Thermoelectric power of single-phase samples of Tl$_2$CaBa$_2$Cu$_2$O$_y$ and Ba$_2$CaSr$_2$Cu$_2$O$_y$

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Abstract. Single-phase 2122 samples of thallium and bismuth superconductors were made by the precursor matrix method. The thermopower of these samples was measured in the temperature range 250 K–T$_c$. The thermopower was positive and decreased linearly with increasing temperature above T$_c$(onset). The exponential enhancement of thermopower seen in the undoped and doped YBCO was not observed in these samples. The linear variation of thermopower can be explained on the basis of either a two-band model or a narrow band model.

Keywords. Thermopower; linear variation; exponential enhancement; two-band model.

1. Introduction

The thermopower of Tl–Ca–Ba–CuO and Bi–Ca–Sr–CuO has been reported in literature (Alcazar et al 1988; Jones et al 1988; Mandal et al 1988; Mitra et al 1988; Bhatnagar et al 1989; Pekala et al 1989). Most of these results are on multiphase samples and the thermopower has been measured in the temperature range 80–300 K. Thermopower is found to be small and positive, around 2 μV/K at room temperature, and increases linearly with decrease in temperature up to T$_c$(onset). Mitra et al (1988) fitted their data with good agreement to a narrow band Hubbard model proposed by Fisher et al (1988). We have measured thermopower on single-phase samples of Tl$_2$CaBa$_2$Cu$_2$O$_y$ and Bi$_2$CaSr$_2$Cu$_2$O$_y$, prepared by the precursor matrix method. The results are described below.

2. Experimental details

The details of the synthesis of these compounds have been described earlier (Gopalakrishnan et al 1988; Sastry et al 1988). The single-phase nature of these compounds has been confirmed by neutron diffraction analysis (Sequeira et al 1988). We have studied two Tl compounds and one Bi compound. The resistivity of these samples was measured by a four-probe method. Tl(a) compound which received additional annealing in flowing oxygen for 24 h at 950°C had a room temperature resistivity, ρ$_0$, of 11.37 mΩ-cm and T$_c$(zero) of 104.33 K. Tl(b) had a ρ$_0$ of 1.609 and a T$_c$(zero) of 102.74 K. The Bi compound had a ρ$_0$ of 1.005 mΩ-cm and T$_c$(zero) at

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79-79 K. The thermopower of all these compounds was measured from 250 K down to
T_c(zero) in an experimental set up described elsewhere (Vasudeva Rao et al 1984).

3. Results and discussions

In all these materials, the thermopower was positive at 250 K with a value of a few
µV/K. The thermopower increased linearly as the temperature was decreased.
Extrapolating this linear variation backwards, the value $S_0$ of the intercept on the
thermopower axis at $T = 0$ K was obtained. We have plotted the reduced thermopower,
$S/T/S_0$, of the different materials in figure 1. The linear decreases in thermopower with
increasing temperature above the peak can be described by the relation,

$$ S = S_0(1 - \alpha T), $$

(1)

where the values of $S_0$ and $\alpha$ are shown in table 1. We have studied well-oxygenated
samples of YBa$_2$Cu$_3$O$_{7-y}$, and yttrium-substituted with rare earths (Srinivasan et al
1987) and copper-substituted with zinc (Vijayashree et al 1989). In these samples, the

![Figure 1. Reduced thermopower as a function of temperature for Tl$_2$CaBa$_2$Cu$_2$O$_7$ (a and
b) and Bi$_2$CaBa$_2$Cu$_2$O$_{y-}$](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$S_0$ (µV/K)</th>
<th>$\alpha$ ($10^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tl$_2$CaBa$_2$Cu$_2$O$_7$ (a)</td>
<td>794</td>
<td>2.96</td>
</tr>
<tr>
<td>Tl$_2$CaBa$_2$Cu$_2$O$_7$ (b)</td>
<td>15.76</td>
<td>2.15</td>
</tr>
<tr>
<td>Bi$_2$CaSr$_2$Cu$_2$O$_y$</td>
<td>10.33</td>
<td>3.04</td>
</tr>
</tbody>
</table>
temperature variation of thermopower was well represented by the formula,

\[ S = a T \left[ 1 + b \exp \left( \frac{-T}{T_e} \right) \right]. \] (2)

The samples showed an exponential enhancement of thermopower as \( T_e \) was approached. The behaviour of the Tl and Bi compounds is very different from the behaviour of the 123 compounds.

The resistivity of the Tl and Bi compounds shows a linear variation with temperature. The Hall coefficient of multiphase TlCa\(_2\)BaCu\(_2\)O\(_x\) was measured as a function of temperature by Mandal et al (1989). The reciprocal of the Hall constant varies linearly with temperature. In this respect, these compounds show the same behaviour as the 123 compounds.

To account for the temperature dependence of resistivity and Hall effect in 123 compounds, Eagles (1989) proposed a two-band model. Here, electrons and holes are both responsible for the transport properties. The inverse mobility of electrons and holes are taken to have a linear temperature dependence. The temperature-independent term and the temperature coefficients of the mobilities are different for the electrons and holes. The carrier concentrations \( n_e \) and \( n_h \) are taken to be temperature-independent. Then, Eagles (1989) has shown that the resistivity can be written as:

\[ \rho = \rho_0 + \rho_1 T. \] (3)

In such a situation, the effective thermopower can be written as

\[ S = \sigma_0 S_0 + \sigma_1 S_1, \] (4)

where \( \sigma_0 \) and \( \sigma_1 \) are the contributions to the electrical conductivity by holes and electrons respectively and \( S_0 \) and \( S_1 \) are the thermopower due to holes and electrons. Vijayashree et al (1990) have shown that taking \( S_0 \) and \( S_1 \) to vary linearly with temperature but with opposite signs, the thermopower will depend on temperature as

\[ S = S_{-1} T^{-1} + S_0 + S_1 T. \] (5)

The coefficient \( S_1 \) can be negative while \( S_0 \) can be positive depending on the relative magnitudes of the various coefficients. The temperature where the thermopower crosses the temperature axis depends on the ratio of the carrier concentrations of the electrons and holes and can vary from specimen to specimen.

There is a second explanation proposed by Bar-ad et al (1988). In this model, the conduction band is assumed to be narrow. A portion of the band-states is separated from the main part to form an upper sub-band of localized states. These localized states do not contribute to transport but participate in the statistics. At \( T = 0 \) K, the chemical potential lies above the middle of the conduction band. As the temperature rises, electrons are transferred from the conduction sub-band to the localized upper-band, thereby increasing the number of holes in the conduction band. This can account for the variation of the Hall coefficient with temperature and for \( p \)-type transport properties. On this basis, Bar-ad et al (1988) have calculated the temperature variation of thermopower, resistivity and Hall effect, assuming some values for the width of the localized band and its position relative to the middle of the conduction band. While one can reproduce the linear fall in thermopower with increasing temperature on the basis of this model, the carrier density required appears to be at least one order of magnitude higher than the observed value.
4. Conclusions

2122 single-phase samples of Tl and Bi were prepared by the precursor matrix method. The thermopower measurements carried out in the temperature range 250 K down to the superconducting transition, showed a behaviour different from those of the 123 compounds. The linear decrease in thermopower of these samples as the temperature is increased above the onset of superconducting transition, can be explained satisfactorily using the two-band model proposed by Eagles (1989). The narrow band model by Bar-ad et al (1988) can also reproduce the thermopower results.

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References

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