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THIN SUPERCONDUCTING FILM CHARACTERIZATION BY SURFACE
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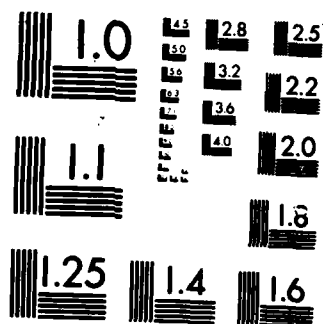
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20 ABSTRACT (Continue on reverse side if necessary and identify by block number) Both the dc electrical resistivity and the attenuation of surface acoustic waves (SAW) were measured in the superconducting state of a granular lead film, when its sheet resistivity was 2000 Ω /sq and 3000 Ω /sq, as a function of a perpendicular mag- netic field. At 4.2 K the film appears to have an upper critical field of about 60 K Gauss. → next page		

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19. Key Words - continued

superconducting states	crystalline electric field
granular lead films	ternary compounds
sheet resistivity	Rayleigh waves
magnetic field	submillikelvin temperatures
upper critical field	dilution refrigerator
bulk ultrasonic measurements	automatic velocity and
attenuation	measuring apparatus
$\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$	submicron photolithography
relaxation mechanism	system
Ho ions	Nb_3Sn
ferromagnetic superconductors	Nb_3Ge
superconducting screening	He^3 cryostat
crystalline field effects	amorphous molybdenum films
spin phonon interaction	quartz substrates
acoustoelectric coupling	lithium niobate substrates
granular Al film	interdigital electrodes
electron phonon interaction	
superconducting energy gap	ErRh_4B_4
electron mean free path	He^3 probe
vortex antivortex bound pairs	$\text{Cu}_2\text{Mo}_6\text{S}_8$
amorphous superconductor	V_3Sn
effective energy gap	superlattice of Nb and Cu
strongly localized superconductor	superlattice of Nb and Zr
piezoelectric coupling	heavy fermion superconductor
granular films	proximity effect
superconducting superlattice films	superinsulated dewars
magnetic superconductors	pure Nb single crystal film
transition metal superconductors	weakly coupled superconductors
renormalization	

20. Abstract-continued

Bulk ultrasonic measurements have been made in the series $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$. At 15 MHz a broad peak in attenuation, due to a relaxation mechanism associated with the Ho ions, is observed around 10 K. It moves to lower temperatures as x is decreased. An increase in attenuation is observed in the superconducting state of those alloys which are ferromagnetic superconductors. This increase may be due to superconducting screening of crystalline field effects which inhibit spin phonon interaction in the normal state.

Preliminary measurements of the acoustoelectric coupling of SAW with an Al granular film, which is held 15 μ 's above the SAW, indicate that at 19 MHz the attenuation increases when the film becomes superconducting. This is an unexpected result since at this frequency the attenuation is expected to decrease when the film becomes superconducting.

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

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RESEARCH OBJECTIVES AND APPROACHES

MATTHEW J. KEMPER

Chief, Technical Information Division

The objective of this investigation is to characterize thin film superconductors with surface acoustic waves (SAW). By measuring the electron phonon interaction in thin films, the temperature dependence of the superconducting energy gap and the electron mean free path may be determined. It may also be possible to determine the existence of vortex antivortex bound pairs in amorphous superconductors and the effective energy gap in strongly localized superconductors. By measuring the piezoelectric coupling to the sheet resistivity of granular films it may be possible to determine the size distribution of the granules and the distribution of the coupling between granules. Surface acoustic wave measurements of Josephson junction networks may be correlated with their signal processing properties. SAW measurements of superconducting superlattice films may provide information about the mechanical properties of these films. Measurements with bulk waves will provide information about spin phonon coupling in magnetic superconductors and electron phonon interaction in the transition metal superconductors.

ACCOMPLISHMENTS

Both the dc electrical resistivity and the surface acoustic wave (SAW) attenuation coefficient were measured in the superconducting state of a granular lead film as a function of an applied magnetic field normal to the film plane at several constant temperatures. Measurements were performed when the film had a sheet resistivity of, 2000 Ω/sq and 3000 Ω/sq . These different sheet resistivities were obtained by oxidizing the film in place. The initial sheet resistivity of the film was 1000 Ω/sq . Both sets of measurements

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appear to indicate upper critical fields for this film of 60 K Gauss at 4.2 K.

We have evolved a theoretical model that takes into account renormalization to explain the experimental discrepancy in the superconducting state between the SAW attenuation in a NbN film and its sheet resistivity. The film has a BCS transition temperature of about 10 K, and a Kosterlitz-Thouless transition temperature of 5 K, and a normal state sheet resistivity of 30 K Ω /sq. An exact solution has been found for the renormalized dielectric function of a two dimensional superconductor which has Kosterlitz-Thouless flux line dipoles.

Bulk ultrasonic measurements in the series of ferromagnetic superconductors $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$ with $x = 1, 0.912, 0.813, \text{ and } 0.6$ (received from Dr. Brian Maple, UCSD) appear to indicate that spin phonon interaction is suppressed by crystalline electric fields but superconductivity screens these fields permitting the interaction to appear. This may be the reason for the increase in attenuation that we have observed in the superconducting state of these ternary compounds.

Measurements on a sample with $x = 0.295$, in addition to the ones above, exhibit a maximum in attenuation centered around 10 K which moves down in temperature as x is decreased. This maximum may be associated with a relaxation process involving a ground state of the Ho ions. The $x = 0.295$ sample also exhibits another broad maximum around 4 K which is similar to the one reported around 5 K on a polycrystalline sample with $x = 0$.

Measurements of the attenuation produced by a granular Al film in close proximity above the path transversed by a surface acoustic wave

have been made at several frequencies between 19 MHz and 281 MHz. The sheet resistivity of the film is about $1000 \Omega/\text{sq}$. The coupling between the SAW and the film is through the acoustoelectric effect, namely the piezoelectric fields accompanying the SAW induce currents in the film which absorb energy thereby attenuating the SAW.

Preliminary measurements show that the attenuation of 19 MHz waves increase when the film becomes superconducting. This is an unexpected result. For Rayleigh waves the acoustoelectric effect is proportional to the sheet resistivity in this frequency range and therefore the attenuation associated with it should vanish when the film becomes superconducting. There are no observable changes for the higher frequencies at the superconducting transition. This indicates that the separation between the granular Al film and the substrate of the SAW device is around $15 \mu\text{'s}$, since a maximum effect is observed for a particular separation, z_0 , when the SAW frequency is such that $z_0 = \frac{\lambda}{4\pi}$.

An invited paper was presented at the Eighth International Conference on Internal Friction and Ultrasonic Attenuation in Solids held at the University of Illinois at Urbana-Champaign on June 3-6, 1985.

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. The rate of expenditure of funds is expected to continue at the proposed level. No significant reorientations are anticipated for the second and third years of this research.

When the equipment provided by DOD-URIP Grant No. 84-0221 is assembled it will be possible to carry out these measurements down to submillikelvin temperatures and up to frequencies of 4 GHz. The dilution refrigerator has been ordered from Oxford Instruments and is expected in a few days. The automatic velocity and attenuation measurement apparatus up to frequencies of 160 MHz has been received from Matec. A schematic and list of the equipment necessary to extend the frequency range up to 4 GHz has been designed in collaboration with Matec and is being assembled at UWM. A computer to interface with this equipment has been ordered. The 2850A illuminator and flow booth for the submicron photolithography system have been ordered.

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PUBLICATIONS

Two papers are to appear in the Proceedings on Materials and Mechanisms of Superconductivity and three papers in the Journal de Physique. Two papers have been submitted to the Physical Review, and one paper to Phys. Rev. Letters.

1. Ultrasonic Attenuation Measurement of $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$, K. J. Sun, M. Levy, M. B. Maple and M. S. Torikachvili, Proceedings on Materials and Mechanisms of Superconductivity, (eds. K. A. Gschneider, Jr. and E. L. Wolf, North Holland Publishing Co. 1985) (to be published).
2. Detection of Bound Vortex-Antivortex Pairs in a Superconducting Thin Film by Surface Acoustic Waves, A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler Proceedings on Materials and Mechanisms of Superconductivity, (eds. K. A. Gschneider, Jr. and E. L. Wolf, North Holland Publishing Co. 1985) (to be published).
3. Magnetic Field Dependence of the Ultrasonic Attenuation and Resistance of a Superconducting Granular Lead Film, J. Schmidt, A. Schenstrom and M. Levy, Journal de Physique (to be published).
4. Detection of Bound Vortex-Antivortex Pairs in a Superconducting Thin Film by Surface Acoustic Waves, A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler, Journal de Physique (to be published).
5. Surface Acoustic Wave Investigation of Superconducting Films, M. Levy, Journal de Physique (to be published).
6. Ultrasonic Attenuation and the Resistive Transition in a Superconducting Granular Lead Film, M. Levy, J. Schmidt, A. Schenstrom, M. Revzen, A. Ron, B. Shapiro, and C. G. Kuper (submitted to Phys. Rev.).

7. Attenuation of Surface Acoustic Waves by Bound Vortex-Antivortex Pairs in a Superconducting Thin Film, A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavalier (submitted to Phys. Rev.).
8. Analytic Solution of the Renormalization Equations of the Kosterlitz-Thouless Transition", A. Schenstrom (submitted to Phys. Rev. Letters).

TECHNICAL PERSONNEL

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

Full Time:

Mr. Anders Schenstrom	(Senior Graduate Research Assistant) Theoretical renormalization model for acoustoelectric effect in superconducting NbN, and SAW investigation of granular films and superlattices.
Mr. Jeff Schmidt	(Senior Graduate Research Assistant) SAW investigation of granular Pb films and amorphous films.
Mr. Keun-Jenn Sun	(Senior Graduate Research Assistant) Ultrasonic investigation of ternary ferromagnetic superconductors and pure vanadium single crystals.
Mr. Roy Wiegert	(Senior Graduate Research Assistant) Responsible for assembling automatic ultrasonic attenuation and velocity measuring apparatus. (DOD-URIP Grant No. 84-0221)

Part Time:

Mr. Hugues-Pierre Baum	(Junior Graduate Research Assistant) Will work on layered compounds, strong coupled superconductors and Al5 superconductors.
Mr. Qiang Qian	(Junior Graduate Research Assistant) Will work on dilution refrigerator. (DOD-URIP Grant No. 84-0221)
Mr. Dale Walikainen	(Junior Graduate Research Assistant) Will work on Josephson coupled superconducting arrays.
Mr. Min Feng Xu	(Junior Graduate Research Assistant) Will work on single crystal vanadium, ternary alloys and chevrel phase superconductors.

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

Polycrystalline samples of Ho_xEr_{1-x}Rh₄B₄ have been obtained from Professor Brian Maple, U.C. San Diego. These samples have a ferromagnetic transition temperature that is accessible with a He⁴ cryostat. Therefore, the interplay between ferromagnetism and superconductivity can be more easily investigated ultrasonically.

3. Amorphous Superconductors

We have obtained from Professor Ted Geballe and 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 will be deposited on the substrates and preliminary measurements will be 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. The first crystals will be of ErRh₄B₄. These crystals will also be measured with the He³ probe.

5. Single Crystal of $\text{Cu}_2\text{Mo}_6\text{S}_8$

Correspondence with Dr. Renee Flukiger, Solid State Institute, Karlsruhe, concerning the possibility of obtaining a single crystal of $\text{Cu}_2\text{Mo}_6\text{S}_8$ was conducted. He has grown such a crystal and hopefully it will be sent to us for characterization.

6. Array of Josephson Coupled Superconductors

Discussions were held with Professor R. S. Newrock, University of Cincinnati, concerning the deposition of an array of Josephson coupled superconductors on a piezoelectric substrate.

Interdigital electrodes will then be evaporated on this substrate in order to investigate the array with surface acoustic waves in the 700 MHz frequency range.

7. Films of V_3Sn

Discussions were initiated with Dr. John Gavaler, Westinghouse, about obtaining thin films which will be measured with surface acoustic waves. Two substrates covered with films have been obtained.

.. Artificially Produced Superlattice

Discussions were initiated 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 surface acoustic waves. Similar discussions were held with Professor Ted Gabelle and Dr. Robert Hammond, Stanford University, to obtain superlattice structures of Nb and Zr.

9. 1984 IEEE Ultrasonic Symposium

On November 14-16 chaired session at the Dallas, Texas, conference.

10. Visit to Physics Department, University of Illinois, Urbana Champaign

Presented seminar on November 20, 1984

"Surface Acoustic Wave Investigation of Superconducting Films."

Discussed measurements on superconducting films with Professor Dan Ginsberg and measurements in the mixed superconducting state with Professor Andrew Granato. Visited the low temperature labs and discussed the installation of their dilution refrigerators because of the installation we were planning for our new refrigerator (DOD-URIP Grant No. 84-0221).

11. During travel in Europe Professor Levy made visits to the following:

11.1 Visit to the Institute of Physical Chemistry, Polish Academy of Science, Warsaw Poland

On December 27, 1984 presented seminar on

"Surface Acoustic Waves."

Visited the surface studies laboratory.

11.2 Visit to Swiss Federal Institute (ETH) Zurich, Switzerland

On January 4-5, 1985, visited the low temperature laboratory and discussed the merits of the SHE and Oxford dilution refrigerators installed at the labs there. Discussed with Dr. Hans Rudi Ott his measurements on heavy fermion superconductors and discussed with Dr. Ana Celia Mota her measurements on the proximity effect at millikelvin

temperatures. Also discussed these topics with Professor Jorgen L. Olsen.

11.3 Visit to the Bavarian Walther Meissner Low Temperature Laboratory, Munich, West Germany

On January 7 and 8, 1985, Professor Levy visited the Walther Meissner Low Temperature Laboratory and discussed with the director, Dr. Klaus Andres, the merits of their different large dilution refrigerators and the advisability of building specialized small dilution refrigerators in order not to require liquid nitrogen in their operation.

12. 1985 IEEE Ultrasonic Symposium

Member of the program committee of the conference held in San Francisco on October 16-18, 1985.

13. March Meeting of the American Physical Society

Attended the conference on March 25-29, 1985, which was held in Baltimore, Maryland and chaired a session on "Superconductivity: Al₅ Compounds." Held discussions with Professor Ted Geballe, and Dr. Robert Hammond, Stanford University, concerning superlattices of Nb and Zr. Held discussions with Dr. John Gavaler about measuring some of their pure Nb single crystal films in order to establish a standard comparison with the Al₅ superconducting films. Held discussions with Dr. George Crabtree, Argonne National Laboratory, about the single crystals of ErRh₄B₄ that they are attempting to grow at Argonne National Laboratory. Discussed with Professor R. Newrock his continuing attempts to make Josephson coupled arrays. They are going to use the

Cornell submicron facility to produce these arrays. Discussed with Dr. Ana Celia Mota the possibility of making surface acoustic wave measurements on systems which display the large superconducting proximity effect that she recently discovered. Continued discussions with Dr. Jim Smith, Los Alamos Laboratory, about the possibility of obtaining heavy fermion superconducting crystals from him for ultrasonic measurements. Discussed our bulk wave measurements on the ternary superconductors and our SAW measurements on granular superconductors with Dr. Lewis Testardi, National Bureau of Standards.

14. Materials and Mechanisms of Superconductivity Conference

Attended the conference on May 29-31, 1985, which was held in Ames, Iowa. Presented two poster papers.

"Detecting Bound Vortex-Antivortex Pairs in a
Superconducting Thin Film by Surface Acoustic Waves",
A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler
and

"Ultrasonic Attenuation Measurement of $\text{Er}_{1-x}\text{Ho}_x\text{Rh}_4\text{B}_4$ ",
J. Sun, M. Levy, M. B. Maple and M. S. Torikachvili

Discussed the results on the Kosterlitz-Thouless vortex antivortex pairs with Art Hebard, Bell Labs. Discussed with Allen Goldman, University of Minnesota, and Cornell Chun, Sperry Computer Systems Division, the possibility of obtaining an array of Josephson coupled superconductors deposited on a piezoelectric substrate. The array would be made at Sperry. Discussed with Brian Maple, UCSD, the possibility of obtaining single crystals of ErRh_4B_4 that were sufficiently large for ultrasonic measurements.

15. Eight International Conference on Internal Friction and Ultrasonic Attenuation in Solids

Attended the conference on June 3-6, 1985 held in Urbana, Illinois. Presented an invited plenary paper

"Surface Acoustic Wave Investigation of

Superconducting Films", M. Levy

and two contributed papers

"Magnetic Field Dependence of the Ultrasonic Attenuation and Resistance of a Superconducting Granular Lead Film",

J. Schmidt, A. Schenstrom and M. Levy

and

"Detection of Bound Vortex-Antivortex Pairs in a

Superconducting Thin Film by Surface Acoustic Waves",

A. Schenstrom, M. Levy, H. P. Fredricksen and J. Gavaler

16. Gordon Research Conference on Superconducting Films

Attended conference on August 26-30, 1985 which was held in Plymouth, New Hampshire. Presented an invited poster

"Surface Acoustic Wave Investigation of Superconducting

Granular Pb Films", M. Levy

Discussed with G. Deutcher, University of Tel Aviv, Art Hebard, Bell Labs, and H. Fink, University of California Davis, different models for explaining the magnetic field dependence of the attenuation of surface acoustic waves produced by superconducting granular lead films. Discussed with A. C. Mota, ETH-Zurich, the proximity effect at millikelvin temperatures and the type of information that ultrasonic measurements would yield about this effect. Discussed with P. Martinolli, University of Neuchatel,

the possibility of depositing a weakly coupled array of superconductors with a sheet resistivity of a few hundred ohms on a piezoelectric substrate in order to perform SAW measurements to determine if a correlation could be obtained between these measurements and those which have already been made on NbN films.

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