Specific heat anomalies in the 108 K superconducting system $Y_{1-x}Ca_xSr_2Cu_2Tl_{1.5}Pb_{5}O_{7}$

This article has been downloaded from IOPscience. Please scroll down to see the full text article.

1991 Supercond. Sci. Technol. 4 S286

(http://iopscience.iop.org/0953-2048/4/1S/081)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 140.112.55.213
The article was downloaded on 07/02/2012 at 07:36

Please note that terms and conditions apply.
Specific Heat Anomalies in the 108K Superconducting System

$Y_{1-x}Ca_xSr_2Cu_2Tl_5Pb_5O_{17}$.

J.W.Loram, K.A.Mirza, R.S.Liu.

IRC in Superconductivity, Madingley Road, Cambridge CB3 OHE, UK.

Abstract. We show the progression with $x$ of the superconducting specific heat anomalies in $Y_{1-x}Ca_xSr_2Cu_2Tl_5Pb_5O_{17}$. The system is superconducting above $x=.5$ and $T_c$ shows a broad maximum at $x=.8$. The size of the specific heat anomaly peaks very much more sharply than $T_c$, reflecting a correspondingly rapid variation with $x$ of the superconducting pair density, similar to the behaviour previously observed in $La_{2-x}Sr_xCuO_4$. At low temperatures we observe a "magnetic" term which anticorrelates with the size of the anomaly at $T_c$ but no additional electronic term.

1. Introduction

The investigation of a new superconducting system is frequently confined to a determination by resistivity or magnetic measurements of the transition temperature $T_c$. We have observed in studies of several systems that the superconducting pair density (order parameter) as determined by the magnitude of the specific heat anomaly varies as a function of composition very much more rapidly than does $T_c$ and this information is essential to properly characterise the system. Note that magnetic susceptibility measurements can at best only reveal a superconducting volume fraction and do not reflect the pair density. In this report we describe specific heat measurements on the new 108K system $Y_{1-x}Ca_xSr_2Cu_2Tl_5Pb_5O_{17}$ (subsequently referred to as the Tl system).

This system is structurally similar to YBa$_2$Cu$_3$O$_7$ (Liang et al,1990) with Sr replacing Ba and Tl$_5$Pb$_5$ replacing the chain Cu(1) in YBCO. It is however tetragonal and therefore has no chain structure. Substituting Ca$^{2+}$ for Y$^{3+}$ adds holes, and the system progresses directly from a semiconducting phase to a superconducting phase at around $x=.5$ with $T_c$(max) ~108K at $x=.8$. The magnetic behaviour of the Tl system has not been established but antiferromagnetic order has been observed in the related compound YBa$_2$Cu$_2$TlO$_7$. It is therefore likely that the magnetic phase diagram of the Tl system is similar to that of other oxide superconductors with antiferromagnetic correlations playing an important role in the semiconducting region $x<.5$.

The system shows increasing metallic conductivity up to $x=1$. The carrier density estimated by iodometric titration similarly increases to $x=1$. Close to the metal insulator transition $x_{MI} ~.5$ the superconducting resistive transition is very broad but has $T_c$(onset) comparable with $T_c$(max). As $x$ approaches the optimum composition $x_0 = 8$ the transition width decreases rapidly to a few $K$ but $T_c$(onset) changes very little. For $x> .8$ $T_c$(onset) drops sharply but the width stays constant.

2. Experimental

To observe the small specific heat anomalies we use a differential technique (Loram 1983) with resolution ~1:10$^4$ above 30K, in which we measure the difference in specific heat between each sample and a reference Tl sample with $x=.2$, thus eliminating most of the large phonon term. Sample masses were ~ 1.8g.
Fig 1. $\Delta C^{el}/T$ for $Y_{1-x}Ca_xSr_2Cu_2Tl_1.5Pb_{5}O_{7}$ where $\Delta C^{el}=C^{el}-C^{cl}$. Labels show 100x.

Fig 2. $T_c$ (o) defined as mid-point of the transition. Step height $\Delta C(T_c)/T_c$ (A); Low temperature anomaly $(C/T)_{2K}$ (Δ)
3. Results.

The specific heat results for the region around $T_C$ after correction for a residual phonon background term are shown in Fig 1, and it is clear that the behaviour is quite different for $x$ below and above $x_0 = 0.8$.

We first observe a very broad anomaly with low entropy (pair density) at $x = 0.6$. The anomalies increase rapidly in area and sharpness as $x$ increases to $x_0 = 0.8$, reflecting respectively a corresponding increase in superconducting pair density and range of phase coherence. In spite of this rapid increase in the pair density, $T_C$ increases only a little, passing through a broad maximum of 108K at $x = 0.8$, and the onset temperature is almost independent of $x$ at around 120K. Above $x_0$, $T_C$, $T_C$(onset) and the anomaly size $\Delta C(T_c)/T_c$ all fall steadily with increase in $x$ and metallic conductivity.

At low temperatures ($1.5 < T < 10$K) specific heat anomalies typical of spin glass order are observed for $x < 0.5$. In the superconducting region $x > 0.5$, $C - C_{Oh}$ is approximately independent of temperature with no clear evidence for a linear $T$ term. There is, however, a striking anti-correlation of this term with the size of the anomaly at $T_c$ (see Fig 2) which strongly suggests that in this composition range the low temperature anomaly is electronic in origin.

4. Discussion

The progression with $x$ of the specific heat anomalies at $T_c$ and at low temperatures is strikingly similar in the present system $Y_{1-x}Ca_xSr_2Cu_2Tl_5Pb_5O_{27}$ to that observed previously in $La_{0.5}Sr_xCuO_4$ (Loram et al 1989). On first emerging from the semiconducting region the pair density is low but $T_c$ is already high. The picture that emerges is one of superconducting fluctuations persisting up to $T_c \sim T_{c,max}$ growing in amplitude with $x$ and finally forming a fully coherent superconducting state over a narrow composition range around $x_0$. This contrasts with the conventional view that $T_c$ increases monotonically with carrier density. We suggest that this behaviour should not to be viewed as spatially separate superconducting and normal regions but as dynamic fluctuations into and out of the superconducting state due perhaps to pair breaking by static or slowly varying magnetic correlations which persist into the metallic region. These rapidly weaken as the carrier density increases allowing the superconducting order parameter to increase in amplitude and phase coherence.

References.