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New findings from positron annihilation measurements on superconducting transition in oxides

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Abstract : For single phase (Bi,Pb)-2223 samples the Doppler broadened positron annihilation lineshape parameter S, giving the fraction of low momentum electrons in the superconductor, shows a new feature : a sharp dip, implying a sharp fall and a sharp rise, at and near the superconducting transition. Its implication to the mechanism of superconducting transition in oxides needs to be explored.

Keywords : Superconductivity, electron momentum distribution, positron annihilation

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1. Introduction

There exists a limited number of studies [1,2], without detailed data near T_c, on a possible change of the Doppler broadened positron annihilation radiation lineshape (DBPARL) across the superconducting transition for conventional and high T_c oxide superconductors. The lineshape parameter S, defined as the ratio of the area under a selected number of central channels of the intensity vs. energy plot of DBPAR spectrum and the total area under the plot, gives a measure of the fraction of the "low" momentum electrons annihilated by the positrons. It was expected that the variation of S across T_c may show a sharp change, as superconductivity involves pairing of conduction electrons in momentum space. But experiments on BCS or metallic superconductors showed no abrupt change of positron annihilation parameters across T_c and in case of high T_c ceramic superconductors some groups [1,2] find abrupt changes. We felt that due to insufficient number of data points in these earlier work, the nature of the S vs. T curve near T_c is not clear. We therefore measured the DBPARL on $(Bi_{0.92}Pb_{0.17})_2Sr_{1.91}Ca_{2.03}Cu_{3.06}O_{10+\delta}$ or (Bi,Pb)-2223 superconducting oxides from 20K to 300K concentrating in the region near the superconducting critical temperature, T_c . The present work records such data at smaller intervals of temperature for a better study of the exact nature of S vs. T variation.

2. Experimental Outline

The sample was prepared from a mixture of weighted amounts of Bi, Pb, and Cu oxides and Sr and Ca carbonates. After repeated grinding, pelletizing and firing [3], X-ray diffraction showed (Bi,Pb)-2223 lines only (Fig. 1). T_c , was detected from electrical resistivity and magnetic a.c. susceptibility, acs, measurements.

A 40 cc HPGe detector having a resolution (FWHM) of 1.12 keV for the 475 keV γ-ray from a ^{102}Rh source was used. A ^{22}NaCl positron-source of strength about 1 μCi, deposited on an ultrathin (2 mg/cm^2) nickel foil, and covered by an identical nickel foil was sandwiched between two identical pellets of the samples. This [3-5] was mounted inside a cryogenerator having a Leybold LTC 60 temperature controller.

3. Observations

4-probe electrical measurements [5] showed T_c(R=0) to be 104K. Fig. 2 shows the the real part of acs (a.c. field = 5 Oe) in arbitrary units.

Fig. 3 shows the S-parameter vs. temperature data in the region of the superconducting transition. We had observed shallow dips [5] at higher temperatures. But these are not shown here as they are of different nature and not related to superconductivity. However, data over the whole range up to 300K, omitting the points at such shallow dips, have been considered to draw the mean straight line graph of S vs. T variation above T_c. This slope is lower than that for S vs. T variation below T_c. If these two graphs are extrapolated to 104K, an abrupt change of S at T_c can be readily concluded as has been done in all earlier experiments [2]. But we further observe a complex behaviour [4,5] of S across T_c : the sharp dips in S-parameter at 99K and 104K indicate sharp changes in electron momentum distribution.

4. Summary and Discussion

A step-like change across T_c in S-parameter vs. temperature variation, as has been reported recently [1,2], is confirmed in the present work. In addition, we experimentally - discover that the region around T_c, of S vs. T, is more complex, as shown in Fig. 3, than such a simple step. It consists of a pair of sharp dips at about 99K and 104K with an effectively step-like reduction of S for still lower temperatures. Each dip in S-parameter involves significantly larger change of S than that is involved in the already established effectively "step-like" reduction at T_c. Each dip is also deeper than the total fall of S due to lattice contraction over the temperature range of either T_c to 20K or 300K to T_c. So, the change of S at each of the dips is much more than what have been studied by earlier authors, in the two above-mentioned cases. The dips have not been found earlier [1,2] due to their narrowness with respect to temperature and insufficient number of data points. Finally let us note that such a

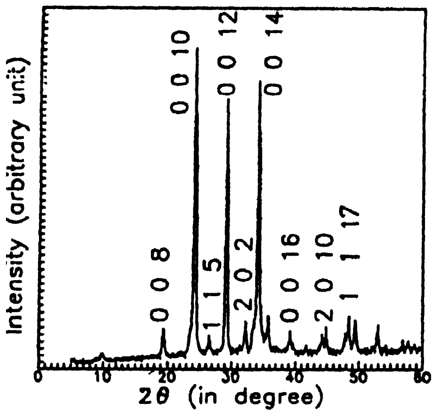

Fig. 1 X-ray diffraction lines for the (Bi,Pb)-2223 sample using CuK_{α} radiation.

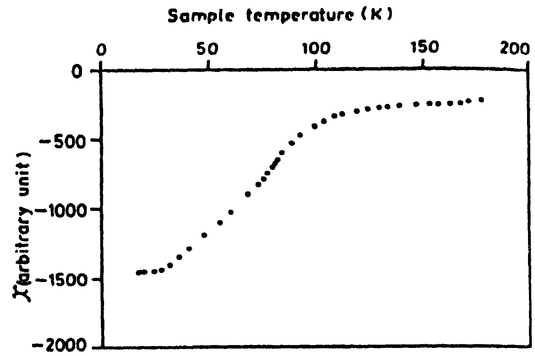

Fig. 2 Real part of susceptibility as a function of sample temperature for (Bi,Pb)-2223 oxide.

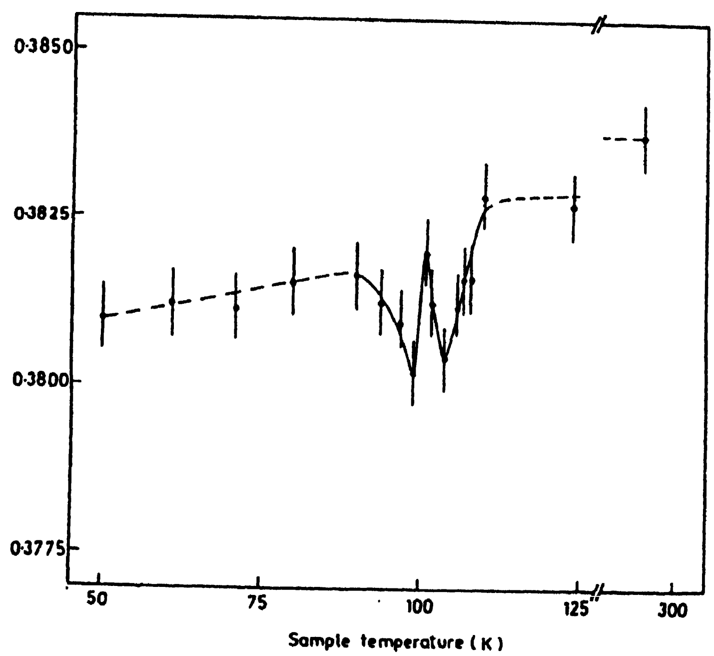

Fig. 3 Variation of S-parameter with temperature in the range 50 to 125K, showing also the room temperature data point. Linear increase of S with temperature is shown by dotted lines separately for regions below and above the superconducting transition region. The solid line in the superconducting transition region is a guide to the eye.

dip indicates a sharp decrease in the fraction of low mementum electrons annihilating with the positrons. This has implications to both positron annihilation processes in the samples and the mechanism of superconductivity. It is anticipated that such phenomenon cannot be limited only to the presently studied (Bi,Pb)-2223 oxide high T_c superconductor (HTSC). We have planned similar measurements on other oxide HTSC samples, to understand these aspects in details.

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