DOE/ER/45283--10

DE92 003653

TECHNICAL PROGRESS REPORT (ANNUAL PERFORMANCE REPORT)

For the report-period 7/1/90 through 6/30/91

DOE GRANT NUMBER DE-FG02-87ER45283

"X-ray Studies of Microstructures in Semiconductors and Superconducting Materials"

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I. SUMMARY OF CURRENT RESEARCH PROJECTS

Several different experimental investigations were carried out during the present report-period (7/1/90-6/30/91). These include x-ray studies of semiconductors, high- T_c superconductors, and various thin films using synchrotron radiation (especially soft x-ray experiments by means of our new detector) and measurements of some fundamental properties of new superconducting materials made in our laboratory at Buffalo.

We have made the first systematic study of electronic structure in the high- T_c superconductors $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ with x ranging from 0 to 0.15 by x-ray absorption spectroscopy (XAS). This experiment was in collaboration with AT&T Bell Laboratories using their Dragon beamline monochromator which has the best energy resolution around the oxygen K edge. This experiment was initiated by our Buffalo group (see our previous joint publications Phys. Rev. B42 (1990) 2635 and Phys. Rev. B42 (1990) 4763). The main breakthrough came after our successful development of a new soft x-ray detector. This result was published in a recent Physical Review Letter (Phys. Rev. Lett. 66 (1991) 104) and also presented as invited talks at the Miami Workshop on Electronic Structure and Mechanisms for High Temperature Superconductivity (paper presented by Y.H. Kao) and at the APS 1991 March meeting (paper delivered by our collaborator F. Sette of AT&T).

After this successful experiment on La-Sr-Cu-O, we have started (by ourselves) a similar x-ray study of the Tl-Ba-Ca-Cu-O system which has the highest record of transition temperature. The purpose is to obtain information on microstructures around oxygen and copper which will help understand a most fundamental question concerning how the local electronic structure is related to high- T_c superconductivity. This experiment is underway.

We are continuing our on-going investigations of interfaces in various layered materials using both hard and soft x-ray scattering and fluorescence techniques. The experiments also help to establish these techniques as practical tools for nondestructive characterization of buried interfaces in semiconductor superlattices and composite superconductive layers -- an area of considerable basic and technical interest in both fields. In semiconductors, we have investigated the effect of growth conditions on the interfacial roughness in heterostructures of InAs/GaAs, InGaAs on GaAs and InP, and SiO₂/Si. In high-T_c superconductors, we have studied the morphology of various thin films and composite structures prepared by our laser ablation technique. Some results have already been published or presented at professional conferences and more experiments are in progress.

EXAFS experiments on the studies of impurities in semiconductors and superconducting materials are progressing very well. We are building a new vacuum chamber with cryostat, which will enable us to take EXAFS data at low temperatures. The low temperature EXAFS measurements will not only increase the signal-to-noise ratio but also allow the possibility to investigate some structural instabilities as a function of temperature.

Some basic physical properties of high-T_c superconductors are also under study in our laboratories mainly for the purpose of material characterization and for probing the physical correlations between our x-ray results and the superconducting properties. This study is important for understanding the effects of chemical doping on flux pinning, flux flow, critical current density, and transition temperature.

II. PROPOSED RESEARCH FOR NEXT YEAR

In view of our exciting XAS results on La-Sr-Cu-O, we would like to use the same technique for a study of two most popular high- T_c systems $Tl_2Ba_2Ca_2Cu_3O_{10}$ and untwinned single crystals of $YBa_2Cu_3O_y$ and $YBa_2Cu_4O_y$ (known as "123" and "124"). The Tl-based material has the highest value of T_c known to date. Our measurements of the unoccupied hole states on the oxygen sites are useful for understanding the important relationship between the transition temperature and local density of states. The "123" and "124" systems deserve special attention. The anisotropy in the density-of-states in the a-b plane has so far not been directly determined. Our results of this XAS experiment will provide a first quantitative measure of the contribution due to chains in these superconductors. This will not only settle the current dispute on the role played by the chains but also point to a new direction for understanding the mechanisms responsible for high- T_c superconductivity. We have been approached by several theoretical groups to compare their calculations with us.

In addition, we would like to perform EXAFS experiments on single crystals of Y-Ba-Cu-O, fluorine-doped Nd_2CuO_4 (a new electron-type high- T_c superconductor), and Pr-doped Y-Ba-Cu-O (a material actively investigated by numerous groups because of its important potential in the fabrication of multilayer structures and for device applications). Our EXAFS results will provide some unique information on the structural distortion/instability around the oxygen or copper atoms in the host material, as well as the position and local structure around the impurity atoms. Some preliminary results on Pr-doping were presented at the MRS Fall meeting in November, 1990. More measurements and detailed analysis are in progress.

The Si/Ge semiconductor system is currently under worldwide intensive study, due to its important electronic properties and potential for device applications. We have already obtained some high quality Si/Ge superlattices and heterostructures from our collaborators at UCLA. First we would like to investigate the local ordering around the constituent atoms and the effect of inverted structure in bilayer systems (e.g. $\text{Si}_{1-x}\text{Ge}_x$ on Ge versus Ge on $\text{Si}_{1-x}\text{Ge}_x$). This fundamental understanding is essential for controlling the appropriate growth conditions in making Si/Ge superlattices with improved interface quality. After this experiment, we will perform x-ray fluorescence and scattering measurements on $\text{Si}_{1-x}\text{Ge}_x/\text{Ge}$ and $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$ superlattices (with different values of x) to probe the microstructures at the buried interfaces. The basic physics and techniques have already been worked out in our previous studies, hence there should be no difficulty for us to produce some significant results. Since all the electronic and optical properties of the superlattices are closely related to the interfacial structures, we view this as an important experimental program, and our group is in a rather unique position to pursue this study.

We also would like to carry out EXAFS studies of diluted magnetic semiconductors with magnetic impurities in III-V compounds (e.g. Mn in InAs, Fe in InAs and InP made by epitaxial growth). The magnetic semiconductors exhibit special physical properties and could be very important for the development of new opto-electronic devices in the future. The EXAFS technique is especially useful for probing the location and short-range-order structure around the magnetic impurities. This fundamental knowledge is essential for understanding the magnetic and opto-electronic properties of this important class of new electronic material and for the design of devices.

Some physical properties of high- T_c superconductors, including transport and magnetic properties, will also be investigated mainly for the purpose of material characterization and to study the correlations between the microstructures probed by our synchrotron radiation experiments and the superconducting behavior.

III. SUPPORT OF GRADUATE STUDENTS AND POST-DOC

At the present, three graduate students working on their Ph.D. theses research and a senior post-doc are partially supported by this grant. Two students Jack Soo and Z.H. Ming (in their third year of graduate study) are stationed at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. Dr. A. Krol (a senior post-doc) and another graduate student and the principal investigator are commuting between NSLS and Buffalo.

IV. OTHER SUPPORTS

Effective October 1, 1991, this research program on x-ray studies of microstructures in semiconductors and superconducting materials will be supported solely by the present DOE grant. In the past, we have also been supported in part by AFOSR and ONR, unfortunately they have terminated our funding due to budget crisis (and also the excuses being that we are currently supported by DOE).

Our SUNY synchrotron beamline (X3) at the National Synchrotron Light Source is currently supported by a separate DOE grant for maintaining the beamline and instrumentation. No support on scientific research can be drawn from this "beamline grant".

V. PUBLICATIONS BY Y.H. KAO (PRINCIPAL INVESTIGATOR) IN THE PRESENT REPORT-PERIOD

a) Published:

1. "Total-Electron-Yield of Synthetic Layered Structures with Interfacial Roughness" (with A. Krol and C.J. Sher) Phys. Rev. B42 (1990) 3829.
2. "X-ray Absorption Studies of Y-Ba-Cu-O and Bi-Sr-Ca-Cu-O Films at Oxygen K-Edge by Means of Fluorescence and Total Electron Yield: A Comparison of Two Techniques" (with A. Krol, C.S. Lin, Z.H. Ming, C.J. Sher, C.T. Chen, F. Sette, Y. Ma, G.C. Smith, Y.Z. Zhu, and D.T. Shaw) Phys. Rev. B42 (1990) 2635.
3. "X-ray Absorption Studies of Nd-Ce-Cu-O" (with A. Krol, C.S. Lin, Z.H. Ming, C.J. Sher, C.L. Lin, S.L. Qiu, J. Chen, J.M. Tranquada, M. Strongin, G.C. Smith, Y. Ma, F. Sette, C.T. Chen, Y.K. Tao, R.L. Meng, P.H. Hor, C.W. Chu, G. Gao, and J.E. Crow) Phys. Rev. B42 (1990) 4763.
4. "Soft X-Ray Investigation of the Effect of Growth Conditions on InAs/GaAs Heterostructures" (with A. Krol, C.J. Sher, D. Storch, S.C. Woronick, L.L. Chang and H. Munekata) Surface Science 228 (1990) 108.
5. "Investigation of Interfacial Roughness of InGaAs Epitaxial Layers on GaAs and InP Substrates by Soft X-ray Reflectivity" (with A. Krol, H. Resat, C.J. Sher, S.C. Woronick, W. Ng, T.L. Cole, A.K. Green, C.K. Lowe-Ma, T.W. Nee, and V. Rehn) J. Appl. Phys. 69 (1991) 949.
6. "Superconducting and Normal State Properties of BiSrCaCuO with Ag and Pb Doping" (with Y.D. Yao, Y.Y. Chen, J.H. Chen and C.L. Liu) Prog. in High Temp. Superconductivity 19 (1990) 249.
7. "Magnetic Field Dependence of Critical Current Density in Silver-Doped Y-Ba-Cu-O Superconductors" (with L.W. Song) Proc. Third Annual Conf. on Superconductivity and Applications, Buffalo, p. 363.
8. "Studies of Microstructures in High-Tc Superconductors by X-ray Absorption Techniques" (with A. Krol, C.J. Sher, Z.H. Ming, C.S. Lin, L.W. Song, G.C. Smith, Y.Z. Zhu, and D.T. Shaw) Proc. Third Annual Conf. on Superconductivity and Applications, Buffalo, p. 281.
9. "A Low Pressure, Parallel Plate Avalanche Chamber for Detection of Soft X-ray Fluorescence" (with G.C. Smith and A. Krol) Nucl. Instr. and Meth. A291 (1990) 135.

10. "Oxygen Content Variation in Cation-Deficient and Chemically-Doped High-Tc Y-Ba-Cu-O and Bi-Sr-Ca-Cu-O Superconductors" (with L.W. Song, Y.D. Yao, Z. Tao, and K.W. Jones) Mat. Res. Soc. Symp. Proc. 169 (1990) 213.
11. "Soft X-ray Studies of Y-Ba-Cu-O Thin Films Prepared by Laser Ablation" (with A. Krol, G.C. Smith, C.J. Sher, D. Storch, L.W. Song, S. Witanachchi, Y.Z. Zhu, S. Patel, and D.T. Shaw) Mat. Res. Soc. Symp. Proc. 169 (1990) 505.
12. "Critical Current Density of Narrow Superconducting Thin Films Prepared by Laser Ablation Techniques" (with L.W. Song, Q.Y. Ying, J.P. Zheng, H.S. Kwok, Y.Z. Zhu, and D.T. Shaw) Mat. Res. Soc. Symp. Proc. 169 (1990) 89.
13. "Superconducting Y-Ba-Cu-O Films on Metallic Substrates Using In-Situ Laser Deposition" (with E. Narumi, L.W. Song, S. Patel, and D.T. Shaw) Appl. Phys. Lett. 56 (1990) 2684.
14. "Critical Current Density of Ag-Doped Y-Ba-Cu-O Superconductors in Low Magnetic Fields" (with L.W. Song) Physica C169 (1990) 107.
15. "Critical Current Enhancement in Multilayered Y-Ba-Cu-O/Y-Ba-(Cu-Ni)-O Structures" (with S. Witanachchi, S.Y. Lee, L.W. Song and D.T. Shaw) Appl. Phys. Lett. 57 (1990) 2133.
16. "Characterization of SiO₂/Si Heterostructures by Soft X-ray Reflection" (with S.C. Woronick, W. Ng, A. Krol, and E. Arnold, J. Appl. Phys. 69 (1991) 1631.
17. "Superconducting Tapes with Critical Current Density of 10⁴A/cm² at 77K and Zero Magnetic Field" (with E. Narumi, L.W. Song, S. Hwa, J. Ye, F. Yang, S. Patel, D.T. Shaw, and J.E. Tkaczyk) IEEE Trans. on MAG. MAG-27 (1991) 1648.
18. "Transport Properties of Silver-Doped Y-Ba-Cu-O Thin Films" (with L.W. Song, E. Narumi, F. Yang, D.T. Shaw, and H.M. Shao), J. Appl. Phys. 69 (1991) 1538.
19. "Fabrication of High-Tc Superconducting Composite Structures" (with J. Chang, L.W. Song, R. Barone, P. Bush, F. Yang, and D.T. Shaw) Mat. Res. Soc. Symp. Proc. 169 (1990) 1227.
20. "Oxygen 1s X-ray Absorption Spectroscopy of Tl₂Ba₂Ca₂Cu₃O₁₀ High-T_c Superconductors" (with A. Krol, C.S. Lin, Y.L. Soc, Z.H. Ming, Y. Ma, C.T. Chen, F. Sette, J.H. Wang, M. Qi, and G.C. Smith) Proc. Fourth Annual Conf. on Superconductivity and Applications, Buffalo, (1990), p. 206.
21. "Transport Measurements of YBa₂(Cu_{0.98}M_{0.02})₃O_y (M=Fe, Co, Ni) Superconducting Thin Films" (with L.W. Song, E. Narumi,

F. Yang, H.M. Shao, and D.T. Shaw), Proc. Fourth Annual Conf. on Superconductivity and Applications, Buffalo, (1990), p. 391.

22. "Critical Current Density Enhancement in $\text{YBa}_2\text{Cu}_3\text{O}_{6.8}$ Films on Buffered Metallic Substrates" (with E. Narumi, L.W. Song, F. Yang, S. Patel, and D.T. Shaw) Appl. Phys. Lett. 58 (1991) 1202.
23. "Transport Properties of $\text{YBa}_2(\text{Cu}_{0.98}\text{M}_{0.02})_3\text{O}_y$ (M=Fe, Co, Ni) Superconducting Thin Films" (with L.W. Song, E. Narumi, F. Yang, H.M. Shao, and D.T. Shaw), Physica C174 (1991) 303.
24. "Electronic States in La-Sr-Cu-O Probed by Soft-X-ray Absorption" (with C.T. Chen, F. Sette, Y. Ma, M.S. Hybertsen, E.B. Stechel, W.M. Foulkes, M. Schluter, S.W. Cheong, A.S. Cooper, L.W. Rupp, Jr., B. Batlogg, Y.L. Soo, Z.H. Ming, A. Krol) Phys. Rev. Lett. 66 (1991) 104.

b) Accepted:

1. "X-ray Refractive Index of Silicon in the Range 400 to 1100 eV" (with S.C. Woronick, W. Ng, and A. Krol), J. Phys. Chem. Solids, in press.
2. "Local Structure Around Mn Impurities in InMnAs/InAs Diluted Magnetic Semiconductors" (with A. Krol, Z.H. Ming, C.S. Lin, Y.L. Soo, C.X. Gu, H. Munekata, and L.L. Chang) Mat. Res. Soc. Symp. Proc. (Symp. B, 1990), in press.
3. "Flux-Flow Noise in Type-II Superconductors" (with W.J. Yeh), Phys. Rev., in press.
4. "Microstructures in Y-Ba-Cu-O Thin Films Investigated by XAFS Techniques" (with A. Krol, Z.H. Ming, C.S. Lin, Y.L. Soo, C.X. Gu, E. Narumi, D.T. Shaw, and G.C. Smith), Mat. Res. Soc. Symp. Proc. (1990), in press.
5. "Short Range Order Structures in Y-Pr-Ba-Cu-O System Studied by X-ray Absorption Fine Structure (XAFS) Techniques" (with A. Krol, Z.H. Ming, C.S. Lin, Y.L. Soo, C.X. Gu, I.S. Yang, and C.C. Tsuei), Mat. Res. Soc. Symp. Proc. (1990), in press.
6. "Y-Ba-Cu-O Thin Films on Amorphous Silicate Glasses Using In-Situ Laser Deposition" (with E. Narumi, L.W. Song, C. Li, S. Patel, D.T. Shaw, S. Shue, and K. Fujino) Jap. J. Appl. Phys., in press.
7. "Studies of Chemical Doping in High-Tc Superconductors", Proc. Miami Workshop on Electronic Structure and Mechanisms for High Temperature Superconductivity (Jan. 3-9, 1991), in press.

VI. A BRIEF SUMMARY

Several experiments on the study of microstructures in semiconductors and high temperature superconductors have been performed successfully during this report-period. The new soft x-ray detector developed by this research group has been utilized to pursue systematic studies of the local electronic structure around the oxygen atoms in the oxide superconductors using x-ray absorption spectroscopy techniques. Further experiments along this direction of approach are in progress. X-ray scattering and fluorescence techniques, some first developed by this research group, are used to continue the on-going investigations of layered materials, especially semiconductor superlattices and heterostructures, as well as thin films and multilayers of high- T_c superconductors. These experiments have produced some significant results on the interfacial roughness in various systems. More EXAFS measurements are in progress to investigate the local structural distortion and instability around the constituent and impurity atoms in chemically-doped new semiconductors and high- T_c superconductors. Some physical properties of new superconducting materials made by laser ablation techniques are also studied.

Three graduate students and a senior post-doc are currently supported in part by the present DOE grant.

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