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POSITRON ANNIHILATION IN A HIGH-TEMPERATURE SUPERCONDUCTOR OF THE YBaCuO TYPE

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The annihilation of positrons from a ^{22}Na radioactive source has been studied in a high-temperature $YBa_2Cu_3O_{7-x}$ superconductor sample. The Doppler broadened annihilation line has been used for the determination of the relevant S parameter in the region of 77 K up to 300 K.

A small variation of S in the region of the critical temperature T_c (~ 90 K) has been observed. It indicates a different behaviour of the studied material as compared to classical metal superconductors.

I. INTRODUCTION

The phenomenon of high-temperature superconductivity belongs to the most significant physical discoveries of the last years [1]. The $YBa_2Cu_3O_{7-x}$ system ranks among materials with the critical temperature of $T_c \approx 90$ K. Though their structure is now known the high-temperature superconductivity of them has not been explained yet.

It is therefore important to obtain any information about the properties of high-temperature superconductors (HTS) in the superconductive as well non-superconductive state.

Positron annihilation spectroscopy can provide useful information about bulk electronic structure and defect properties of materials [2]. The annihilation characteristics of a positron in a matter are governed by the overlap of the positron and electron wavefunctions. For example, the electron momentum distribution determines the shape of annihilation radiation line by the Doppler effect. Due to this fact the positron annihilation spectroscopy is expected to yield some information on processes in HTS near the superconducting transition.

Recently several papers [3—8] dealing with the annihilation of positrons in $YBa_2Cu_3O_{7-x}$ samples have been published. Unfortunately these published results differ each other. These is no common characteristic besides the fact that the so-called S parameter depends on the temperature of the sample.

In the present paper we report upon the results of the Doppler-broadened lineshape measurements in $YBa_2Cu_3O_{7-x}$ samples across the superconducting transition in the temperature range of 77 K up to 300 K.

II. EXPERIMENT

Two superconducting $YBa_2Cu_3O_{7-x}$ samples were prepared by standard techniques. The YBaCuO powder was synthesized by the citrate method described of 110 MPa and heat-treated in [9]. Then it was pressed into pellets under a pressure of 110 MPa and heat-treated in an oxygen atmosphere at 930° C for 7 hrs. The final 10 mm diam, the 3 mm thick pellets have the density of 4.3 and 4.9 g/cm^3. The critical temperature $T_c = 93$ K was determined by the four-point resistivity measurement for both samples. Transition widths of a few K were observed. The superconductive state was also checked by observing the Meissner effect for a period of ~ 6 months.

The chemical composition of the samples was determined by the X-ray fluorescence method but an oxygen content can be determined with a very large error only. In our case, $x = (0.2$ and $1.0) \pm 0.4$, respectively [10].

For the positron annihilation measurements, a ^{22}NaCl positron source deposited on an aluminized Mylar foil was sandwiched between two YBaCuO samples. This sandwich was embedded in a box inserted in a copper cryostat. The inner vessel of the cryostat, which contained the box, was evacuated and plunged into liquid nitrogen. A heater coil was used for a rising of temperature. The sample temperature was monitored by a Chromel — alumel thermocouple. Because of a lack of space, we did not measure the resistivity (T_c) simultaneously.

A high purity Ge detector with an active volume of 114 cm^3 and 1.5 keV resolution at 661.6 keV (^{137}Cs) was used for the Doppler broadened annihilation radiation lineshape determination. The energy calibration of the spectrometer during measurements was 83 eV/ch. Each of the measured spectra contained approximately 10^6 counts.

The magnitude of the Doppler effect in a positron-electron annihilation is illustrated by Fig. 1. A spreading of the annihilation line with the energy of 511.0 keV as compared to the 661.6 keV line is entirely due to the Doppler effect.

Such Doppler broadened spectra were analysed in terms of a line parameter, S, defined as the ratio of counts in the central 23 channels to the total counts in the 140 channels covering the whole photopeak. The S parameter reflects the relative fraction of annihilations with low momentum electrons.

The variation of the S parameter was expected to be small as it follows from all previous works [3—8]. Therefore, great attention was paid to possible errors

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arising from the unstabilities of electronics, e.g. a shift of the maximum of annihilation line, a left-right asymmetry of the line.

To minimize such effects the annihilation line was described by the simple Gaussian (in the central region of the line) and two different exponential functions (in the wings of the line).

A background under the photopeak was, as usually, described by a straight line. All free parameters of the functions used have been determined by the non-linear least squares method.

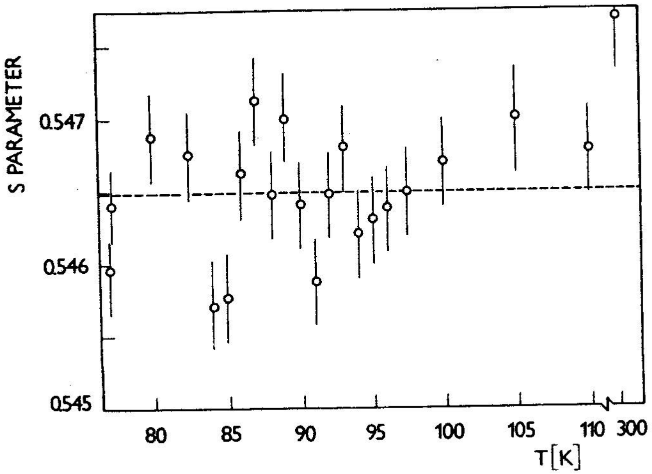

Fig. 1. Demonstration of the Doppler effect in a positron-electron annihilation. Black points show a response of all detection systems to monoenergetic gamma-quanta with the energy of 661.6 keV. Circles show the registered annihilation quanta.

Next the S parameter was calculated numerically using the above-mentioned description of the annihilation line. The error of the S parameter was deduced from the error matrix of the parameters obtained by the least squares procedure.

The variation of this S parameter as a function of temperature is shown in Fig. 2. It is seen that the S parameter shows small variation with temperature.

Such a conclusion was tested assuming that S is a constant. In such a case the value of the reduced χ^2 is equal to 4. If two minimal points (around 85 K) are excluded from statistical analysis, the value of χ^2 drops to 2.2.

There is an indication that we observed a "resonance" decrease of the S parameter in the range of the superconducting transition temperature. Our result supports the results of Zhongjing et al. [6] and Ishibashi et al. [3].

Zhongjing et al. [6] observed several minima of the S parameter from which one corresponds to the onset temperature and the other to the temperature of "zero" resistance. Ishibashi et al. [3] observed a gradual decrease in the S parameter in the temperature range of 105 K to 70 K with some dip at 85 K. Comparing our results (see fig. 2) with the results reported by all the other groups [4, 5, 8] we find a common characteristic i.e., the decrease of the S parameter at low temperature relative to that at higher (e.g. room) temperature.

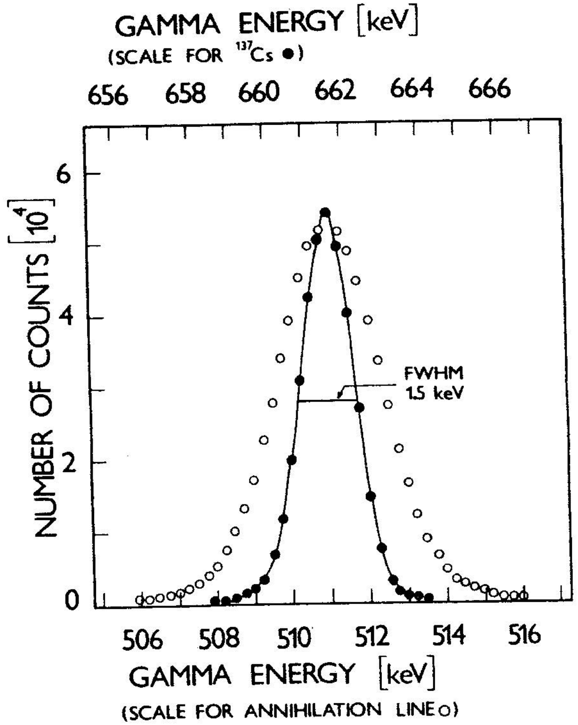

Fig. 2. Variation of the Doppler-broadened lineshape parameter S with temperature in the superconducting $YBa_2Cu_3O_{7-x}$ sample.

Our results differ from those reported by Jean et al. [4]. We did not observe a relatively sharp decrease of the S parameter in the range of the critical temperature.

A general conclusion can be drawn that the annihilation characteristic — the S parameter — is not independent of the temperature of the high-temperature superconducting samples. This behaviour was not observed in the previous positron annihilation experiments on lead [11].

There are several possible causes for an explanation of the observed effect but the existence of a "resonance" behaviour of the S parameter has not yet been setted. Therefore we consider it premature to draw an unambiguous physical conclusion in a not clear experimental situation.

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АННИГИЛЯЦИЯ ПОЗИТРОНА В ВЫСОКОТЕМПЕРАТУРНОМ СВЕРХПРОВОДНИКЕ ТИПА YBa_2CuO

Изучена аннигиляция позитрона из радиоактивного источника ^{22}Na в образце высокотемпературного сверхпроводника $YBa_2Cu_3O_{7-x}$. Была использована доплеровски расширенная аннигиляционная линия для определения соответствующего S-параметра в области температур от 77 K до 300 K. Наблюдалось малое изменение в области критической температуры T_c (~ 90 K). Это говорит о различном поведении изучаемого материала в сравнении с классическим металлическим сверхпроводником.