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Electron–phonon interaction in $Gd_{1-x}Ca_xBaSrCu_3O_{7-\delta}$ superconductors

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ABSTRACT

Polycrystalline $Gd_{1-x}Ca_xBaSrCu_3O_{7-\delta}$ samples ($0 \le x \le 0.1$) were prepared via solid-state reaction. The superconducting critical temperature T_c and lattice parameter decrease with doping content. Temperature dependence of the specific heat of all samples was measured with the thermal relaxation technique using a Physical Property Measurement System from about 2 K to 150 K. The calculated Debye temperature Θ_D at 10 K is found to be inversely proportional to T_c. Subsequently, the electron–phonon coupling constant was estimated based on standard BCS theory (λ_{BCS}) in the weak coupling limit and two-dimensional Van Hove scenario (λ_{VH}). The calculated values of λ_{VH} in this study (around 0.04) are close to the experimental data as reported by other researchers on Bi-based and YBCO samples. Hence, the two-dimensional Van Hove scenario seems to be a viable candidate for the mechanism of superconductivity if electron–phonon coupling plays a role in superconductivity of these materials.

1. Introduction

It is well known that the electronic state of high-T_c superconductors (HTSCs) dramatically changes with carrier concentration. Substitution of Gd^{3+} ion by Ca^{2+} ion with lower valence is one of the methods for increasing the hole concentration in this system. Previous studies on YBCO system imply that the reduction of charge at Y site due to the Ca substitution is partially balanced by oxygen loss [1–3] as a result hole concentration little exceeds that of non-substituted compound [4]. Decrease of the oxygen content by Ca doping decreases the value of lattice parameters and the distance between CuO_2 planes as well. This enhances the antiferromagnetic correlation between Cu-spins in the planes along the *c*-axis and destroys the superconductivity.

Besides, the electron–phonon coupling strongly influences the electronic properties of the HTSC materials. Various experimental results point towards the important role of phonons in the mechanism of cuprate high temperature superconductors ([5,6] and references therein). In two dimensions, electrons in a periodic potential show a logarithmic density of states, named a Van Hove singularity. The Van Hove singularity is based on the assumption that, in HTSC, the Fermi level lies close to such a singularity. This hypothesis has been confirmed by many experiments, in particular by angular resolved photoemission spectroscopy in different compounds.

Specific heat measurements, for example, are a reliable technique to investigate the elastic properties of these HTSC especially at low temperatures. The Debye temperature derived from specific heat measurements may explain the importance of the phonons and their interaction with T_c as well in order to explore the possible mechanism of HTSC materials.

In this study, polycrystalline $Gd_{1-x}Ca_xBaSrCu_3O_{7-\delta}$ samples ($0 \le x \le 0.1$) were prepared via solid-state reaction. Four point probes were used for resistance versus temperature measurement. Results show decrease in T_c with increase of doping content (x). This variation is assumed to be irrelevant to the different of phases or impurity effects since X-ray patterns show all samples are in tetragonal phase.

Specific heat measurements from about 2 K to 150 K of all samples were carried out using the thermal relaxation technique in a Physical Property Measurement System (PPMS). Results reveal an obvious specific heat jump around the critical temperature for the $GdBaSrCu_3O_{7-\delta}$ sample reflecting the bulk nature superconductivity in this HTSC material. This specific heat jump is shifted to lower temperature upon decreasing T_c. Subsequently, the Debye temperature Θ_D at 10 K was calculated and used to estimate the electron–phonon coupling constant based on standard BCS theory (λ_{BCS}) in the weak coupling limit and a two-dimensional Van Hove scenario (λ_{VH}). Details of this research will be discussed in this communication.

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