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

The objective of this research is to characterize high T_c superconductors with ultrasonic waves.

A peak in ultrasonic attenuation has been observed at the superconducting phase transition of a thalium superconducting compound with a T_c = 103 K. The position of this peak is independent of frequency and therefore should not be produced by a relaxation mechanism. It may be produced by interactions with fluctuations associated with the superconducting phase transition. The magnitude of the peak decreases in magnetic fields up to 6 Tesla. This appears to be the first time that an attenuation effect has been observed which is directly associated with the superconducting state of a high T_c superconductor. Shear waves propagating parallel to the CuO planes and

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18. Subject Terms - continued

sinter forged $YBa_2Cu_3O_7$

ultrasonic attenuation
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19. Abstract - continued

polarized in the CuO planes of a sinter forged $YBa_2Cu_3O_7$ sample exhibit only one maximum in attenuation at around 180 K. This is consistent with the model presented in the previous report, wherein only compressions of the CuO planes produced the other two maxima at 70 K and 250 K. Velocity measurements in the copper free high T_c superconductors $Ba_{1-x}K_xBiO_3$ show a definite change in slope at the phase transition. Measurements in the heavy Fermion superconductor UPt_3 show a 40 ppm change in velocity around 4.5 K, its antiferromagnetic phase transition temperature.

Annual Summary Report

Bulk Wave Characterization of High T_c Superconductors

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November 1, 1989

ANNUAL SUMMARY REPORT

I. Description of Project

Measurements are being performed with longitudinal and transverse ultrasonic waves on the high T_c superconductors in order to help determine the nature of the interaction that is producing the high superconducting transition temperatures in these systems. Maxima in attenuation as a function of temperature have been observed in yttrium, and thalium based CuO superconducting compounds and even in the copper free superconducting compounds. Some of these maxima shift to higher temperatures at higher frequencies and therefore can be assumed to be produced by relaxation mechanisms. Activation energies can be deduced for the excitations which are producing these relaxation maxima. These activation energies can be compared with the energies of the possible excitations responsible for the superconducting interactions which are postulated by different theoretical models. Measurements on sinter forged samples appear to provide some selection rules for the ultrasonic interactions and thus may help to determine the orientation of the excitations. In this manner it may be possible to distinguish between different theoretical models that have been proposed to explain the high transition temperatures of these superconducting systems.

The temperature position of one set of maxima on the thalium compounds appears to be at T_c and independent of frequency. The effect of a magnetic field should determine if these maxima are associated with the superconducting transition, in which case it will become possible to investigate via ultrasonic attenuation the superconducting phase itself of these high T_c superconductors.

II. Scientific Approaches

The attenuation and velocity of both longitudinal and transverse waves are being used to characterize superconducting samples as a function of temperature, frequency and magnetic field. Measurements are being performed on sintered samples and sinter forged samples of the high T_c superconductors. Attempts are being made to measure single crystals of these samples. However, the single crystals of the Y based compounds that are available have not been sufficiently large for the pulse echo technique being employed, and the Bi based single crystals obtained have not had the degree of perfection necessary to propagate bulk waves. Attempts are being made to develop a surface acoustic wave pontoon-bridge technique to measure sound propagation in these single crystals.

III. Accomplishments

A. High T_c Superconductors

1. Superconducting Thalium CuO Compounds

The thalium compounds exhibit the highest superconducting transition temperature that has been verified, 125 K. We have done both attenuation and velocity measurements on a thalium sample that we obtained from the Naval Research Laboratory. The velocity measurements just showed a gradual increase in velocity as the temperature was lowered. However, attenuation measurements with 30 MHz shear waves showed a peak in attenuation at the superconducting transition temperature T_c of our sample which is 103 K. This peak remained at T_c for 10 and 67 MHz shear waves, and for 10 MHz longitudinal waves. These are very promising data since they show that the peak may be associated with the superconducting phase transition. If so, they may be due to an interaction of the sound waves with superconducting fluctuations. Preliminary measurements in a magnetic field indicate that the position of the peaks does not appear to shift in a magnetic field but

that their magnitude decreases appreciably. These data are consistent with the peaks being associated with the superconducting phase transition; namely, in 6 Tesla the position of the peak should only move slightly; and, depending on the nature of the interaction, the magnitude of the peak could be very sensitive to a magnetic field.

2. Bismuth CuO Superconducting Compounds

We have obtained several single crystal samples of bismuth high T_c superconductors from Argonne National Laboratory. To date, we have not been able to get good sound wave echoes through these samples. We shall continue to try to obtain better samples and try to propagate good echoes through the samples we have.

3. Sinter Forged $YBa_2Cu_3O_7$

We have made attenuation measurements with shear waves propagating perpendicularly to the forging axis and also polarized perpendicularly to the forging axis. These measurements are consistent with the predictions that could be made from the model we presented in our previous progress report. Namely, we only observed one maximum in attenuation at around 180 K, since the CuO planes which lie in planes which are perpendicular to the forging axis are not compressed or bent by these shear waves. We are now attempting to send shear waves along the same direction but polarized parallel to the forging axis. In this case we would expect to see all three peaks at 70 K, 180 K and 250 K.

B. Heavy Fermion Superconductors

1. URu_2Si_2

We have made both attenuation and velocity measurements on a single crystal sample of URu_2Si_2 that we obtained from Argonne National Laboratory. We have found a drop in attenuation in the superconducting state that is preceded by a peak in attenuation that appears slightly below the superconducting transition temperature. The peak in attenuation vanishes in

a 1 KOe magnetic field. The velocity also decreases in the superconducting state.

2. UPt_3

Very careful measurements as a function of temperature, magnetic field, and orientation have been repeated on the lambda peak in attenuation that we observed in the mixed state of UPt_3. We have also carefully studied the position of the peak in attenuation at the superconducting transition. These data have been used to compose a phase diagram for the superconducting state of UPt_3.

C. Instrumentation

As implied earlier in this report, we did not observe any velocity change at T_c in the superconducting thalium compound. We checked the sensitivity of our automated velocity and attenuation apparatus and found out that its velocity sensitivity was only a few parts in 10^5 in the 10 to 50 MHz range. We have spent several weeks improving the signal to noise ratio and have increased the velocity sensitivity by an order of magnitude in this same frequency range. Preliminary measurements on the copper free high T_c superconductors $Ba_{1-x}K_xBiO_3$ indicate that we are now able to observe a change in slope of the velocity near the superconducting transition temperature.

Initial measurements of UPt_3 show a change in velocity of 40 ppm around 4.5 K. This change has been theoretically predicted since there is neutron diffraction evidence for an antiferromagnetic phase transition at this temperature. The change was expected to be small since there are only 0.02 Bohr magnetons per uranium atom.

A cryostat containing an 8 Tesla magnet has been assembled which allows us to perform magnetic field measurements on the high T_c superconductors in the 4 to 300 K temperature range.

A He^3 system that will extend this temperature range down to 0.3 K is being assembled.

IV. Publications

A. Papers published in refereed journals

1. Magnetic Field Dependent Sound Attenuation in UPt_3, A. Schenstrom, M.-F. Xu, Y. Hong, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, J. B. Ketterson and D. Hinks, 18 Rare Earth Research Conference, Lake Geneva (1988) J. of the Less Common Metals 149, 349-351 (1989). Work at Northwestern University supported by NSF (S.A., Z.Z., and J.B.K.).

2. Hysteresis in Ultrasonic Attenuation of UPt_3 in Low Magnetic Fields, A. Schenstrom, M.-F. Xu, Y. Hong, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, J. B. Ketterson and D. Hinks, 18 Rare Earth Research Conference, Lake Geneva (1988), J. of the Less Common Metals 149, 353-356 (1989). Work at Northwestern University supported by NSF (S.A., Z.Z., and J.B.K.).

3. Ultrasonic Attenuation in Sintered-forged High T_c Superconductor $YBa_2Cu_3O_{7-\delta}$, M.-F. Xu, Y. Hong, M. Levy, B. K. Sarma, Z. Zhao, K. R. Poeppelmeir and J. B. Ketterson, 18 Rare Earth Research Conference, Lake Geneva (1988), J. of the Less Common Metals 149, 447-450 (1989). Work at the Northwestern University supported by NSF (Z.Z., S.A., A.M., Q.R., D.L.J., S.J.H., K.R.P., and J.B.K.).

4. Ultrasonic Velocity Anomalies in Sinter-forged High T_c Superconductor $YBa_2Cu_3O_{7-\delta}$, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeir, J. B. Ketterson, M.-F. Xu, Y. Hong, M. Levy and B. K. Sarma, 18 Rare Earth Research Conference, Lake Geneva (1988), J. of the Less Common Metals 149, 451-454 (1989). Work at the Northwestern University supported by NSF (Z.Z., S.A., A.M., Q.R., D.L.J., S.J.H., K.R.P., and J.B.K.).

5. Frequency Dependent Ultrasonic Attenuation of $YBa_2Cu_3O_{7-\delta}$, K. J. Sun, W. P. Winfree, M.-F. Xu, B. K. Sarma, M. Levy, R. Caton and R. Selim, Phys. Rev. B38, 11988 (1988). Work at Cristopher Newport College supported by NASA (R.C. and R.S.).

6. Ultrasonic Velocity Anomalies in Superconducting Sinter-forged $YBa_2Cu_3O_{7-\delta}$, Z. Zhao S. Adenwalla, A. Moreau, J. B. Ketterson, Y. Hong, R. F. Wiegert, M. Levy and B. K. Sarma, Phys. Rev. B39, 721 (1989). Work at Northwestern University supported by NSF (Z.Z., S.A., A.M., B.K., Q.R., D.L.J., S.J.H. and K.R.P.).

7. Ultrasonic Attenuation Measurements in Sinter-forged $YBa_2Cu_3O_{7-\delta}$, M.-F. Xu, D. Bein, R. F. Wiegert, B. K. Sarma, M. Levy, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Peoppelmeier and J. B. Ketterson, Phys. Rev. B39, 843 (1989). Work at Northwestern University supported by NSF (Z.Z., S.A., A.M., Q.R., D.L.J., S.H.J., K.R.P. and J.B.K.).

8. Anisotropy of the Magnetic Field Induced Transition in Superconducting UPt_3, A. Schenstrom, M. F. Xu, Y. Hong, D. Bein, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, T. Tokuyasu, D. Hess, J. B. Ketterson, J. A. Sauls and D. G. Hinks, Phys. Rev. Lett. 62, 332 (1989). Work at Northwestern University supported by NSF (S.A., Z.Z., T.T., D.H., J.B.K., and J.A.S.).

9. 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, Phys. Rev. Letters, 63, 453 (1989).

10. Relaxation Mechanism of Ultrasonic Attenuation in Ho-rich $Er_{1-x}Ho_xRh_4B_4$, K. J. Sun, R. S. Sorbello and M. Levy, Phys. Rev. 40, 2133 (1989).

11. Relaxation Behavior of Ultrasonic Attenuation in $YBa_2Cu_3O_7$, K. J. Sun, W. T. Winfree, M.-F. Xu, B. K. Sarma, R. Caton and R. Selin, 1988 Applied Superconductivity Conference (San Francisco). IEEE Transactions on Magnetics 25, 2410-2413 (1989). Work at College of William and Mary and at Christopher Newport College supported by NASA (K.J.S., and R.C. and R.S., respectively).

12. Measurement of the Pair-Breaking Edge in Superfluid ^3He-B, S. Adenwalla, Z. Zhao, J. B. Ketterson and B. K. Sarma, Phys. Rev. Lett. 63, 1811 (1989). Work at Northwestern University supported by NSF (S.A., Z. Z., and J. B. K.).

B. Papers published in non-refereed jounrals

1. Relaxation Behavior of Ultrasonic Attenuation in $YBa_2Cu_3O_{7-\delta}$, K. J. Sun, M.-F. Xu, M. Levy and B. K. Sarma, IEEE 1988 Ultrasonics Symposium Proceedings (88CH2578-3, Ed. B. R. McAvoy, IEEE, New York, 1988) pgs. 1089-1092.

2. Ultrasonic Attenuation Measurements on the Flux-Lattice Phase Transition in the Heavy-Fermion Superconductor UPt_3, S. Adenwalla, Z. Zhao, J. B. Ketterson, D. Hinks, A. Schenstrom, M.-F. Xu, Y. Hong, M. Levy and B. K. Sarma, IEEE 1988 Ultrasonics Symposium Proceedings (88CH2578-3, Ed. B. R. McAvoy, IEEE, New York, 1988) pgs. 1085-1088. Work at Northwestern University supported by NSF (S.A., Z.Z., J.B.K.).

3. Ultrasonic Properties of Oriented Ceramic High T_c Superconductors, M. Levy, M.-F. Xu, B. K. Sarma, Z. Zhao, S. Adenwalla, Q. Robinson and J. B. Ketterson, IEEE 1988 Ultrasonics Symposium Proceedings (88CH2578-3, Ed. B. R. McAvoy, IEEE, New York, 1988) pgs. 1097-1103. Work at Northwestern University Supported by NSF (Z.Z., S.A., Q.R., J.B.K.).

C. Papers submitted to refereed journals

1. Ultrasonic Attenuation Anomaly of Tℓ-Ca-Ba-Cu-O at the Superconducting Transition, Proceedings of International Conference on Materials and Mechanisms of Superconductivity and High Temperature Superconductors, Physics C, K. J. Sun, W. P. Winfree, M.-F.-Xu, M. Levy, B. K. Sarma, A. K. Singh, M. S. Osofsky and V. M. LeTourneau. Work at NASA Langley supported by NASA (K.J.S. and W.P.W.).

2. Ultrasonic Behavior of the Heavy-Fermion Superconductor URu_2Si_2, K. J. Sun, A. Schenstrom, B. K. Sarma, M. Levy and D. G. Hinks, Phys. Rev. B. Work at Argonne supported by D.O.E. (D.G.H.).

D. Invited Presentations at Topical or Scientific/Technical Society Conferences

Moises Levy "Surface Acoustic Wave Investigation of Superconductors." International Symposium on Surface Wave in Solids and Layered Structures, Varma Bulgaria, September 14, 1989 (Talk presented by Fred S. Hickernell).

Bimal Sarma "UPt_3 is an Unconventional Superconductor — An Experimental Review." 17th Midwest Solid State Theory Symposium, Indiana University, October 9-10, 1989.