

Reversible Magnetization of Melt-Processed NEG-123 Superconductor

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Specific heat of superconducting electrons was measured in a melt-processed (Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba₂Cu₃O_y superconductor (NEG-123) with 5 mol% of Gd-211, 1 wt% Ag, and 0.035 mol% of Zn. The thermodynamic characteristics of this compound are still not well known. From calorimetric measurements the reversible magnetization, critical fields, penetration depth, and coherence length were deduced. In the vicinity of T_c , the reversible magnetic moment was additionally measured by means of SQUID.

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1. Introduction

The LRE-123 (LRE = light rare earth, LRE = Nd, Sm, Eu, Gd) materials exhibit exceptional pinning properties partly due to point-like LRE/Ba solid solution clusters, partly for the introduced nanoscopic secondary phase particles. As the LRE/Ba clusters substitute the role of oxygen vacancies, representing the typical point-like defects in bulk RE-123 compounds, the LRE-123 compounds can be optimally oxygenated to reach the highest possible T_c together with a high secondary peak. A high remnant critical current density is due to secondary phase nanoparticles. The (Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba₂Cu₃O_y compound studied here exhibits one more distinguished type of defects, nanoscale lamellas filling channels between regular twin boundaries. The aim of this work is for the first time to look at the thermodynamic properties of this interesting material.

The sample in size of $0.7 \times 0.7 \times 0.4$ mm³ was cut from a pellet of (Nd_{0.33}Eu_{0.38}Gd_{0.28})Ba₂Cu₃O_y doped with 5 mol% Gd-211, 1 wt% Ag, 0.035 mol% of ZnO, and 0.5 mol% Pt [1]. The pellet, prepared by the oxygen-controlled-melt-growth (OCMG) process in Ar/0.1% O₂, had 16 mm in diameter and was 8 mm high. T_c reached 92.8 K.

2. Results and discussion

The differential specific heat measurement, presented in terms of $C(T)/T$, was measured in the temperature range 73 to 99.3 K, in a series of constant magnetic fields $B = \mu_0 H = 0, 1, 2, 3, 5, \text{ and } 7$ T. The measured curves are seen in Fig. 1a. With the aim to evaluate the reversible magnetization, the data were processed with the

help of the following thermodynamic relations [2]:

$$\Delta S(B, T) = - \int_{T^*}^T \frac{\Delta C(B, T)}{T} dT$$

and

$$\Delta F(B, T) = - \int_{T^*}^T \frac{\Delta S(B, T)}{T} dT, \quad (1)$$

where $\Delta C(B, T) = C(B, T) - C(0, T)$ (see Fig. 1b), ΔS is entropy and ΔF is free energy of the system. T^* is the highest measured temperature, $T^* = 99.3$ K.

The $\Delta F(T)_B$ results obtained by the integration of Eq. (1) are shown in Fig. 1b. As the original experimental data were not calibrated, all the following data processing gives only relative quantities. Reversible magnetization comes from $M_{\text{rev}}(B, T) = -(\partial \Delta F(B, T) / \partial B)_T$. At higher magnetic fields $M_{\text{rev}}(B)$ should obey the functional dependence $M_{\text{rev}}(B, T) = -\alpha + \beta \ln B$. We used the integral function to this dependence, $\gamma - (\alpha + \beta)B + \beta B \ln B$, where γ is integration constant, to fit directly the $\Delta F(B)$ data. These data were obtained from vertical cuts at a series of temperatures, with 1 K step (indicated by dashed lines in Fig. 1b) in the system of five $\Delta F(T)_B$ curves for different fields. The $\Delta F(B)_T$ dependences (all going to (0, 0)) are shown in Fig. 1c, together with their fits (lines). The parameters α and β obtained in this way enabled us to construct the $M_{\text{rev}}(B)$ dependences presented in Fig. 2a. As indicated above, the data were obtained in arbitrary units. An indicative scale, provided on the right side of the figure, was obtained from direct measurements of reversible magnetization by SQUID (RM). It is seen that the reversible magnetization data in vicinity of T_c lie deep below 1 Oe (≈ 80 A/m). Any direct experimental determination of such curves (SQUID,

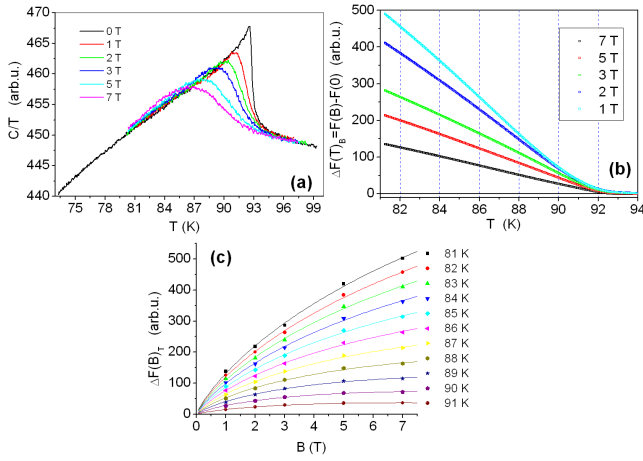


Fig. 1. The temperature dependences of (a) $C(B,T)/T$, (b) the free energy difference as a function of temperature, as obtained from the integration in Eq. (1), and (c) the same data as in (b), however transferred to the $\Delta F(B)_T$ representation (symbols) and fitted by the functional dependence $\gamma - (\alpha + \beta)B + \beta B \ln B$ (lines).

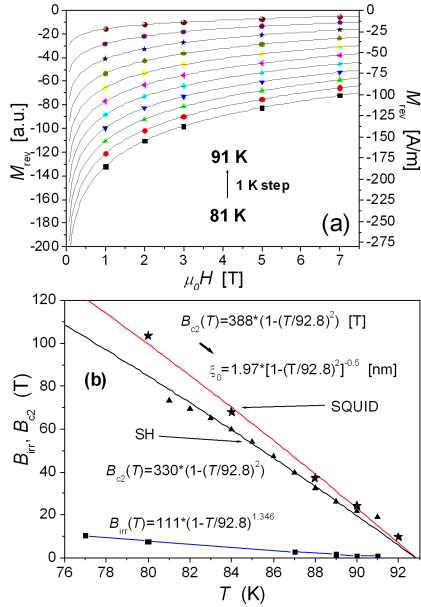


Fig. 2. (a) $M_{rev}(B)$ constructed from the fits of Fig. 1c; (b) temperature dependences of B_{c2} obtained from CP and SQUID measurements and $B_{irr}(T)$ from independent irreversible vibrating sample magnetometer (VSM) experiment.

VSM) is then associated with a high experimental error.

Results of the CP evaluation are shown in Fig. 2b, together with the direct reversible magnetization measured by SQUID. The lines are fits to common theoretical formulae. Coherence length at zero temperature deduced from B_{c2} in RM and CP experiments were $\xi_0 = 1.97$ nm and 2.13 nm, respectively, similar to those observed in YBCO. The calculation was made using $\kappa \approx 100$.

3. Conclusion

In summary, we measured the electronic specific heat by a differential calorimetry in temperature range 74 K to 99 K and inferred the temperature dependence of reversible magnetization, M_{rev} , from the data. This procedure was confronted with a direct measurement of M_{rev} made by SQUID. Both experiments gave results similar to those commonly observed in $YBa_2Cu_3O_7$ (YBCO).

Acknowledgments

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References

- [1] M. Jirsa, M. Rameš, K. Jurek, M. Muralidhar, P. Das, M.R. Koblischka, T. Wolf, *Mater. Sci. Engin. B* **151**, 25 (2008).
- [2] W.Y. Liang, J.W. Loram, *Physica C* **404**, 230 (2004) or A.M. Campbell, J.W. Loram, N. Hari-Babu, J.R. Cooper, D.A. Cardwell, *Phys. Rev. B* **70**, 214518 (2004).