Curie temperature.

MATERIALS AND METHODS

Experimental: The alumel samples were cut of a square sheet with dimensions of $25\times25\times0.62$ mm^3 which were provided by Alpha-Ventron with a purity of 99.99%. The dimensions of the specimens were $4\times1\times0.09$ mm^3. Two iron wires (99.99%, 0.05mm in diameter) were spot welded to the opposite ends of the sample in one of the faces while the other face was exposed to chopped light which heats one-half of the specimen while the other half is shadowed by a mask (Trujillo, 2003). In order to maximize the absorption of light and increase its uniformity over the illuminated one-half face of the sample, this was coated with a thin film of graphite. The heating light was provided by a quartz iodine lamp and an optical system was used for collimating the beam. A regulated power supply (HP 6031A) was used to monitor the power input of the lamp. Two fine type-K and R thermocouples (25 and 50 μm in diameter, respectively) were also spot welded to the opposite face of the sample, one of the thermocouple (R) locate at center of the face was used to measure the absolute temperature of the sample, T_{dc}, the other one (K) for measuring the amplitude of the temperature oscillation $|T_{ac}|$ induced in the illuminated part (Bonilla *et al*., 2012). The measured signal across the iron wires is related to the T_{ac} signal by the relation:

$$V_{ac} = (S_{alum}-S_{Fe})T_{ac}$$

Where:
S = The absolute TEP of each material; therefore
$S_{alum}-S_{Fe}$ = The TEP of alumel with respect to iron (Fisher and Langer, 1968; Trjilo *et al*., 2008)

The two signals, V_{ac} and T_{ac}, were simultaneously measured by two sensitive lock-in amplifiers (PAR 5210) following a 1: 100 amplification provided by low-noise PAR 1900 transformers whereas T_{dc} was measured using a HP 3478A nanovoltmeter. Data were read and recorded using a personal computer combined with software implemented by National Instruments Labview. The

Corresponding Author: J. A. Trujillo, Department of Physics, Cartagena University, Cartagena, Colombia

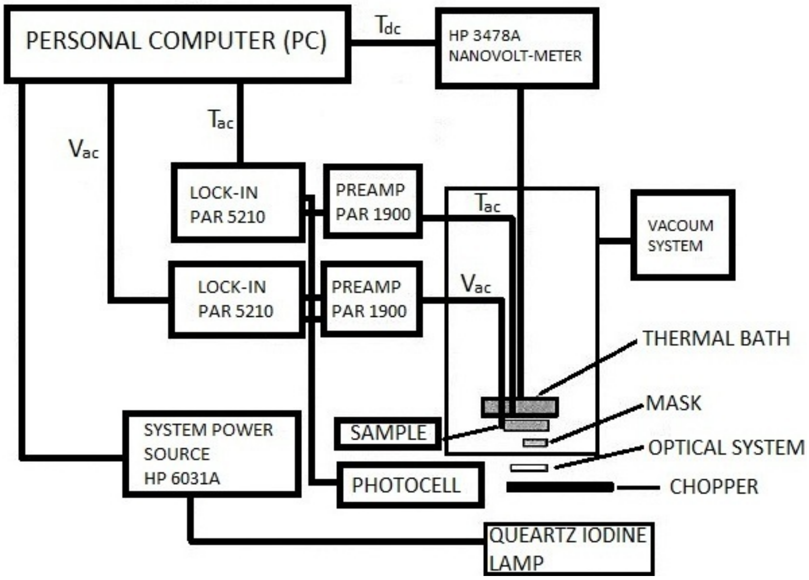

Fig. 1: The block diagram of the experimental set-up to measure the thermoelectric power of a sample

heating light was provided by a quartz iodine lamp and an optical system was used for collimating the beam. A regulated power supply (HP 6031 A) was used to monitor the power input of the lamp (Trujillo *et al*., 2000) (Fig. 1).

RESULTS AND DISCUSSION

The ac calorimetric data for all samples tested in the 300-600 K temperature range for H = 0 consistently show a marked $C_P(T)$ anomaly in the vicinity of T_c = 463 K Fig. 2 with no latent heat, suggesting the corresponding T_c for this alloy. Figure 3 shows a typical $S_{\text{alum-Fe}}(T)$ plot in the 450-485 K region for an alumel sample with respect to iron. Below T_c, the derived TEP is a continuous monotonically decreasing function of temperature with a minimum at T_c. This behavior is very similar to that observed for pure Ni (Papp, 1983) indicating similar effect of their magnetic ordering on the electronic transport for these two metallic systems. We also compare the data for TEP with those of the specific heat of alumel (Ortiz *et al*., 1996) and pure Ni (Sill and legvold, 1965) near the critical temperature, T_c = 463 K for alumel and 632 K for Ni but a quantitative agreement was not found. A strict equivalence between a transport property (S) and a thermodynamic property (specific heat) cannot be expected on theoretical ground. Nevertheless, it is apparent the influence of the short range magnetic order or the magnetic fluctuations (near T_c) on TEP. These results also reflect the small influence of the long-range magnetic ordering (i.e., magnetization) on the thermoelectric power close to T_c when this is changed in pure Ni (Papp, 1983) by the replacement of some of the Ni atoms by other atoms.

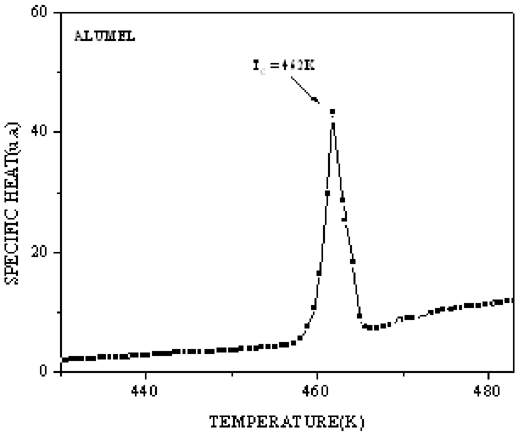

Fig. 2: The temperature dependence of the specific heat of alumel near its Curie Temperature TC

For pure Ni, it was reported previously that the critical behavior of the Seebeck coefficient is very similar to that of the electrical resistivity. An extension of the theory of resistivity was done using Mott's expression for the Seebeck coefficient, however, it was concluded that in the case of Ni and transition metals Mott's theory probably is not applicable, therefore, a more elaborate theory is needed to explain the observed critical behavior of S(T) based on the nature of the correlation of critical fluctuations.

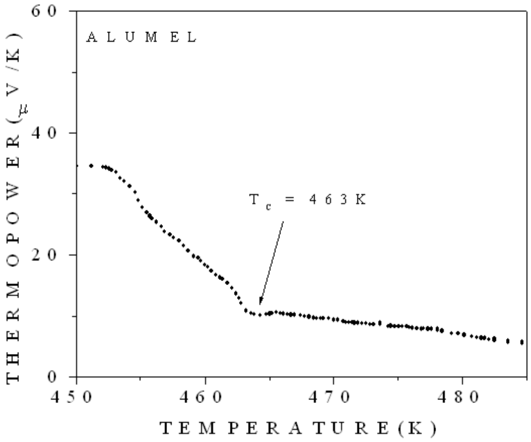

Fig. 3: Temperature variation of the thermoelectric power of alumel with respect to iron (Salum-Fe) near the Curie temperature TC

CONCLUSION

The ferromagnetic ordering of a Ni alloy, alumel, was further studied with thermoelectric power measurements, performed with an ac technique. The $S_{alum\text{-}Fe}$ (T) data near the Curie temperature of alumel at 463 K is characterized by a critical behavior in the same region as that shown by the heat capacity of alumel and pure Ni when $T \rightarrow T_C$ from either side of the transition. Moreover, the TEP behavior for alumel is very similar to that reported previously for pure Ni. This behavior might have indicated that the correlations of critical magnetic fluctuations that persist above and below T_C also influence TEP.

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