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THIN SUPERCONDUCTING FILM CHARACTERIZATION BY SURFACE
ACOUSTIC WAVES(U) WISCONSIN UNIV-MILWAUKEE DEPT OF
PHYSICS M LEVY 13 NOV 86 AFOSR-TR-86-2098

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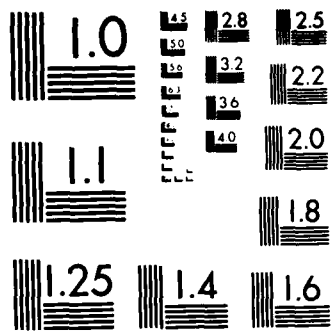
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AFOSR-TR- 86-2090	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Thin Superconducting Film Characterization by Surface Acoustic Waves.		5. ANNUAL REPORT & PERIOD COVERED Research Progress Forecast Report 9-30-85 to 9-30-86
7. AUTHOR(s) Moises Levy		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Wisconsin-Milwaukee Department of Physics Milwaukee, WI 53201		8. CONTRACT OR GRANT NUMBER(s) AFOSR 84-0350
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research /NE Bolling APT Building 410 Washington, D. C. 20332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102T- 2306/C1
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same as 11		12. REPORT DATE 11/13/86
		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES B		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
thin superconducting film	sheet resistivity	
surface acoustic wave	spin phonon interaction	
SAW	supercurrent screening	
electrical resistivity	crystalline electric fields	
vortex antivortex dipoles	spin fluctuations	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Surface acoustic wave attenuation (SAW) and electrical resistivity on In/InO _x films has been measured. On one film it was found that both vortex antivortex dipoles associated with a Kosterlitz Thouless transition and excess local resistivity associated with the granularity of the film contribute to the energy absorption in the film. On another film, with a high sheet resistivity, a peak in attenuation is observed which may be associated with a metal insulator transition at the local level. A		

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19. Key Words - continued

Kosterlitz Thouless
 excess local resistivity
 granularity
 metal insulator transition
 average grain size
 acoustoelectric coupling
 granular Al superconducting film
 In/InO_x films
 Er_{1-x}Ho_xRh₄B₄
 velocity
 URu₂Si₂
 electron phonon interaction
 superconducting energy gap
 electron mean free path
 amorphous superconductors
 strongly localized superconductors
 Josephson junction networks
 ternary magnetic superconductors
 Chevrel phase superconductors
 heavy fermion superconductors

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relaxation mechanism
 Debye relaxation expression
 specific heat
 relaxation time
 URu₂Si₂
 longitudinal waves
 dilution refrigerator
 mixing chamber
 submicron photolithography
 percolation model
 lead film
 renormalization equations
 heavy fermion superconductor
 He³ cryostat
 Cu₃Mo₆S₈
 V₃Sn
 UPt₃
 superlattices

20. Abstract - continued

technique for determining average grain size in a granular superconductor has been proposed. Proximity acoustoelectric coupling to a granular Al superconducting film has been demonstrated. This technique may be used to determine the separation between two surfaces that are less than 1000Å apart.

Measurement on the Er_(1-x)Ho_xRh₄B₄ alloy system have been completed. A theoretical relaxation expression has been derived and is being used to analyze the maxima that have been observed in the attenuation curves.

Preliminary measurements of both the attenuation and velocity of longitudinal waves in a single crystal of URu₂Si₂ have been performed.

The research goals and objectives of this investigation will remain the same. No significant reorientations are anticipated for the third year of this project.

RESEARCH OBJECTIVES AND APPROACHES

The objective of this investigation is to characterize thin film superconductors with surface acoustic waves (SAW). If it is possible to measure electron phonon interaction in these films, then the temperature dependence of the superconducting energy gap and the electron mean free path may be determined. In addition, the density of vortex antivortex bound pairs in amorphous superconductors and the effective energy gap in strongly localized superconductors could also be determined. If the predominant interaction is the acoustoelectric effect, then size distribution of grains and the coupling between grains in granular superconductors could be determined by SAW measurements. When Josephson junction networks are deposited on SAW devices, it will be possible to correlate SAW attenuation and velocity changes with the signal processing properties of these arrays. SAW measurements on superconducting superlattice films will provide information about the elastic properties of these films. Bulk wave measurements on ternary magnetic superconductors, Chevral phase superconductor, and heavy fermion superconductors should provide information about spin phonon coupling in their superconducting phase.

ACCOMPLISHMENTS

Measurements of the SAW attenuation and electrical resistivity have been performed on films of In/InO_x . In the first of these films it was found that the attenuation of SAW waves in the superconducting state was displaced from the resistivity curve towards slightly lower temperatures, and that there was an excess attenuation in the superconducting state from what would be expected if the SAW attenuation were simply proportional to the sheet resistivity. These differences are attributed to a shift in attenuation due to vortex-antivortex dipoles associated with a Kosterlitz-Thouless transition and an excess local resistivity due to the granularity of the film.

In an In/InOx film whose sheet resistivity monotonically increased as its temperature was lowered to 1.5 K, it was found that the SAW attenuation exhibited a peak at 2.0 K and then the attenuation remained relatively constant below this peak. It may be possible that the peak is evidence for a metal insulator transition which is occurring locally in the film. We have shown that the SAW can probe dimensions of the order of 500Å, and if a transition is occurring in islands of these dimensions it could be that electrical currents are not sensitive to these transitions while the SAW are.

We have presented a paper that describes a technique for determining average grain size in a granular superconductor by measuring the excess SAW attenuation in the superconducting state of the film. As the average grain size gets much smaller than the SAW wavelength the excess attenuation should decrease. We have developed a theory that would determine the average grain size from this excess attenuation.

Proximity coupling of surface acoustic waves to the sheet resistivity of a superconducting granular Al film via the acoustoelectric effect has been demonstrated. In addition to obtaining information about the granular films from these measurements, it is also possible to determine the average separation between the two surfaces. We estimate that the two surfaces used in this experiment, one carrying the SAW and the other being the granular film which was deposited on a glass surface, were at most 1000Å apart. The technique is very sensitive for separations of less than 1000Å.

Measurements on the $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$ system have been completed. The data are being analyzed and prepared for publication. We are proposing that the increase in attenuation observed in the Ho rich superconducting samples of this system is being produced by spin phonon interaction in the superconducting state which is induced by supercurrent screening of the crystalline electric fields which suppress spin fluctuations in the normal state of

these superconductors. We are also proposing that the maximum in attenuation which is exhibited by the Ho rich samples, both superconducting and non superconducting, is produced by a relaxation mechanism which is associated with the ground state and first excited state of the Ho^{+3} ions. We have derived a theoretical formula that gives the attenuation as a product of a Debye relaxation expression times the specific heat times the temperature. The data are presently being analyzed in order to deduce the temperature dependence of the relaxation time associated with this mechanism.

Preliminary measurements of both the attenuation and velocity of longitudinal waves in a single crystal of URu_2Si_2 have been performed. We have found that the attenuation goes through a broad maximum immediately below the superconducting transition temperature, and that the velocity decreases monotonically below the superconducting transition temperature.

FORECAST

The research goals and objectives of this investigation will remain the same. The number of graduate research assistants will be maintained at the same level. No significant reorientations are anticipated for the third year of this research program.

The equipment provided by DoD URIP Grant No 84-0221 has been received. The dilution refrigerator has been installed and tested. It attained 4.5 mK without any electrical wire connections to its mixing chamber. When the room temperature probe, together with all the necessary sample holding slugs were installed, temperatures down to 50 mK were attained. Modifications in the design are progressing so that temperatures below 50 mK will be routinely possible. The automatic velocity and attenuation measurement apparatus up to frequencies of 4 GHz has been tested and is being assembled and permanently installed. A computer to interface with this equipment has

been received and is being programmed to run the equipment and to receive and analyze data. The 2850A illuminator and flow booth for the submicron photolithography system have been received and are being assembled.

PUBLICATIONS

During this period three papers have been published, six papers have been accepted for publication and one paper is being prepared for publication.

1. Percolation Model for the Surface Acoustic Wave Attenuation in a Superconducting Lead Film, J. Schmidt and M. Levy, IEEE 1985 Ultrasonic Symposium Proceedings 1089, (85 CH 2209-S, Ed. B. R. McAvoy, IEEE, New York, 1985).
2. Ultrasonic Attenuation Measurement of the Re-entrant Superconductors $\text{Er}_{0.187}\text{Ho}_{0.813}\text{Rh}_4\text{B}_4$, Keun J. Sun, Moises Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1985 Ultrasonics Symposium Proceedings 1105, (85 CH 2209-S, Ed. B. R. McAvoy, IEEE, New York, 1985).
3. Ultrasonic Attenuation and the Resistive Transition in a Superconducting Granular Lead Film, M. Levy, J. Schmidt, M. Revzen, A. Ron, and B. Shapiro, C. G. Kuper, Phys. Rev. B 43, 1508 (1986).
4. Attenuation of SAW Due to Electron Phonon Interaction, M. Levy and S. Schneider, Condensed Matter Physics: The Theodore D. Holstein Symposium (Ed. Raymond Orbach, Springer Verlag, New York, 1986) (to be published).
5. A Possible Technique for Determining the Average Grain Size in Thin Superconducting Granular Films, J. Schmidt and M. Levy, 1986 Applied Superconductivity Conference Proceedings (to be published).
6. Proximity Coupling of Surface Acoustic Waves to a Superconducting $\text{Al}_x\text{O}_{1-x}$ Film, A. Schenstrom and M. Levy, 1986 Applied Superconductivity Proceedings (to be published).

7. Relaxation Attenuation in $\text{Er}_{0.187}\text{Ho}_{0.813}\text{Rh}_4\text{B}_4$ and HoRh_4B_4 , K. J. Sun, R. Sorbello, M. Levy, M. B. Maple and M. S. Torikachvilli, IEEE 1986 Ultrasonics Symposium Proceedings (to be published).
8. Attenuation of surface Acoustic Waves in a Superconducting In/InOx Films, J. Schmidt, M. Levy and A. Hebard, IEEE 1986 Ultrasonics Symposium Proceedings (to be published).
9. Analytic Solution of the Renormalization Equations of the Kosterlitz-Thouless Transition, A. Schenstrom, Physics Letters (to be published).
10. Induced Spin Phonon Interaction in the Superconducting State of Ho-Rich $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$, K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvilli (to be submitted to Phys. Rev. Letters).



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TECHNICAL PERSONNEL

In addition to the principal investigator, the following technical personnel have worked and will be working on this grant. The university has supported some of them as part of their matching commitment.

Faculty

Dr. Bimal Sarma (Assistant Professor - University supported)
Supervised installation of (DoD URIP Grant No. 84-0221) dilution refrigerator, and design of He³ cryostat. Ultrasonic investigation of heavy fermion superconductors, SAW investigation of granular superconductors, bulk investigation of superconducting vanadium and tungsten.

Postdoctoral Fellow

Dr. Qian Yong Jia (Visiting Scholar - University supported)
Installation and daily running of dilution refrigerator (DoD URIP Grant No. 84-0221).

Graduate Students

Mr. Anders Schenstrom (Senior Graduate Research Assistant - University supported)
Theoretical renormalization model for acoustoelectric effect in superconducting NbN, SAW investigation of granular films, development of technique for proximity coupling of SAW to superconducting granular films.

Mr. Jeff Schmidt (Senior Graduate Research Assistant)
SAW investigation of granular Pb films, amorphous films, and In/InOx films.

Mr. Keun-Jenn Sun (Senior Graduate Research Assistant)
Ultrasonic investigation of ternary ferromagnetic superconductors.

Mr. Hugues-Pierre Baum (Graduate Research Assistant)
Design of He³ cryostat, SAW investigation of superlattice superconductor, bulk investigation of vanadium and tungsten.

Mr. Min Feng Xu (Graduate Research Assistant - University supported)
Ultrasonic investigation of ternary alloys, heavy fermion superconductors, and Chevrel phase superconductors.

Technicians

Ms. Li Huali

(Visiting Scholar - Self supported)
Part time on this project. Preparation of SAW devices.

Mr. Michael Mitchell

(Technician and Machinist - University supported)
Part time on this project. Construction of components for dilution refrigerator and He³ cryostat.

Ph.D. Thesis Granted

Mr. Keun-Jenn Sun received his Ph.D in physics on August 1986. His thesis advisor was Professor Levy. The title of his Ph.D. dissertation was "Ultrasonic Investigation of the Re-entrant Superconductor and Ferromagnetic Compounds of $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$ System".

SCIENTIFIC INTERACTIONS

1. Nb₃Sn and Nb₃Ge Films

For our research, Dr. Robert Hammond, Stanford University will attempt to deposit Nb₃Ge films on aluminum nitride substrates. He will also attempt to deposit Nb₃Sn and Nb₃Ge films on passivated lithium niobate substrates.

2. Ternary Alloys

An experimental study of polycrystalline samples of Er_{1-x}Ho_xRh₄B₄ system has been completed. These samples were obtained from Professor Brian Maple, U.C. San Diego. The results are being prepared for publication.

3. Amorphous Superconductors

We have obtained from Professor Ted Geballe and Dr. Robert Hammond, Stanford University, amorphous molybdenum films stabilized with a small amount of niobium, which were deposited on quartz and lithium niobate substrates. Interdigital electrodes have been deposited on the substrates and preliminary measurements have been initiated.

4. Single Crystals of the Ternary Alloys

Continued discussions with Dr. David Hinks, Argonne National Laboratory, concerning the possibility of obtaining single crystals of the ternary alloys. Initiated similar discussions with Dr. Brian Maple, U.C. San Diego.

5. Single Crystal of Cu₂Mo₆S₈

Continued discussions with Dr. Rene Flukinger, Solid State Institute, concerning the possibility of obtaining his single crystal of Cu₂Mo₆S₈ for ultrasonic measurements.

6. Array of Josephson Coupled Superconductors

Continued discussions with Professor R. S. Newrock, University of Cincinnati, concerning the deposition of Josephson coupled superconducting arrays on piezoelectric substrates we have sent him for SAW investigation. Sent piezoelectric substrates to Professor P. Martinolli, University of Neuchatel, Switzerland, for a similar purpose.

7. Films of Va_3Sn

Obtained two films of Va_3Sn deposited on a piezoelectric substrates from Dr. John Gavaler, Westinghouse Research Corporation. Interdigital electrodes have been deposited on the substrates and preliminary measurements will be initiated.

8. Artificially Produced Superlattices

Continued discussions with Dr. Ivan Schuller, Argonne National Laboratories, about the possibility of obtaining superlattices made of Nb and Cu in order to investigate their characteristics with SAW. Similar discussions were continued with Professor Ted Geballe and Dr. Robert Hammond, Stanford University, to obtain superlattice structures of Nb and Zr.

9. Heavy Fermion Superconductors

Obtained single crystals of URu_2Si_2 and UPt_3 which are heavy fermion superconductor from Dr. David Hinks, Argonne National Laboratory. Preliminary velocity and attenuation data have been obtained on the URu_2Si_2 single crystal. Initiated discussions with Professor Brian Maple, U. C. San Diego, concerning the possibility of obtaining single crystals of the heavy fermion superconductors from his laboratory.

10. Chevrel Phase Superconductors

Professor Donald Ginsberg, University of Illinois-Urbana, has grown single crystals of Chevrel phase superconductors which he will send us for ultrasonic characterization in the superconducting state.

11. In/InOx Films

A collaborative effort has been initiated with Dr. Arthur Hebard, Bell Telephone Laboratories to measure In/InOx films with SAW. The properties of the films will range from amorphous to granular, and from superconducting to high resistivity to almost exhibiting metal insulating transitions. Several films have already been measured and measurements on one film will be reported at the IEEE 1986 Ultrasonics Symposium.

12. IEEE 1985 Ultrasonics Symposium

Chaired session at symposium which was held on October 16-18, 1985 in San Francisco, California. Presented two papers

"Percolation Model for the Surface Acoustic Wave Attenuation in a Superconducting Lead Film," J. Schmidt and M. Levy

and

"Ultrasonic Attenuation Measurement of the Re-entrant superconductors

$\text{Er}_{0.187}\text{Ho}_{0.813}\text{Rh}_4\text{B}_4$ and $\text{Er}_{0.705}\text{Ho}_{0.295}\text{Rh}_4\text{B}_4$," K. J. Sun, M. Levy, M. B. Maple, and M. S. Torikachvilli.

13. 1985 March Meeting of the American Physical Society

Attended the conference on March 31 to April 4, 1986. Discussed data obtained on the ternary superconductors with Professor Brian Maple, U.C. San Diego. Discussed the possibility of obtaining single crystals of both ternary superconductors and heavy Fermion superconductors for ultrasonic measurements. Arranged with Dr. Art Hebard, Bell Telephone Labs, to measure with SAW In/InO_x films prepared by him. Discussed with Dr. David Hinks, Argonne National Laboratory, and Professor John Ketterson, Northwestern University, preliminary data obtained on a single crystal of URu₂Si₂, which is a heavy fermion superconductor.

14. IEEE 1986 Ultrasonics Symposium

Member of the program committee of the conference to be held in Williamsburgh, Virginia, on November 17-19, 1986.

15. Workshop on Nondestructive Evaluation of Ceramics and Composites

Attended workshop held at the Illinois Institute of Technology on May 28-30, 1986.

16. Visit to the Max Planck Institute for High Magnetic Fields, Grenoble, France.

On July 10, visited the laboratory and was informed about different magnet designs for attaining 30 Tesla.

On July 11, presented a seminar

"Ultrasonic Investigation of the Er_xHo_{1-x}Rh₄B₄ Ferromagnetic Superconducting System."

And discussed with Dr. Peter Wyder, Lab Director, the possibility of performing experiments in their high magnetic field facility.

17. International Conference on Anomalous Rare Earths and Actinides.

Attended conference which was held on the University campus of Grenoble (Domaine Universitaire de Grenoble - St. Martin d'Herès) on July 7-11, 1986. Discussed with Prof. Bruno Luthi, University of Frankfurt, ultrasonic measurements on URu_2Si_2 .

18. Conference on the Review of Progress in Qualitative NDE

Attended conference held in San Diego, California, on August 3-8, 1986. Discussed with Dr. Larry Kessler, Sonoscan, electromagnetic absorption measurements and SAW measurements on niobium samples taken from sheets that are being used for producing superconducting cavities. Sonoscan is supporting a research assistant at UWM to perform these measurements.

19. 1986 Applied Superconductivity Conference

Attended conference which was held in Baltimore, Maryland on September 28 to October 3, 1986 and presented two papers at a poster session.

"Possible Technique for Determining the Average Grain Size in Thin Superconducting Granular Films," J. Schmidt and M. Levy

and

"Proximity Coupling of Surface Acoustic Waves to a Superconducting Al_xO_{1-x} Film," A. Schenstrom and M. Levy

Discussed paper to be presented at IEEE 1986 Ultrasonics Symposium with Dr. Art Hebard, Bell Telephone Labs. Discussed with Professor Ted Geballe, Stanford University, possibility of obtaining superconducting superlattices from Stanford.

END

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