Conf-9103112--7

UCRL-JC--107283

DE92 002763

An Outline of Positron Measurements of Superconducting Oxides

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This paper was prepared for submittal to
Journal of Physics and Chemistry of Solids
and
Workshop on Fermiology of High-T_c Superconductors
Argonne, Illinois
March 25-27, 1991
March 1991

Lawrence Livermore National Laboratory

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An Outline of Positron Measurements of Superconducting Oxides

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Positron measurements on superconducting oxides have gone through an evolution from divergent results of low statistical precision on samples of suspect quality to convergent results of higher statistical precision on high quality samples. We outline the elements affecting the progress of these experiments and questions that can be addressed at our present state of the art.

In the papers presented in this symposium we are attempting to answer a question of special significance to the study of high temperature superconductors i.e. what is the distribution of the electrons in the material, the electronic structure. There are both experimental and theoretical investigations of the existence and shape of a Fermi surface in the materials and the value of the superconducting gap. Three experimental techniques are reporting results in this symposium. They are angular correlation of positron annihilation radiation, (ACAR), angle resolved photo emission, PE, and de Haas van Alphen measurements.

Positron ACAR measurements occupy a position between angle resolved photo emission measurements and de Haas van Alphen measurements. The first, PE, can supply the energy spectrum for some selected momentum in the Brillouin zone and follow the dispersion of resolved bands up to the Fermi energy in a series of spectra. Momentum selection is achieved by limiting the angular acceptance in the electron detector. In order to map the entire electron momentum distribution and see the full shape of the Fermi surface, the measurement must be performed for each momentum bin. This is rarely done. Best photo emission angular acceptances are of the order of 2 degrees and the full momentum of the Brillouin zone depends on photon energy but is typically 18 degrees[1,2]. This results in a momentum resolution of about 11 % of the reciprocal lattice vector and is the limit on which the momentum position of bands crossing the Fermi surface can be determined in photo emission. Photo emission must be performed on cleaved crystals at low temperatures and thus has some difficulty in determining normal state properties and is vulnerable to effects of surface contamination.

De Haas van Alphen measurements on the other hand measure the area enclosed by the Fermi surface in a plane defined by an external magnetic field. These are low temperature measurements of bulk magnetic properties in the normal state due to the high magnetic fields. However at present only orientated polycrystalline samples have been measured by this technique[3].

Positron ACAR measurements determine only the pair momentum of the electron and positron in each annihilation event. Since the momentum of the positron is low, the pair momentum distribution is dominated by the electron momentum. The distribution is determined by measuring the angular shift of the annihilation gamma-rays from collinearity using high resolution, position sensitive gamma-ray detectors. Therefore, data taken in an ACAR spectrometer does not distinguish between electrons in bound and unbound states at the same momentum. Fortunately the Fermi surface is defined by the momentum limit set by the dispersion of the bands and can be easily seen as a sharp break or discontinuity in the measured distributions in the momentum of occupied states. Typical ACAR spectrometer resolutions are .4 to .7 mrad or 6 to 11 % of the Brillouin zone as compared to 11 % for the best PE. More importantly the ACAR measurement maps out the entire momentum space in bins much smaller than the system resolution and the measured distribution covers the center zone and higher order zones in a single experiment. Thus the continuous shape of a Fermi surface is determined in one measurement and broadening of the Fermi surface can be found in the sharpness of the discontinuity. Such measurements have been very successful in studying Fermi surface driven order-disorder transitions in binary alloys where the shape and broadening of the Fermi surface are central issues in the physics of the transitions.

Since the positron is a bulk probe there is no vulnerability to surface effects. Also the sample temperature of the positron measurement can be set at any temperature so that the measurements can clearly be those of the normal state or superconducting state.

Predictions of the existence of a continuously connected Fermi surface are not specific to all proposed theories for describing superconducting oxides. Consequently the analysis of the positron data for the existence of a Fermi surface must first be done independently of the predictions of any particular theory. This restriction presents a special challenge to the positron technique and requires levels of precision in the measurement beyond those of any previous experiments on elemental metals or alloys.

Demands for statistical precision are reinforced by difficulties presented to the technique by the physics of the superconducting oxide materials. Since the positrons can annihilate with all of the electrons, the small fraction of the electron population expected in unfilled bands leads to a proportionally small set of features associated with the Fermi surface. There are also spatial variations of the electronic charge density within a unit cell that distort the positron wave function and result in features with the symmetry of the crystal that must be separated from the Fermi surface contributions. Lastly, defects in an imperfect sample can trap positrons, removing them from effective overlap with the conduction band electrons and farther reducing the size of interesting features in the data.

In spite of these difficulties attempts to demonstrate a Fermi surface using positrons were made as soon as single crystal samples of the materials became available. Early data on YBCO and other superconducting oxides was complicated by low statistical precision resulting from the very small size of the available samples and concerns about sample durability in the measurement[4-6]. Later data with higher statistical precision was obtained on larger samples of highly twinned crystals[7,8]. Early claims of conduction band features were not reproduced in higher statistics measurements or from one group to another. Features in these data sets that were statistically significant and reproduced by more than one group were in reasonable agreement with the effects of distortion of the positron and electron wave functions by the non-uniform charge densities in the oxide lattice[9].

We have now entered an era of relatively high quality samples and high statistics data. Good samples of untwinned single crystals of YBCO are available to more than one group. An ultra high statistics measurement of the ACAR distribution has been performed on untwinned crystals in a collaboration between LLNL and UTA and incontrovertible evidence of the Fermi surface from the chain bands was found[10]. Moreover, the general features of those data, including those identified with a Fermi surface were reproduced in a lower statistics measurement from ANL[11]. These new data represent the first generally reproducible Fermi surface features found using the ACAR technique in superconducting oxides. They guide the way to a new level of sophistication in which quantitative questions about the details of the electronic structure of superconducting oxides can be addressed.

There are still unanswered questions regarding the electronic structure in superconducting oxide materials. First is the shape of the Fermi surface of the CuO plane. Is it definite and sharp? This question will be best answered by high statistics data now being collected on a 214 material where the positron strength is maximum on the CuO planes. Also now that the Fermi surface is seen in reproducible conditions we can begin quantitative comparisons with theory. We can also expect to follow changes in the Fermi surface induced by changing composition or structure in the sample. Happily some of these studies can be done with significantly lower statistics now that a theory independent demonstration of the existence of a Fermi surface has been accomplished. The positron ACAR technique has become a significant addition to the techniques available to study significant questions of high Tc materials; the evolution of the metallic state from the Mott-Hubbard insulator and the nature of the electron coupling.

References

1. For this and the following refererces please see the authors in this symposium and the references therein.

2. C. G. Olsen et al., Phys. Rev. B42, 381 (1990); J. G. Tobin et al. unpublished.

3. F. M. Mueller et al., Physica B (in press).

4. The status of the early data can be evaluated in the chapter on superconductors in Positron Annihilation eds. L. Dorikens, M. Dorikens, D. Seeger, World Scientific, Singapore (1988).

5. M. Peter, L. Hoffman and A.A. Manuel, Physica C153-155, 1724 (1988)

6. L. C. Smedskjaer et al., Physica C156, 269 (1988).

7. H. Haghighi et al., J. Phys. Condens Matter 2, 1911 (1990)

8. M. Peter and A. A. Manuel, Physica Scripta T29, 106, (1989) and H. Hoffman, unpublished thesis, 1989.

9. P. E. A. Turchi et al., J. Phys. 2, 1635 (1990).

10. H. Haghighi et al., Proceedings of the Workshop on Electronic Structurer and Mechanism for High Temperature Superconductivity, ed. J. Ashkanazi, Miami Fla, Jan 1991 and H. Haghighi et al. this symposium.

11. L. C. Smedskjaer this symposium and private communication.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48

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DATE FILMED

12/30/91