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Specific heat of $REBaSrCu_3O_7$ compounds (R = Nd, Sm, Dy, Er)

Z. Tarnawski [a,b,*], X.Z. Wang [c], N.-T.H. Kim-Ngan [d], R.J. Radwański [d], J.J.M. Franse [b]

[a] Solid State Physics Department, Academy of Mining and Metallurgy, Mickiewicza 30, 30-059 Kraków, Poland
[b] Van der Waals–Zeeman Institute, Universiteit van Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, The Netherlands
[c] Angewandte Physik, J. Kepler Universitat, A4040 Linz, Austria
[d] Center for Solid State Physics, Św. Filipa 5, 31-150 Kraków, and Institute of Physics, Pedagogical University, 30-084 Kraków, Poland

Abstract

Specific heat measurements have been performed on polycrystalline $REBaSrCu_3O_7$ (R = Nd, Sm, Dy, Er) in the temperature range from 0.3 to 3 K. Antiferromagnetic order is indicated by the λ-type peak in the specific heat at 1.2 and 0.6 K for Dy and Er compounds, respectively, whereas only a broad anomaly around 0.6 K is observed for Nd and Sm compounds. The specific heat data for Nd and Sm compounds are well fit with a Schottky-type anomaly with an energy splitting of 1.4 K, indicating the existence of an internal field of 2.42 T at the RE site. The magnetic singlet ground state of $ErBaSrCu_3O_7$ and $DyBaSrCu_3O_7$ is produced by exchange interactions of −0.05 and −0.035 T f.u./μ_B, respectively.

Keywords: Crystal field; High-T_C; $REBaSrCu_3O_7$; Specific heat

High-T_C superconductors $REBa_2Cu_3O_7$ (RE-123O_7, RE = most rare earths) crystallize in the orthorhombic structure. The c-axis (and the cell volume) increases continuously with increasing radius of the RE^{3+} ion. The superconducting temperature T_C (∼ 90 K) exhibits a very small change for different RE ions. Compounds $REBaSrCu_3O_7$ are known to belong to the RE-123O_7 family with T_C between 54 and 86 K. However, with Sr substitution, compounds with ionic radius $r_{RE} < r_{Dy}$ preserve an orthorhombic structure, while those with $r_{RE} > r_{Dy}$ have a tetragonal structure [1]. The c-axis (and the cell volume) was found to decrease from RE = La to Dy, and then increase again. The maximum T_C is obtained for RE = Gd and Dy, i.e. close to the tetragonal/orthorhombic phase transition. The Dy compound can be stabilized in both the orthorhombic and tetragonal structure with the same oxygen content, depending on the heat treatment [2].

In this paper, we present specific heat measurements performed on polycrystalline $REBaSrCu_3O_7$ (RE = Nd, Sm, Dy, Er) in the temperature range from 0.3 to 3 K.

$REBaSrCu_3O_{7-\delta}$ (R = Nd, Sm, Dy, Er; δ = 0.06–0.07) samples were prepared by a standard ceramic technique. Details of sample preparation, crystal structure and oxygen content determination, and studies of the superconducting properties have been published elsewhere [1,2]. Specific heat measurements in the temperature range 0.3–3 K were performed in a ^3He cryostat. Measurements were carried out on five samples with Nd, Sm (tetragonal), Dy (both tetragonal and orthorhombic) and Er (orthorhombic). For comparison, data for the (same) RE-123O_7 compounds [3,4] are also reported.

The specific heat $C(T)$ of $NdBaSrCu_3O_7$ is shown in Fig. 1. The broad anomaly around 0.6 K becomes more visible in the Sr-substituted compound, whereas the small peak indicating the antiferromagnetic order of the Nd^{3+}

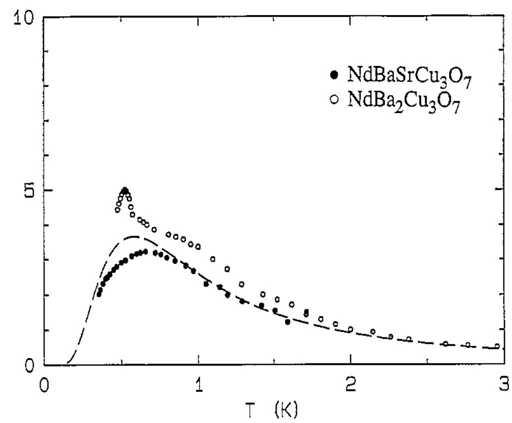

Fig. 1. Specific heat plotted as C vs. T for $NdBaSrCu_3O_7$ (●). The data for Nd-123O_7 (○) are taken from Ref. [4]. (---) The Schottky anomaly with an energy splitting ΔE of 1.4 K.

* Corresponding author. Email: tarnawsk@uci.agh.edu.pl.

ions in the Nd-$123O_7$ compound at $T_N = 0.5$ K [4] disappears. The entropy amounts to 4.8 J/kmol at 3 K for Nd-$123O_7$, whereas it reaches only 4 J/kmol for the Sr-substituted compound. The $C(T)$ data for $SmBaSrCu_3O_7$ are shown in Fig. 2. The sharp peak at $T_N = 0.6$ K with an entropy of almost $R \ln 2$ disappears with Sr substitution and only a broad anomaly is observed for this compound around 0.6 K. This indicates that the substitution of Ba by Sr causes not only a change from the orthorhombic to the tetragonal structure, but also affects the magnetic properties of the Nd and Sm compounds. Our calculations show that the $C(T)$ data for the two Sr-substituted compounds with Nd and Sm exhibiting a broad anomaly around 0.6 K follow a Schottky-type curve for a two-level system with an energy splitting ΔE of 1.4 K. Such a two-level system is expected to originate from the Kramers doublet ground state as found for other Nd and Sm systems [5]. The splitting indicates the presence of an internal field of 2.42 T at the RE site.

The specific heat $C(T)$ of Dy and $ErBaSrCu_3O_7$ compounds is shown in Fig. 3. The formation of antiferromagnetic order is indicated by the λ-type peak at 1.2 and 0.6 K, respectively. Sr substitution results in an enhancement of T_N (from 0.9 to 1.2 K) for the Dy compound. The $C(T)$ data are almost the same for Dy compounds with tetragonal and orthorhombic structure except for a slight downward shift of T_N of 0.1 K. The entropy reaches a value of $R \ln 2$ in these compounds. Moreover, superconducting properties are found to be very similar for both phases. The Curie behaviour of the paramagnetic susceptibility, with the effective paramagnetic moment close to the Dy^{3+} free-ion value, was not found to be influenced by the different structures [2]. The Dy magnetic moments lie along the c-axis, and thus the change of anisotropy in the a–b plane due to the tetragonal–orthorhombic phase transition would not affect the magnetic properties. The Er

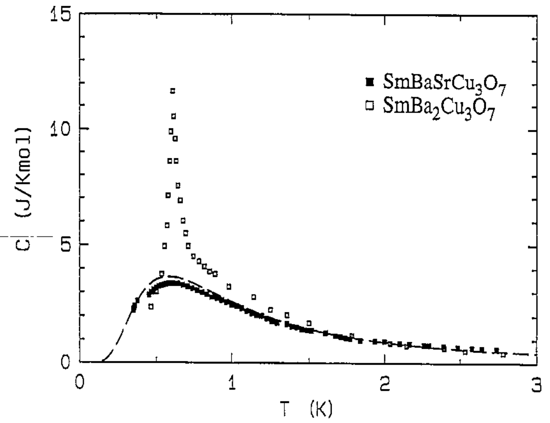

Fig. 2. Specific heat plotted as C vs. T for $SmBaSrCu_3O_7$ (■). The data for Sm-$123O_7$ (□) are taken from Ref. [4]. (---) The Schottky anomaly with an energy splitting ΔE of 1.4 K.

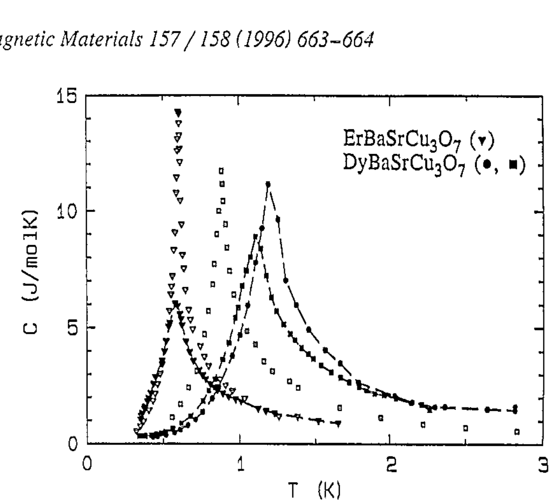

Fig. 3. Specific heat plotted as C vs. T for tetragonal (■) and orthorhombic (●) $DyBaSrCu_3O_7$, and for orthorhombic $ErBaSrCu_3O_7$ (▼). The data for Dy- (□) and Er-$123O_7$ (▽) are taken from Refs. [4,3].

compound forms the orthorhombic structure. Sr substitution causes only a broadening of the λ-type peak at T_N, which is mostly related to the change of the anisotropy ratio in the a–b plane. Moreover, the entropy only reaches 70% of $R \ln 2$ in this case. As the Neél temperature is the same at 0.6 K, we expect that the magnetic singlet ground state, produced by weak exchange interactions of -0.05 T f.u./μ_B as for the Er-$123O_7$ compound [3], would also be appropriate for $ErBaSrCu_3O_7$. The exchange interaction was estimated to be -0.027 and -0.035 T f.u./μ_B for Dy-$123O_7$ and $DyBaSrCu_3O_7$, respectively.

In conclusion, the substitution of Ba by Sr in RE-$123O_7$ superconductors has a significant influence on the structural and magnetic properties for light RE (Nd, Sm), whereas only a small effect is observed for heavy RE (Dy, Er). The specific heat data for Nd and Sm compounds indicate the presence of an internal field of 2.42 T at the RE site. All considered RE ions are Kramers systems and lifting of the Kramers degeneracy may be the reason for the large low-temperature specific heat [5].

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