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Th Superconducting Film Characterization by Surface Acoustic Waves

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Moises Levy

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16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	high T_c superconductors; piezoelectric coupling; thin film; sheet resistivity; granular films

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A dilution refrigerator was installed tested and modified. Several cryogenic probes were frabricated to measure resistivity, ac susceptibility and ultrasonic attenuation in hiT_c superconductors. Ultrasonic attenuation measurements were performed on single crystals of UPt_3 and URu_2Si_2. A maximum in attenuation was found below the superconducting tr sition temperature T_c of URu_2Si_2. A magnetic field decreased this maximum.

The temperature of the attenuation in the normal and superconducting states below T_c was measured in UPt_3. The ratio of the attenuation follows a power law dependence indicative of an anisotropic superconducting energy gap. A peak in attenuation was found in the mixed state of UPt_3, which may be associated with a phase transition of the flux line lattice.

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18. Subject Terms - continued

Josephson tunnel junctions
weak links
heavy fermion superconductors
dilution refrigerator
top loading
ultrasonic attenuation
UPt_3
URu_2Si_2
Quantum Hall Effect
Fractional Quantum Hall Effect
$YBa_2Cu_3O_7$
$LuBa_2Cu_3O_7$
$HoBa_2Cu_3O_7$
Single target sputter deposition
Perovskite structure superconductor thin film

19. Abstract - continued

Proximity acoustoelectric coupling to a two dimensional electron gas exhibiting both the Quantum Hall Effect and the Fractional Quantum Hall Effect was observed for the first time. Attenuation and velocity measurements were performed on sintered polycrystalline high T_c superconducting samples of $YBa_2Cu_3O_7$, $HoBa_2Cu_3O_7$ and $LuBa_2Cu_3O_7$. The attenuation coefficient of a single phase sample of $YBa_2Cu_3O_7$ exhibited a maximum at around 250 K and another maximum slightly below T_c. Several models are proposed to explain these observations. Surface acoustic wave measurements will be used to characterize high T_c superconducting films and bulk samples.

RESEARCH OBJECTIVES AND APPROACHES

The objective of this investigation is to characterize thin film superconductors with surface acoustic waves (SAW). A new objective was to include high T_c superconductors in this investigation. By measuring the piezoelectric coupling to the sheet resistivity of granular films both in the normal and superconducting states it is possible to determine the average size of the granules and the distribution of the intergranular resistances. These measurements may also provide some insight about whether the coupling between granules is produced by Josephson tunnel junctions or weak links. Bulk wave measurements on the ternary reentrant superconducting systems and on heavy fermion superconductors provide insight into novel superconducting mechanisms which may be applicable to the new high T_c superconductors.

ACCOMPLISHMENTS

I. Cryogenic and Electronic Developments

(A) The Oxford dilution refrigerator was installed and tested. The base temperature reached was 5 mk under no load (no experiments are possible in this mode). After testing, the system was modified and installations were added.

(i) 8 Co axial and 54 electrical leads (specially designed for low temperature applications) were added.

(ii) The system was modified to do ultrasonic acoustic measurements in the top-loading mode. This permits a rapid change of samples, without having to open up the system. This resulted in one publication (ref. 3). All design, machining and installation were done at UWM; and this is the first top-loading dilution refrigerator system allowing measurements (acoustics or nmr) with a high frequency co-axial contact.

(iii) Various electronic systems were built to interphase with the measurements.

(a) a cryogenic control box, distributing the various electrical leads

(b) A mutual inductance bridge for a.c. susceptibility

(iv) Various modifications were made on the Oxford external pumping system for easier and better operation.

(B) High T_c program: various new cryogenic probes (5 in number) were made to study the near high T_c materials over a temperature range 4-300 K; allowing quick measurements on

(i) resistivity

(ii) susceptibility

(iii) ultrasonic attenuation

II. Heavy Fermion Superconductors (UPt_3 and URu_2Si_2)

Samples of these materials were obtained from Argonne National Laboratory (D. Hinks). Ultrasonic attenuation measurements confirm that these are nonconventional superconductors (i.e. non-singlet pairing; the pairing is in a higher angular momentum state). A thorough study in a magnetic field was done on the UPt_3 sample. A new feature (a peak in the attenuation) was discovered (independently and almost simultaneously with Muller et al in Germany). This new feature may be a phase transition, between two different vortex structures. A part of the data has been analyzed and reported in publications (#1, 2, 5, 6, 7, 8, and 15).

The measurements on the second heavy-fermion system URu_2Si_2 (publication #1 and #4) were performed on a ^3He cryostat. A maximum in attenuation was found below the superconducting transition temperature T_c of URu_2Si_2. A magnetic field decreased this maximum.

III. Quantum Hall Effect (QHE)

Proximity coupling of SAW to a two-dimensional electron gas (2 DEG) was observed for the first time in samples with heterojunctions of GaAs-$Ga_{1-x}Al_xAs$. One of the samples was obtained from Prof. H. Morkoc, the University of Illinois-Urbana. The frequency dependence and power dependence on the attenuation of samples exhibiting both the Quantum Hall Effect and the Fractional Quantum Hall Effect were studied and reported (publications: #4, 9, and 11).

IV. High T_c Superconductivity

Stimulated by some discoveries on certain LaBaCu ceramic oxides, worldwide research activity has pushed up the superconducting critical temperature to 95 K. These ceramics are now also being made at UWM (collaboration with Profs. B. Sarma, B. Tonner and W. Millman). Thin films that are superconducting are also being grown at UWM.

We have measured resistivity, a.c. susceptibility and ultrasonic attenuation on these materials. Samples (pressed pellets) have also been obtained from various other labs (Houston, Ames, NRL) on which ultrasonic attenuation has been measured, resulting in a few manuscripts submitted for publication (publications: #11, 12, 13, 14, 15, and 20).

In a single phase $YBa_2Cu_3O_7$ sintered sample obtained from NRL, two maxima in longitudinal wave attenuation were observed, one at 250 K and the other slightly below the superconducting transition temperature. It is possible that the high temperature maximum may be produced by a relaxation process involving soft plasmons. The attenuation below the lower temperature maximum appears similar to that observed in heavy Fermion superconductors so it could be indicative of an anisotropic superconducting energy gap. The lower temperature maximum may also be associated with a soft plasmon relaxation process, an electronically driven structural phase transition, or one dimensional and two dimensional fluctuations. Frequency

and magnetic field dependent measurements are needed to select between these different models.

FORECAST

The emphasis of this research project will concentrate on surface acoustic wave SAW characterization of superconductors with high transition temperatures. These measurements will yield information about the average local sheet resistivity of these materials, the proportion of material that becomes superconducting at T_c, whether the intergranular coupling is due to Josephson coupling or weak links, the extent of flux pinning, and the critical current and critical magnetic field distribution on the scale of the SAW wavelength.

PUBLICATIONS

Twenty one papers have been submitted for publication, fourteen of which have either been published or been accepted for publication.

1. Possible Phase Transition in UPt_3 in a Magnetic Field, M.-F. Xu, Y. J. Qian, A. Schenstrom, H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and Bimal K. Sarma, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1259.
2. Oscillations in Ultrasonic Attenuation: Real or Spurious? Y. J. Qian, A. Schenstrom, M.-F. Xu, H.-P. Baum, Bimal K. Sarma, M. Levy and J. B. Ketterson, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1733.
3. Top-Loading Dilution Refrigerator for High Frequency Measurements, H. P. Baum, Y. J. Qian, A. Schenstrom, M.-F. Xu, M. Levy and B. K. Sarma, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 1731.

4. Oscillations in the Attenuation of Surface Acoustic Waves Due to Proximity Coupling to a 2D Electron Gas, A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy and Y. J. Qian, Proc. 18th Intl. Conf. on Low Temperature Physics, Kyoto, 1987, Jpn. J. Appl. Phys., Vol 26, (1987) Supplement 26-3, 759.

5. Ultrasonic Investigation of Novel Superconducting Systems, M. Levy, A. Schenstrom, K. J. Sun and B. K. Sarma, Proceedings of the International Workshop on Novel Mechanisms of Superconductivity, June 22-26, 1987, Berkeley, California (to be published).

6. Field Dependent Behavior of Longitudinal Ultrasonic Attenuation in UPt_3, M.-F. Xu, A. Schenstrom, H.-P. Baum, Y. J. Qian, J. B. Ketterson, D. J. Hinks, M. Levy and B. K. Sarma, Proceedings of Conference on Magnetism and Magnetic Materials, Chicago, Nov. 9-12, 1987 (to be published in J. of Appl. Phys.).

7. Shift in Maximum of Sound Attenuation with Magnetic Field in UPt_3, H.-P. Baum, M.-F. Xu, Y. J. Qian, A. Schenstrom, J. B. Ketterson, D. H. Hinks, M. Levy and B. K. Sarma, Proceedings of Conference on Magnetism and Magnetic Materials, Chicago, Nov. 9-12, (1987) (to be published in J. of Appl. Physics).

8. Longitudinal Sound Measurements on UPt_3 in a Magnetic Field, Y. J. Qian, M.-F. Xu, A. Schenstrom, H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and B. K. Sarma, Solid State Commun. 63, 599 (1987).

9. Oscillations in the Acousto-Electric Proximity Coupling to a 2D Electron Gas, A. Schenstrom, Y. J. Qian, M.-F. Xu, H.-P. Baum, M. Levy and B. K. Sarma, Solid State Commun. (accepted for publication).

10. Frequency Dependent Breakdown of the Dissipationless State in the Quantum Hall Effect, A. Schenstrom, B. K. Sarma, M. Levy and H. Morkoc, Submitted for publication to Phys. Rev. Lett.

11. An ESR study of the Magnetism and Co-ordination of Cu in High T_c $YBa_2Cu_3O_{9-\delta}$ Superconductors, W. S. Millman, W. C. Timmer, M. Ulla, S. R. Hast, B. P. Tonner, M. Levy, Z. Han, H.-P. Baum, M.-F. Xu, and B. K. Sarma, J. of Physical Chemistry (1987) (to be published).

12. Ultrasonic Attenuation Measurements on $LuBa_2Cu_3O_7$ and $HoBa_2Cu_3O_7$, K. J. Sun, M. Levy, B. K. Sarma, H. C. Ku, H. D. Yang, R. N. Shelton, R. W. McCallum and P. Klavins, (submitted for publication to Solid State Commun.).

13. Ultrasonic Measurements on Polycrystalline $YBa_2Cu_3O_{6+\delta}$, K. J. Sun, M. Levy, B. K. Sarma, P. H. Hor, R. L. Meng, Y. Q. Wang and C. W. Chu, (submitted for publication to Physics Letters).

14. Ultrasonic Attenuation Measurements in Single Phased $YBa_2Cu_3O_7$, M.-F. Xu, H.-P. Baum, A. Schenstrom, B. K. Sarma, M. Levy, K. J. Sun, L. E. Toth, S. A. Wolf and D. U. Gubser, (submitted for publication to Phys. Rev. Letters).

15. Ultrasonic Attenuation Measurements in High T_c Superconductors and Heavy-Fermion Superconductors, M. Levy, M.-F. Xu, H.-P. Baum, A. Schenstrom, Y. J. Qian, K. J. Sun and B. K. Sarma, IEEE 1987 Ultrasonics Symposium Proceedings, Denver, October 14-16 (1987).

16. SAW Measurements of a Superconducting Granular Lead Film in an Applied Magnetic Field, J. Schmidt and M. Levy, (submitted to Journal of Low Temperature Physics).

17. Relaxation Attenuation in $Er_{0.187}Ho_{0.813}Rh_4B_4$ and $HoRh_4B_4$, K. J. Sun, R. Sorbello, M. Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1986 Ultrasonics Symposium Proceedings, 1123 (86 CH 2375-4, Ed. B. R. McAvoy, IEEE, New York 1986).

18. Attenuation of Surface Acoustic Waves in a Superconducting In/InO_x Films, J. Schmidt, M. Levy and A. Hebard, IEEE 1986 Ultrasonics Symposium Proceedings, 1097 (86 CH 2375-4, Ed. B. R. McAvoy, IEEE, New York, 1986.

19. Enhanced Ultrasonic Attenuation in the Superconducting State of Ho-Rich $Er_{1-x}Ho_xRh_4B_4$, K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvilli (submitted to Phys. Rev. Letters).

20. Single Target Sputter Deposition, Post Processing and Electron Spectroscopy of Perovskite Superconductor Thin Film, Z. Han, L. Bourget, H. Li, M. Ulla, W. S. Millman, H.-P. Baum, M.-F. Xu, B. K. Sarma, M. Levy and B. P. Tonner, Porceedings American Vacuum Society (to be published).

21. Poisson's Ratio Dependence of Electron Phonon SAW Attenuation Susan C. Schneider and Moises Levy, IEEE 1987 Ultrasonics Symposium (to be published).

TECHNICAL PERSONNEL

In addition to the principal investigator the following faculty, post docs and graduate students have worked on this grant. One graduate student received a Ph.D. during this period.

Faculty

Assistant Professor Bimal Sarma	Installation, testing and modification of dilution refrigerator. Measurements on heavy Fermion superconductors, high T_c superconductors and Quantum Hall Effect. Fabrication of new probes to measure resistivity, ac susceptibility and ultrasonic attenuation in high T_c superconductors.

Post Docs

Y. J. Qian	Installation, testing and modification of dilution refrigerator. Measurements on heavy Fermion superconductors and Quantum Hall Effect.

Graduate Research Assistants

Full time:

Mr. Hughes Pierre Baum	Ultrasonic measurements on heavy Fermion superconductors and high T superconductors.

Mr. Anders Schenstrom	Ultrasonic measurements on heavy Fermion superconductors, High T_c superconductors, and the Quantum Hall Effect.
Mr. Jeff Schmidt	SAW investigation of superconducting granular Pb films and amorphous In/InO_x films.
Mr. Min Feng Xu	Ultrasonic measurements on heavy Fermion superconductors and high T_c superconductors.

Part Time

Mr. David Bein	Preparation of high T_c superconducting sintered samples
Ms. Jin Zheng	SAW measurements of high T_c superconductors.

Ph.D.

Mr. Jeffrey Schmidt submitted his Ph.D. thesis entitled "Surface Acoustic Wave Investigation of Amorphous and Granular Superconducting Films," under the supervision of M. Levy. He received his Ph.D. in August 1987.

SCIENTIFIC INTERACTIONS

1. $YBa_2Cu_3O_7$ Superconducting Films.

   Two films have been obtained from Ted Geballe, Stanford one strontium titanate, the other on zirconium oxide. SAW attenuation measurements by proximity coupling of the acoustoelectric effect are being presently performed on these films.

2. $YBa_2Cu_3O_7$ Bulk Sintered Samples.

   One sample was obtained from Paul Chu, Houston, and another from Don Gubser and Stu Wolf, NRL. Both samples have been measured ultrasonically. The data are reported in papers 13 and 14 and 15.

3. $HoBa_2Cu_3O_7$ and $LuBa_2Cu_3O_7$, Bulk Sintered Samples.

   One sample of each was obtained from R. N. Shelton and R. W. McCallum, Iowa State. Both samples have been measured ultrasonically. The data are reported in paper 12.

4. In/InO_x Amorphous Superconducting Films.

   Films were obtained from Art Hebard, Bell Labs. SAW measurements on these films are reported in paper 18.

5. Heavy Fermion Superconductor Single Crystals — UPt_3 and URu_2Si_2.

   One sample of each was obtained from David Hinks, Argonne National Lab. Ultrasonic measurements are reported in papers 1, 5, 6, 7, 8, and 15.

6. GaAs, $GaAs_{1-x}Al_x$ Heterojunctions.

   Two samples were measured by acoustoelectric proximity coupling with SAW. One of the samples was obtained from H. Morkoc, University of Illinois-Urbana. The data are reported in papers 4, 9, and 10.

7. 1986 IEEE Ultrasonic Symposium.

Conference was held Nov. 17-19, 1986 in Williamsburgh, Virginia. M. Levy attended the conference and chaired a session. Two papers were presented

"Relaxation Attenuation in $Er_{0.187}Ho_{0.813}Rh_4B_4$ and $HoRh_4B_4$," K. J. Sun, R. Sorbello, M. Levy, M. B. Maple and M. S. Torikachvilli;

"Attenuation of Surface Acoustic Waves in a Superconducting In/InO_x Films," J. Schmidt, M. Levy and A. Hebard.

8. 112th Meeting: Acoustical Society of America.

Meeting was held on December 8-12, 1986 in Anaheim, California. M. Levy presented an invited talk,

"Surface Acoustic Wave Interaction with Thin Magnetic Films".

9. 1987 March meeting of the American Physical Society.

Meeting was held March 16-20, 1987 in New York, New York. M. Levy, B. S. Sarma, and A. Schenstrom attended. Presented three papers at the meeting,

"Ultrasonic Attenuation in URu_2Si_2," K. J. Sun, A. Schenstrom, B. K. Sarma, M. Levy, J. B. Ketterson and D. Hinks, Bull. Amer. Phys. Soc. 32, 641 (1987).

"Ultrasonic Attenuation Measurements in the Mixed State of UPt_3," Y. J. Qian, M.-F. Xu, A. Schenstrom, H. P. Baum, M. Levy, B. K. Sarma, J. B. Ketterson and D. Hinks, Bull. Amer. Phys. Soc. 32, 1410 (1987).

"Proximity Coupling of Surface Waves to a 2D Electron Gas," A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy and Y. J. Qian, Bull. Amer. Phys. Soc. 32, 1425 (1987).

10. Amdahl Corporation

M. Levy visited Amdahl Corporation in San Jose, California in May 1987, to discuss computer applications of high T_c superconductors.

11. Wright Patterson Air Force Base

M. Levy visited Dr. Pat Hemenger WPAFB on May 21 and 22 to discuss possible collaboration on high T_c superconductors. Presented two talks,

"Bulk Wave Measurements on Superconductors"

"SAW Measurements on Superconducting Films"

12. Novel Mechanism of Superconductivity

M. Levy attended conference held in Berkeley California on June 22-26, 1987. Presented an invited talk,

"Ultrasonic Investigation of Novel Superconducting Systems".

13. 18th International Conference on Low Temperature Physics

B. Sarma attended conference held in Kyoto, Japan, August 1987. Four papers were presented at the conference,

"Possible Phase Transition in UPt_3 in a Magnetic Field," M.-F. Xu, Y. J. Qian, A. Schenstrom, H.-P. Baum, J. B. Ketterson, D. Hinks, M. Levy and Bimal K. Sarma.

"Oscillations in Ultrasonic Attenuation: Real or Spurious?"

Y. J. Qian, A. Schenstrom, M.-F. Xu, H.-P. Baum, Bimal K. Sarma, M. Levy and J. B. Ketterson.

"Top-Loading Dilution Refrigerator for High Frequency Measurements," H. P. Baum, Y. J. Qian, A. Schenstrom, M.-F. Xu, M. Levy and B. K. Sarma.

"Oscillations in the Attenuation of Surface Acoustic Waves Due to Proximity Coupling to a 2D Electron Gas," A. Schenstrom, M.-F. Xu, H.-P. Baum, B. K. Sarma, M. Levy and Y. J. Qian.

14. Superconductors and Superconducting Materials

M. Levy chaired three day workshop and seminar held in the Physics Department at the University of Wisconsin-Milwaukee on September 28-30, 1987. $YBa_2Cu_3O_7$ sintered samples made at UWM were given to Wright Patterson AFB to be used as targets for producing films and to Mike Orovez, Sonoscan, for studies with an ultrasonic microscope. The superconducting resistive transition of a sintered sample of $YBa_2Cu_3O_7$ made at Amdahl Corp. was measured for Dr. Pin Chiang, Amdahl Corporation.

15. IEEE 1987 Ultrasonics Symposium

M. Levy attended conference held in Denver, Colorado on October 14-16, 1987, chaired a poster session, and presented an invited paper

"Ultrasonic Measurements in High T_c Superconductors"