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Structural characteristics of Bi-based superconductors studied by positron annihilation

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ABSTRACT

We have measured the positron lifetime spectra as a function of temperature from 80 to 300 K and Doppler-broadening annihilation radiation (DBAR) spectra in normal and superconducting states for three kinds of Bi-based superconductors: Bi2212, Pb- and F-doped Bi2223. For Pb-doped Bi2223 superconductor, anomalies in the temperature dependence of positron lifetimes indicate the structural instabilities. However, a continuous increasing in the mean lifetime is observed for F-doped Bi2223 system and interpreted in terms of a simple thermal expansion with an average linear expansion coefficient $\alpha \sim 35 \times 10^{-6}$. The difference spectra of DBAR spectra after deconvolution between two states show an evidence for charge transfer between the Cu-O and Bi-O planes in Bi-based superconductors. The role of oxygen defects in charge transfer was discussed.

INTRODUCTION

The electronic structure of high-Tc superconductors has been a subject of intense study since their discovery. Elements substitution in cuprate superconductors is a very useful method to change its structural characteristics. Positron annihilation spectroscopy is an established experimental method for an electronic structure and defect study of solids. In this study, we have prepared three kinds of polycrystalline Bi-based samples doped in Bi-O layers, measured positron lifetime spectra as a function of temperature from 80 to 300K and DBAR spectra in normal and superconducting states for these samples and clarify the origin of the temperature dependence of positron annihilation parameters.

EXPERIMENT

The samples used in the experiments were prepared by the solid state reaction method[1], and were characterized by means of powder x-ray diffraction. The transition temperature Tc of the Bi2212, Bi(Pb)2223, F-doped Bi(Pb)2223 were determined to be 89K, 109.6K and 118K respectively by the resistivity measurements.

Positron lifetime measurements were carried out using a fast-fast coincidence spectrometer with timing resolution of 240 ps. Each spectrum contained one million counts and was analyzed using the PATFIT program. DBAR spectra were measured by using a coaxial HPGe detector with a resolution (FWHM) of 1.5 Kev at 514 Kev line of ^{85}Sr . The Total number of counts collected for each spectrum was five millions,

and was analyzed by applying a point by point deconvolution process[2] to eliminate the affection of instrumental resolution. In order to study the changes of electronic structure, the difference spectra after deconvolution between normal and superconducting states were took.

RESULTS AND DISCUSSION

1. Structural instability

All the positron lifetime spectra were best fitted to two exponential components. The long-lived component τ_2 can be attributed to positron annihilation in the lower electron density region, e.g., defects. τ_2 as a function of temperature from 80 to 300 K for the Bi(Pb)2223 and the F-doped Bi(Pb)2223 are shown in Fig.1,2. The variations in the lifetime τ_2 for Bi2212 are more irregular than those for Bi(Pb)2223 and F-doped Bi(Pb)2223. From Fig.1, we can see that, the positron lifetime results display three narrow valleys near 120, 140, 160K and two wide valleys near 240 and 270K. McMullen et al. [3] has calculated the positron density distribution (PDD) in the Bi2212 system. The results show that the PDD is greatest between the Bi-O layers and the oxygen defects cannot bind positrons. The anomalies in the lifetime indicate the structural instabilities of the Bi(Pb)2223 in normal state, which may be caused by structural changes, such as the softening of the lattice, or the motion of vacancies in Bi-O layers[4]. However, we don't observe any anomaly from Fig.2, this fact suggests that adding F impurities can stabilized Bi-O layers in the Bi(Pb)2223 system.

2. Thermal expansion

The temperature variations of τ_n for the F-doped Bi(Pb)2223 are shown in Fig.3. From Fig.3, it can be seen that τ_n increases continuously from 212 ps to 217 ps. This temperature dependence can be understood in terms of a simple thermal expansion which should result in a longer τ_n while the temperature increases. Therefore, we can write

$$\lambda(T) = \lambda(T_0) [1 + \alpha(T - T_0)]^{-1/3} \quad (1)$$

$$[\tau(T)/\tau(T_0)]^{1/3} - 1 = \alpha(T - T_0) \quad (2)$$

where T_0 is a reference temperature and α is the coefficient of the average linear thermal expansion for the F-doped Bi(Pb)2223.

A value of $\alpha \sim 35 \times 10^{-6}$ can be evaluated by the weighted least-squares fit which is agree with recent reported value of $\alpha \sim 23-27 \times 10^{-6}$ for c-axis by neutron diffraction method[5].

3. Evidence for charge transfer

The difference spectra for the Pb- and F-doped Bi2223 after deconvolution is shown in Fig.4, the difference spectrum for Bi2212 is the same as that for the Bi(Pb)2223. Fig.4 shows that the density of high momentum electrons in the Bi-O layers increases at superconducting state. From the variation in positron lifetime parameter, we don't observe any evidence for shallow trap in the Bi-based system. In the charge transfer model, when the sample is cooled to S state, the electron from Cu in the Cu-O layer may be transferred to vacancies in the Bi-O layers where the electrons generally have much lower momentum, and carriers are created in the Cu-O plane[5], which will result in the increasing density of high momentum

electrons in the Bi-O layers. Since F atom substitute the oxygen atom and doping F atom can greatly change charge transfer, it can be inferred that oxygen defects play an important role in the charge transfer process.

Fig.1 Positron lifetime τ_2 vs. temperature in the Pb-doped Bi(Pb)2223

Fig.2 Positron lifetime τ_2 vs. temperature in the F-doped Bi2223

Fig.3 Mean lifetime τ_n vs. temperature in the F-doped Bi(Pb)2223

Fig.4 The difference spectra for DBAR spectra (N-S) for the Pb- and F-doped Bi2223

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