Midwest Superconductivity Consortium

1991 Progress Report

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ABSTRACT

The Midwest Superconductivity Consortium's, MISCON, mission is to advance the science and understanding of high T_c superconductivity. Programmatic research focuses upon key materials-related problems: synthesis and processing; and limiting features in transport phenomena. During the past year twenty-one projects produced over eighty-seven (87) talks and seventy-two (72) publications.

Key achievements this past year expand our understanding of processing phenomena relating to crystallization and texture, metal superconductor composites, and modulated microstructures. Further noteworthy accomplishments include calculations on 2-D superconductor insulator transition, prediction of flux line lattice melting, and an expansion of our understanding and use of microwave phenomena as related to superconductors.

PROGRAM SUMMARY

The Midwest Superconductivity Consortium, MISCON, in the second year of operations has further developed its mission to advance the science and understanding of high T_c superconductivity. The goals of the organization were modified to reflect the current state of knowledge in the field and the unique capabilities of the institutions involved. An emphasis on group efforts was strengthened and the foundations for industrial involvement coupled with technology transfer were instituted. Activities of the participants during the past year illustrate an interactive and high level of performance.

The programmatic research continues to focus upon key materials-related problems in two areas. The first area has a focus upon Synthesis and Processing while the second is centered around limiting features in Transport Properties of High T_c Materials. The two areas involve twenty-one (21) research projects and thirty-three (33) senior participants. These participants have published forty-nine (49) papers and have submitted twenty-three (23) more in the past year. Further, the participants have given over eighty-seven (87) talks or conference presentations this past year.

Group activities and interactions with others were again a major strength of the operation. MISCON group meetings were held in January and August. A two day schedule for each meeting provided ample opportunity for the desired interactions to take place. Based upon these meetings the Program Committee reviewed the goals and programmatic research. A revision of each was instituted to provide the framework for the new focus of the program. Coupled with the group meetings the participants were very active in cooperative interactions with other organizations. Among these activities were eleven (11) external speakers, twelve (12) collaborations on papers/abstracts, twelve (12) collaborations on facilities use, twenty (20) exchanges of samples and/or measurements, and four (4) gifts of equipment from industry.

To further enhance the group activities, some new programs were established. First, a new Information/Seminar Exchange was established to promote interaction within and between the groups. Second, a Programmatic Exchange was initiated to facilitate the use of special capabilities by all participants. Finally, a special capital equipment competition was held with group needs as the primary need requirement. Cost sharing was a key issue and over \$400K worth of equipment was obtained with less than \$200K of MISCON funds.

The formalization of the industrial program has been initiated. The extensive nature of the interactions made it important that a more formal structure be implemented. Primary reasons for inaugurating this program was to make all participants aware of these activities and to provide a mechanism for efficient flow of information to enable any technology transfer possible.

RESEARCH PROGRAM THRUSTS

MISSION: The basic mission of the Consortium is to advance the science and understanding of high- T_c superconductivity and to promote the development of new materials and improved processing technology for commercialization of superconductivity.

GOALS: The goals of the Consortium are:

- (a) to develop, utilizing effective group efforts, the scientific and technological foundation for the industrial applications and commercialization of high-temperature superconductivity;
- (b) to facilitate the transfer of technology from the Consortium research laboratories into the industries of the Midwest; and
- (c) to ensure that there is a continuing supply of engineers and scientists trained in this important field.

PROGRAMMATIC RESEARCH: To achieve some of the goals and in response to the mission of the Consortium, two general research programs have been defined. These two areas were selected from many possible ones to focus upon key materials-related problems where unique capabilities exist within the Consortium. Cooperative research programs in the following programmatic areas are supported. In addition, the Consortium encourages proposals for studies of new materials which can be expected to exhibit useful high-temperature superconductivity.

Area 1: High-Temperature Superconducting Materials: Phase Relations, Reactions, Synthesis and Processing

The development of high-temperature superconductors is contingent upon a thorough understanding of their material properties and of the processing variables to control these properties. Such properties include both thermodynamic and kinetic information about superconducting and normal-state phases. Processing variables encompass those necessary for the formulation of optimal synthesis and processing procedures to control the material properties. The Consortium supports investigation of these topics, as well as studies pertaining to the fabrication and characterization of

high-temperature superconducting composites, multilayers, modulated structures, thin films, and other novel structures of potential usefulness.

Area 2: Transport Properties of High-Temperature Superconductors: Optimization of Critical Currents, Magnetic Screening, Dynamical Behavior and Other Limiting Factors

Most proposed applications of high-temperature superconductors involve their ability to carry bulk supercurrents (e.g., wires, ribbons), to screen magnetic fields (e.g., enclosures, cavities), or to be components of electronic devices (e.g., sensors, magnetometers). All of these applications are contingent upon an understanding and control of transport properties. The Consortium supports research in this general area, including studies of weak links (both artificially produced, and naturally occurring, as by defects, grain boundaries and textures); dynamics (flux lattice pinning, melting, and related phenomena); and interfacial transport (such as that between grains, films, contacts, substrates, and coatings).

SELECTED RESEARCH HIGHLIGHTS

The following are selected research accomplishments by MISCON participants in the past year. These achievements provide an insight into some of the new and exciting areas of research in progress by MISCON participants.

Crystallization of High Temperature Superconducting Filaments

A. I. Goldman, D. K. Finnemore, and L. S. Chumbley

Iowa State University

High temperature x-ray studies of the melting of $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_{8-\delta}/\text{Ag}$ composites have been used to select precipitates that can be used as pinning centers for high performance conductors. The melting always takes place with the sequential formation of 3 distinct solid phases in equilibrium with the liquid, $(\text{Sr,Ca})_1\text{Cu}_1\text{O}_2$, $(\text{Sr,Ca})_2\text{Cu}_1\text{O}_3$, and $(\text{Sr,Ca})\text{O}$. By controlling the temperature, the oxygen partial pressure, the dispersion of Ag and the amount of excess Bi, the nucleation and growth rates of these phases. This is the first step in understanding the melt-texture processing of these composites for high performance magnet conductor.

Crystallization of $\text{REBa}_2\text{Cu}_3\text{O}_{7-x}$ High Temperature Superconducting Materials from the Solidified Melt

R. W. McCallum, M. J. Kramer, L. S. Chumbley, and T. J. Folkerts

Iowa State University

Using a novel melt-spinning technique, we have been able to produce oxide glasses of $\text{REBa}_2\text{Cu}_3\text{O}_{7-x}$ (RE123) for RE=Nd, Gd when operating in a reduced oxygen partial pressure. By increasing the partial pressure of oxygen, the melt-spun material forms 5-10 nm grains of tetragonal RE123. The recrystallization of the amorphous glass has been studied using high temperature x-ray diffraction. The materials were found to recrystallize directly to the tetragonal RE123 structure upon heating to 700°C-800°C in oxygen. By controlling the nucleation from the amorphous state, we can better control the subsequent microstructure. Y123 has not been produced with an amorphous structure. These differences in microstructure have been modeled in terms of the liquidus temperature as a function of RE and oxygen partial pressure. This melt-spin technique produces samples with a more uniform dispersion of elements than can be obtained with more conventional melt processing techniques. The highly disordered nature of these melt-spun materials should reduce and disperse secondary phases in the

recrystallized RE123. This is an important step toward producing technologically useful bulk material with large critical currents.

*Microstructural Dependence of Critical Current Density in Melt Textured
YBa₂Cu₃O_{6+x} Superconductors*

P. J. McGinn

University of Notre Dame

Additions of BaSnO₃ to YBCO have been found to markedly improve the magnetization properties over similarly textured YBCO wires in low fields. Magnetic critical current densities (J_c) in excess of 1.2×10^5 A/cm² in zero field, and 3.0×10^4 A/cm² at 1 T have been observed.

Annealing studies on textured YBCO wires indicate that high temperature annealing degrades the properties, including J_c of the wires.

*Study of Compositional Modulation in High-Temperature Superconductor Structures
and Its Influence on Their Superconducting Properties*

K. M. Choudhary and S. T. Ruggiero

University of Notre Dame

Epitaxial Dy₁Ba₂Cu₃O_{7- δ} (001) thin films showing 90K critical transition temperature have been prepared by molecular beam deposition. Dy, BaF₂ and Cu in 1:2:3 ratio were coevaporated from effusion cells in presence of molecular oxygen. The epitaxy was achieved for the first time after post-annealing. The Dy_{1.3}Ba_{1.7}Cu₃O_{7- δ} (001) thin films show superconductivity at 53K. Epitaxial NdMnO₃(100) thin films have been prepared for the first time by molecular beam deposition and post-annealing. NdMnO₃ has a perovskite-type cubic unit cell ($a_0 = 3.80$ Å) and it is ideally suited for making Dy₁Ba₂Cu₃O_{7- δ} (001)/NdMnO₃(100) superlattices.

High T_c Superconducting Composites/Films

J. C. Garland

The Ohio State University

We have developed a bulk superconducting composite material which combines the mechanical advantages of normal metals, i.e., high thermal conductivity, machinability and low normal state resistivity, with the superconducting properties of high T_c oxide superconductors. The composite is made by a powder metallurgy process in which a random matrix of silver metal is intermixed with a fused "skeleton" of yttrium barium copper oxide. Transport requirements have shown that the composite

is superconducting at 90K with as little as 16% volume fraction of superconductor. Since the composite may be readily machined, we believe that it is perfectly suitable for applications which do not require very high critical densities.

We have developed a novel method of making proximity-effect (S-N-S) Josephson junctions which involves a single continuous layer of 5- μm wide YBCO film overlaying an approximately 1 μm wide cross-strip of either silver or gold. The presence of the metal layer at the junction disturbs the c-axis alignment of the overlaying YBCO film, and possibly the oxygen stoichiometry, resulting in a locally depressed transition temperature. Typical junction critical currents are about 0.2mA at 60K.

Normal Properties, Magnetism, and Onset of Superconductivity in $\text{La}_{1-x}\text{Sr}_x\text{NiO}_{4+\delta}$ and $\text{La}_{2-x}\text{Cu}_y\text{Ni}_{1-y}\text{Sr}_x\text{NiO}_4$ Systems, and Real Space Pairing in High- T_c Systems

J. M. Honig

Purdue University

We have recently attempted to improve the superconducting characteristics of $\text{La}_2\text{CuO}_{4+\delta}$ and of $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ ceramics by fluorination. It was observed that the substitution of oxygen by fluorine was inhomogeneous; i.e., most of the fluorine was concentrated in the surface layers. Nevertheless penetration into the bulk was also achieved, as documented by observed changes in lattice parameters. The effect was similar to that achieved by oxidizing the cuprate, thereby rendering $\text{La}_2\text{CuO}_{4+\delta}$ nonstoichiometric; the nonstoichiometric material then becomes superconducting. Similar results prevail when fluorination is carried out. Superconducting temperatures as high as 39 K have been encountered.

Study of Naturally Modulated High T_c Superconducting Compounds

H. Sato

Purdue University

A new type of twin is found to exist in the $n=2$ type superconductors in the Bi-Sr-Ca-Cu-O system obtained by annealing from amorphous precursors. The twin plane is (015) if the period of the incommensurate modulation in the b-direction is disregarded. Because the structure has an incommensurate modulation in the b-direction with the period $b = 5b_0$, features of discommensuration are observed in the twin plane. High resolution, structural images with respect to fine structures of the boundary are successfully obtained. This is the first observation of twins in which detailed features of incommensurate structure are involved.

Quantum Effects in Quasi-Two-Dimensional Superconductors

A. H. MacDonald and S. M. Girvin

Indiana University

We have clarified the relationship between the superconducting mixed state and magnetic field strength. When the magnetic field is treated quantum-mechanically superconductivity can persist to arbitrarily strong magnetic fields.

We have solved the microscopic mean-field equations for the vortex-lattice state in magnetic fields of arbitrary strength.

We have performed the first Monte Carlo calculation of the universal conductivity at the two-dimensional superconductor-insulator transition in a model of interacting bosons which includes both disorder and long-range Coulomb interactions. We find that Coulomb interactions significantly change the universality class and yield $(\sigma^* \sim 0.8 \pm 0.3)(2e)^2/h$ in reasonable agreement with current experimental estimates of the value in thin high- T_c films.

Thermally Activated Flux Motion and Anisotropy in High-Temperature Superconductors

J. R. Clem and V. G. Kogan

Iowa State University

We have theoretically examined the melting temperature of T_m of the flux-line lattice in an anisotropic superconductor and have predicted the dependence of T_m upon the field orientation relative to the crystal. The prediction that the angular dependence is controlled in a simple way by the superconducting mass anisotropy has been verified experimentally in low-frequency torsional oscillator experiments performed in Professor David E. Farrell's group at Case Western Reserve University, Cleveland. A preprint describing this work (R. G. Beck et al.) has been submitted to Physical Review Letters.

The graph shows the theoretical prediction (the solid curve) superimposed on the data points for T_m versus the angle between the external field (2 T) and the c axis of a twin-free $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ single crystal. No adjustable parameters have been used in this plot.

*Microwave Dissipation in High Temperature Superconductors: Flux-Lattice Dynamics,
Crystal Anisotropy, and Flux Pinning*

H. A. Blackstead

University of Notre Dame

Using a contact-less microwave technique, with an applied magnetic field varying to a maximum of 1.9T, we have observed flux-flow and phase-slip resistivity in a microsyntactically intergrown two phase Pb doped superconducting Bi-Sr-Ca-Cu-O of nominal composition $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_{1.7}\text{Ca}_2\text{Cu}_3\text{O}_x$. The onset temperature for the high temperature phase is 106.5 K, while the lower temperature phase manifests itself at 71K. Flux-flow is observed superimposed on an isotropic background phase-slip resistivity, and is locally maximal several degrees below each transition temperature. Flux-flow resistivity, a consequence of the Lorentz force on a fluxoid, varies as $\sin^2(\phi)$, where ϕ is the angle between the applied magnetic field and the rf current. The fit to the experimental data, was achieved with relatively small error, even though the sample was polycrystalline. The measurements revealed the relative concentrations of the two phases.

Far Infrared and Microwave Magneto-Dissipation in High T_c Superconductors

W. J. Tomasch and J. K. Furdyna

University of Notre Dame

We have developed a leaderless nondestructive microwave technique for evaluating high temperature superconductors. The method utilizes the transmission and reflection of mm microwaves and yields both the surface resistance and surface reactance.

Microwave reflection and transmission measurements have been employed to demonstrate magneto-reflection and magneto-transmission effects in a 1800 angstrom thick YBCO(123) film.

Comparisons of our microwave data with predictions of a recent theory, developed by MISCON scientists at Iowa State University (Mark W. Coffey and John R. Clem), are expected to yield valuable quantitative information regarding flux pinning at microwave frequencies in high temperature superconductors.

Our microwave and far-infrared transmission data ($H=0$) both suggest the occurrence of paraconductivity (fluctuation superconductivity) for approximately five degrees kelvin above the transition temperature.

Measurement of the Bernoulli Potential in $Y_1Ba_2Cu_3O_{7-\delta}$ and $Y_1Ba_2Cu_4O_x$ Films

Thomas R. Lemberger

The Ohio State University

We measured the Bernoulli voltage V_B and kinetic inductance L_k for the same high quality $YBa_2Cu_3O_{7-\delta}$ film. The film has a critical current density J_c more than $2 \times 10^6 A/cm^2$ at 4.2K with the sample dimension, $w \times d \times l = 90 \mu m \times 1000 \text{ \AA} \times 17 \text{ cm}$.

The measurement of V_B shows the reproducibility of our previous measurement of V_B , even with a different counter-electrode geometry: the sign of V_B is positive, and V_B is about 5nV at $J=10^6 A/cm^2$ and $T=4.2K$. Previously V_B was about 6nV with positive sign.

Neutron Diffraction and Defect Studies of High T_c Superconductors

W. B. Yelon and J. W. Farmer

University of Missouri-Columbia

Verification of the high quality of the single crystals of $YBa_2Cu_3O_7$ grown at MURR ($300,000 A/cm^2$ critical current at 4000 Oe at 30 K) was completed.

The effect of Zn, Ni, Ga and mixed doping on the structure of $YBa_2Cu_3O_7$ has been determined by neutron diffraction and will be correlated to the changes in electrical properties (T_c , J_c , etc.).

Intrinsic and Induced Weak Link Behavior in $YBa_2Cu_3O_{7-\delta}$ Films

M. W. McElfresh and R. G. Reifenberger

Purdue University

YBCO epitaxial thin films with superconducting transition temperatures as high as 92 K are being routinely produced in our Pulsed Laser Deposition (PLD) system. Samples on bicrystal boundaries and on substrates with ion-milled step edges, in order to produce isolated grain boundary superconducting weak links, are being prepared in collaboration with Steve Ruggiero of Notre Dame University and James Garland of Ohio State University.

We have shown that the topography of YBCO thin films can account for the extraordinary critical current densities ($>10^7 A/cm^2$) routinely observed in these materials. Screw dislocations are effective pinning sites at low magnetic fields (<0.25 kOe) while the weaker pinning at surface growth steps can still give large pinning strengths up to very high fields.

TALKS and PRESENTATIONS

1. "Superconductivity in Very Strong Magnetic Fields", **A. H. MacDonald**, University of British Columbia, December 4, 1991.
2. "Universal Conductivity of Dirty Bosons in Two Dimensions", **S. M. Girvin**, March APS Meeting, Indianapolis, IN, March, 1992.
3. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensions", **S. M. Girvin**, Nobel 90th Jubilee Symposium, Goteborg, Sweden, December 5, 1991.
4. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensions", **S. M. Girvin**, Midwest Solid State Theory Symposium, E. Lansing, MI, October 7, 1991.
5. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensions", **S. M. Girvin**, 1991 Yukawa Int. Seminar on Low-Dimensional Field Theories and Condensed Matter Physics, Kyoto, Japan, July 31, 1991.
6. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensions", **S. M. Girvin**, Winter School on "Anyons, Fractional Statistics and 2D Magnetism," ICCMP, Brasilia, Brazil, July 8-19, 1991.
7. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensions", **S. M. Girvin**, Gordon Research Conf., Brewster Academy, Wolfeboro, NH, June 12, 1991.
8. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensional Films", **S. M. Girvin**, Argonne National Lab, Argonne, IL, May 7, 1991.
9. "Universal Conductivity at the Superconductor-Insulator Transition in Two Dimensional Films", **S. M. Girvin**, NORDITA, Copenhagen, Denmark, May 17, 1991.
10. "Universal Conductivity of Dirty Bosons", M. Wallin, **S. M. Girvin**, E. S. Sorensen, and A. Peter Young, March APS Meeting, Indianapolis, IN, March, 1992.
11. "Universal Properties of the Superconductor to Insulator Transition in 2D Charged Boson Films", E. S. Sorensen, A. P. Young, M. Wallin, and **S. M. Girvin**, March APS Meeting, Indianapolis, IN, March, 1992.
12. "Universal Conductivity of 2D Films at the Field-Tuned Superconductor-Insulator Transition", M. Cha, M. Wallin, and **S. M. Girvin**, March APS Meeting, Indianapolis, IN, March, 1992.
13. "Vortex Lattices in Superconducting Films", D. P. Arovas, K. Mullen, **S. M. Girvin** and **A. H. MacDonald**, March APS Meeting, Indianapolis, IN, March, 1992.
14. "Critical Currents for Vortex Depinning in the Presence of Line and Point Defects", **D. Stroud**, K. H. Lee, and **S. M. Girvin**, March APS Meeting, Indianapolis, IN, March, 1992.
15. "Exact Mean Field Solutions for Flux Lattice States", M. R. Norman, H. Aker, **A. H. MacDonald**, March APS Meeting, Indianapolis, IN, March, 1992.

16. "Universal Properties of the 2D Superconductor-Insulator Transition", **S.M. Girvin**, Brown University, Nov. 15, 1991.
17. "Quantum fluctuations in 2D Superconductors", **S.M. Girvin**, Condensed Matter Physics Gordon Conference, Brewster Academy, June 13, 1991.
18. "Universal Conductivity at the 2D Superconductor-Insulator Critical Point", Min-Chul Cha (**MacDonald, Girvin Group**)
 - a) Ohio State University, Feb. 1991.
 - b) University of Illinois, Urbana-Champaign, Feb. 1991.
 - c) University of Minnesota, Feb. 1991.
 - d) Boston University, March, 1991.
19. "Flux Lattice States at High Magnetic Fields", (given by our collaborator, M.R. Norman) at the Physics at High Magnetic Fields Conference, Florida State University, May 1991.
20. "Future Applications of Superconductivity", **D.K. Finnemore**, Student Awards Dinner Talk, Luther College, 23 April 1991.
21. "Melting and Freezing of Bi-Sr-Ca-Cu-O Compounds", **D.K. Finnemore**, 6th International Workshop on Critical Currents, Cambridge University, UK, July 11, 1991.
22. "Critical Fields in High Temperature Superconductors", **D.K. Finnemore**, Advanced Studies Symposium, Los Alamos National Laboratory, August 22, 1991.
23. "Flux Pinning and Critical Currents in Superconductor-Normal Metal Composites", **D.K. Finnemore**, Tokai University 4th International Conference on Superconductivity, Tokai University, Honolulu, Hawaii, October 10, 1991.
24. "Strain Tolerant Superconductors", **D.K. Finnemore**, The Metallurgical Society (TMS) Spring Meeting, New Orleans, Feb. 19, 1991.
25. "Ideas and Applications of Superconductivity", **D.K. Finnemore**, Seminar, Carleton College, April 5, 1991.
26. "The Structure of Glassy Bi(2212)", J. Hammonds, Argonne National Laboratory, Jan. 1991.
27. "2D Pancake Vortices and Josephson Strings", **J. R. Clem**, IBM Thomas J. Watson Research Center, Yorktown Heights, New York, April 15, 1991.
28. "General Theories of the Magnetic Responses of Crystalline and Granular Superconductors", **J. R. Clem**, International Workshop on Magnetic Susceptibility of Superconductors and Other Spin Systems, Coolfont, Berkeley Springs, West Virginia, May 21, 1991.
29. "Fundamentals of Vortices in the High-Temperature Superconductors", **J. R. Clem**, Allied-Signal, Torrance, California, August 9, 1991.
30. "Magnetic Properties of the High-Temperature Superconductors", **J. R. Clem**, NATO Advanced Study Institute on Physics and Materials Science of High-Temperature Superconductors II, Porto Carras, Neos Marmaras, Halkidiki, Greece, August 20, 1991.

31. "Magnetic Field Dependence of ac Permeability and rf Surface Impedance in Type-II Superconductors", **J. R. Clem**, Physics Seminar, University of Neuchatel, Neuchatel, Switzerland, October 14, 1991.
32. "Phenomenology of Conventional and High- T_c Superconductors: An Overview", **J. R. Clem**, Fifteenth Gwatt Workshop, Gwatt, Switzerland, October 17, 1991.
33. "A Survey of Some Recent Experimental and Theoretical Results on Critical Currents in the High-Temperature Superconductors", **J. R. Clem**, Electric Power Research Institute, Palo Alto, California, October 29, 1991.
34. "Phenomenological Theories of the Anisotropic Vortex Structure in High-Temperature Superconductors", **J. R. Clem**, Materials Research Society Fall 1991 Meeting, Boston, Massachusetts, December 2, 1991.
35. "Phenomenology of the Electrodynamical Properties of the High-Temperature Superconductors: Anisotropy, Intragranular Properties, and Intergranular Weak-Link Effects", **J. R. Clem**, Conference on High- T_c Superconductivity (three lectures), International Centre of Condensed Matter Physics, Universidade de Brasilia, Brazil, December 5 and 6, 1991.
36. "Two-Dimensional Pancake Vortices, Josephson Strings, and Their Roles in the High-Temperature Superconductors", **J. R. Clem**, Condensed Matter Physics Seminar, Indiana University, Bloomington, Indiana, December 13, 1991.
37. "Vortices in Layered Superconductors with Josephson Coupling", **V. G. Kogan**, Conference on Superconductivity with Applications, New York State Institute on Superconductivity, Buffalo, New York, September 24-26, 1991.
38. "Vortices and Flux-Line Lattices in Anisotropic Superconductors", **V. G. Kogan**, University of California, San Diego, CA, December 18, 1991.
39. "Line Energies of Josephson Strings Connecting 2D Pancake Vortices in a Josephson-Coupled-Layer Model of Highly Anisotropic High-Temperature Superconductors", **J. R. Clem**, American Physical Society March Meeting, Cincinnati, OH, March 20, 1991.
40. "Reversible Magnetization and Torques in Anisotropic High- k Type-II Superconductors", Z. Hao and **J. R. Clem**, American Physical Society March Meeting, Cincinnati, Ohio, March 22, 1991.
41. "Magnetic Properties of a $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ Single Crystal Below T_c ", J. H. Cho, Z. Hao, D. C. Johnston, and **J. R. Clem**, American Physical Society March Meeting, Cincinnati, Ohio, March 22, 1991.
42. "Flux-Line Lattices of Highly Anisotropic Superconductors in Small Fields", L. J. Campbell, L. Daemen, and **V. G. Kogan**, American Physical Society March Meeting, Cincinnati, Ohio, March 22, 1991.
43. "A Scaling Property in the Reversible Magnetization of Anisotropic High- k Type-II Superconductors", Z. Hao and **J. R. Clem**, Materials and Mechanisms of Superconductivity - High-Temperature Superconductivity III, Kanazawa, Japan, July 25, 1991.
44. "Radio Frequency Surface Impedance of Type-II Superconductors: Dependence Upon The Magnitude and Angle of an Applied Static Magnetic Field", **J. R. Clem** and M. W. Coffey, Materials and Mechanisms of Superconductivity - High-Temperature Superconductivity III, Kanazawa, Japan, July 25, 1991.

45. "Line Energies of Josephson Strings Connecting 2D Pancake Vortices in a Josephson-Coupled-Layer Model of Highly Anisotropic High-Temperature Superconductors", **John R. Clem**, March Meeting of the American Physical Society, Cincinnati, OH, March 20, 1991, Bull. Am. Phys. Soc., 36, 775 (1991).
46. "Recrystallization of Rapidly Quenched and $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ ", **R.W. McCallum**, presented at the Spring MRS Meeting in Anaheim, CA, May 2, 1991.
47. "Grain Boundaries in Highly Textured Ceramic Superconductors Crystallized from an Amorphous Precursor", **R.W. McCallum**, presented at the Spring MRS Meeting in Anaheim, CA, May 2, 1991.
48. "Flux Creep and Pinning Potential in Zone Melted $\text{YBa}_2\text{Cu}_3\text{O}_x$ ", D. Shi, K. Goretta, J. Chen, S. Salem-Sugui, **P. McGinn**, W. Chen, and N. Zhu, TMS Annual Meeting, New Orleans, LA, February 1991.
49. "Zone Melt Texturing of $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ and Related Compounds", **P. McGinn**, Purdue University, March 12, 1991.
50. "Textured Microstructures in $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ and Related Compounds by Zone Melting", **P. McGinn**, W. Chen, N. Zhu, L. Tan, and S. Sengupta, American Ceramic Society Annual Meeting, Cincinnati, OH, April 1991.
51. "Effect of Y_2BaCuO_5 Phase Additions on the Magnetic Properties of $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ Textured Wires", **P. J. McGinn**, S. Sengupta, N. Zhu, W. Chen, and L. Tan, American Ceramic Society Annual Meeting, Cincinnati, OH, April 1991.
52. "Annealing Effects on the Critical Current Density of Zone Melt Textured $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ ", W. Chen, **P. J. McGinn**, S. Sengupta, N. Zhu, and L. Tan, American Ceramic Society Annual Meeting, Cincinnati, OH, April 1991.
53. "Microstructure Effects in Zone Melt Textured $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ with Y_2BaCuO_5 and BaSnO_3 Additions", **P. McGinn**, C. Varanasi, D. Balkin, W. Chen, and N. Zhu, Ceramic Superconductors Symposium, Electronics/Glass and Optical Materials Meeting of the American Ceramic Society, Arlington, VA, October 1991.
54. "Microstructure Effects in Zone Melt Textured $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ with Y_2BaCuO_5 and BaSnO_3 Additions", **P. McGinn**, C. Varanasi, D. Balkin, W. Chen, and N. Zhu, TMS Fall Meeting, Cincinnati, OH, October 1991.
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60. "Fluctuation Conductivity in Model Granular Superconductors in Zero and Strong Magnetic Fields: Glassy Behavior", Z.Q. Wang and **D. Stroud**, Bull. Am. Phys. Soc., 36, 517 (1991).
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67. "Studying Magnetic Properties with a Squid Magnetometer", **M. McElfresh**, Florida State University, Tallahassee, FL; June 1991.
68. "Correlation of Surface Topography and Flux Pinning in Superconducting YBaCuO Films", **M. McElfresh**, Los Alamos National Laboratory, Los Alamos, NM, September 1991.
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70. "New Directions with High T_c Superconductors", **M. McElfresh**, presented at International Society for Hybrid Microelectronics Meeting, Lafayette, IN, May 1991.
71. "Reversible and Irreversible Properties of High T_c Superconductors", **M. McElfresh**
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76. "Growth of $\text{Dy}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}$ (001) and $\text{Dy}_{1+x}\text{Ba}_{2-x}\text{Cu}_3\text{O}_6$ (001) High-Temperature Superconductor Thin Films by Molecular Beam Epitaxy", **Krishna M. Choudhary**, to be presented at the SC GLOBAL 92 - Fifth Annual International Superconductor Applications Convention, January 29-31, 1992, San Diego, CA.
77. "Landau Quantization and Superconductivity at High Magnetic Fields", M.R. Norman, H. Aker and **A.H. MacDonald**, invited talk "Physical Phenomena at High Magnetic Fields", Florida State University, May 15-18, 1991
78. "Synthesis of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Films from Metallo-Organic Precursors", C. Venkatraman, **G.L. Liedl**, **A.I. Schindler**, TMS - March 1992 in San Diego, CA.
79. "The Materials Science of YBCO Superconductors", **D. V. Baxter**, Seminar on Solid-State Chemistry/Solid-State Physics, Indiana University, December 17, 1991.
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15. "Interactions Between $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ and BaSnO_3 During Melt Texturing", **P. McGinn**, C. Varanasi, D. Balkin (submitted to Physica C, November 1991).

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Appendix I

1991 Cooperative Laboratory Interactions

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
SEMINARS AND GUEST SPEAKERS		
Dr. Stuart A. Wolf Office of Naval Research	Guest Speaker at Group Meetings	Purdue University
Dr. Robert Beyers IEM Almaden Research Center	Invited as Seminar Speaker	Purdue University
Dr. Sungho Jin AT&T Bell Laboratories	Guest Speaker at Group Meetings	Purdue University
Dr. Robert Cava AT&T Bell Laboratories	Invited as Seminar Speaker	Purdue University
Dr. Monisha Bose Bose Institute, Calcutta, India	Invited as Seminar Speaker	Purdue University
Dr. Sergio Zannella CISE, Milan, Italy	Invited as Seminar Speaker	Purdue University
A.P. Malozemoff American Superconductor Corporation	Guest Speaker at Group Meetings	Purdue University
Dr. Aharon Kapitulin Stanford University	Guest Speaker at Group Meetings	Purdue University
David G. Stroud The Ohio State University	Invited as Seminar Speaker	University of Notre Dame
M. Konczykowski Ecole Polytechnique, Palaiseau, France	Invited as Seminar Speaker	Purdue University

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ACTIVITY

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Valerii Vinokur Argonne National Laboratory	Invited as Seminar Speaker	Purdue University
M. Klausmeier Brown John R. Clem	Invited as Seminar Speaker Invited as Seminar Speaker	University of Notre Dame Indiana University

CO-OP EFFORTS/COLLABORATIONS

M. D. Lan & J. Z. Liu University of California - Davis	Collaboration on writing of a paper	H. A. Blackstead
M. D. Lan & J. Z. Liu University of California - Davis	Collaboration on writing of an abstract	H. A. Blackstead
M. D. Lan & J. Z. Liu University of California - Davis	Collaboration on writing of an abstract	W. J. Tomasch
C. C. Almasan & M. B. Maple University of California - San Diego	Collaboration on writing of a paper	J. C. Garland
Matthew P. A. Fisher IBM T.J. Watson Research Ctr.	Collaboration on writing of a paper	S. M. Girvin
R. A. Gleixner, J. Righi & D. Zeigler Babcock & Wilcox Research Center	Collaboration on writing of a paper	A. Goldman and D. Finnemore
A. Umezawa & G. W. Crabtree Argonne National Laboratory	Collaboration on writing of a paper	A. Goldman and D. Finnemore
R. E. Muenchausen, M. Hawley, S. R. Foltyn, and X. D. Wu Los Alamos National Laboratory	Collaboration on writing of a paper	M. McElfresh
J. G. Chen, Donglu Shi, & C. M. Wayman Argonne National Laboratory	Collaboration on writing of a paper	P. J. McGinn
T. E. Mitchell Los Alamos National Laboratory	Collaboration on writing of a paper	H. Sato
A. H. Cardona & L. C. Bourne Superconductor Technologies, Inc.	Collaboration on writing of an abstract	S. T. Ruggiero

COMPANY/CONTACT	ACTIVITY	MISCON	PI/LOCATION
E. A. Early, Y. Dalichaouch, M. C. De Andrade, R. F. Jardim, & M. B. Maple University of California - San Diego C. C. Almasan & M. B. Maple University of California - San Diego	Collaboration on writing of an abstract	J. C. Garland	
National Nanofabrication Facility Cornell University Ithaca, NY	Collaboration on magnetization measurements & exchange of samples	J. C. Garland	
Carlos A. R. Sa de Melo Argonne National Laboratory	Collaboration on using the facility to fabricate two-dimensional high-Tc Josephson junction arrays	J. C. Garland	
Dr. Ceber Simpson and Vito Mitkus Naval Avionics	Preliminary Collaboration on Research on Vortex Effective Mass	D. Stroud	
John P. Hammonds Argonne National Laboratory	Collaboration on high frequency applications	G. Liedl	
Mike Norman Argonne National Laboratory	Collaboration on glassy fiber studies at IPNS using neutron scattering	A. Goldman, D. Finnemore, & L. Chumbley	
J.R. Gaines Superconductive Components, Inc.	Collaboration on effects of YBCO superconductors & writing of papers	A. MacDonald	
J.R. Gaines Superconductive Components, Inc.	Collaboration on possible application of YBCO films	T. Lemberger	
	Collaborative research agreement involving sputter target fabrication	T. Lemberger & J. Garland	
SAMPLE EXCHANGE/COLLABORATE			
E. A. Early, Y. Dalichaouch, M. C. De Andrade, R. F. Jardim, & M. B. Maple University of California - San Diego	Exchange of Electron-doped SmCeCuO samples	J. C. Garland	
C. C. Almasan & M. B. Maple University of California - San Diego	Exchange of Ag/YBaCuO composite samples	J. C. Garland	

COMPANY/CONTACT	ACTIVITY	MISCON	PI/LOCATION
A. P. Malozemoff American Superconductor Corporation	Development of a theory for the magnetic field dependence of the critical current density of Bi-based high-temperature superconducting tapes	J. Clem & V. Kogan	
T. Miller & M. McElfresh Purdue University	Collaboration on Scanning Tunneling Microscope measurements & exchange of samples	J. C. Garland	
K. H. Lee & D. Stroud Ohio State University	Collaboration on developing a theory for the observed double-peaked resistive transition of SmCeCuO samples	J. C. Garland	
Lawrence Berkeley Laboratory	Sample/Collaboration on crystalline defects using the Atomic Resolution Microscope	W. McCallum, L. Chumbley, & M. Kramer	
Jeff Barner Bellcore	Samples and AC susceptibility measurements	W. Tomasch & J. Furdyna	
Steve Schwarzbek TRW	Samples/Collaboration	W. Tomasch & J. Furdyna	
Ross Muenchausen Los Alamos National Laboratory	Samples and paper	M. McElfresh	
D. Ginley Sandia National Laboratory	Samples of thallium films & crystals	H. A. Blackstead	
Doug Chrisey National Research Laboratory	Samples of Y123 films & Gd123 films	H. A. Blackstead	
Arun Inam Bellcore	Samples of thin films	W. Tomasch & J. Furdyna	
Eli Zeldov Leonardo Civalo	Collaborations involving sample exchange, data exchange, and joint papers	M. McElfresh	
Joe Bringley Fred Holtzberg	Collaborations involving sample exchange, data exchange, and joint papers	M. McElfresh	
Arunava Gupta IBM T.J. Watson Research Center	Collaborations involving sample exchange, data exchange, and joint papers	M. McElfresh	

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Stuart Parkin IBM Almaden Research Center	Collaborations involving sample exchange, data exchange, and joint papers	M. McElfresh
Kurt Fincher and Stan Tozer DuPont Central Research	Collaborations involving sample exchange, data exchange, and joint papers	M. McElfresh
A. Gupta IBM T.J. Watson Research Ctr. Quantum Design	Samples	M. McElfresh
	Collaborations involving data exchange and joint papers	M. McElfresh
General Electric Medical	Collaborations involving data exchange	M. McElfresh
GIFTS FROM INDUSTRY		
Amoco	Nicolet 200 NMR instrument	M. McElfresh
IBM T.J. Watson Research Center	Microscope for laser ablative patterning	M. McElfresh
IBM T.J. Watson Research Center	Oscilloscope, gaussmeter, frequency sources, plotter, provided design details & circuit board	M. McElfresh
General Motors	Scanning auger, laser patterning system	M. McElfresh
FOREIGN INTERACTIONS		
R. Rammal Centre de Recherches sur les Tres Basses Temperatures, France	Collaboration on writing of a paper	J. Clem
Z. X. Zhao Institute of Physics, Chinese Acad. of Sciences, China	Collaboration on writing of a paper	A. Goldman & D. Finnemore
P. M. Hui National Central University, Republic of China	Collaboration on writing of a paper	D. Stroud
A. Peter Young Service de Physique Theorique CEA, France	Collaboration on writing of a paper	A. MacDonald & S. Girvin

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Mats Wallin Umea University, Umea, Sweden	Collaboration on writing of a paper	A. MacDonald & S. Girvin
Dr. L.N. Boulaevskii Lebedev's Physical Institute, Moscow, USSR	Visiting Scientist	J. Clem & V. Kogan
Dr. J.J. Neumeiser & Dr. C. Algeier University of Munich, Munich, Germany	Collaboration	W. Yelon & J. Farmer
S. Tanaka & H. Yamauchi ISTEC, Japan	Collaboration	H. Sato
T. Onozuka, Y. Iwabuchi & T. Fukase Tohoku University, Sendai, Japan	Collaboration on writing of a paper	H. Sato
D. Shindo & M. Hirabayashi Tahoku University, Sendai, Japan	Collaboration on writing of a paper	H. Sato
K.S. Nanjundaswamy & C.N.R. Rao Indian Institute of Science, India	Collaboration on writing of a paper	J. Honig
G.H. Lander Karlsruhe Establishment, European Institute for Transuranium Elements, Germany	Visiting Researcher	J. Honig
F. A. Chudnovskii Ioffe Institute, St. Petersburg, U.S.S.R.	Visiting Scientist	J. Honig

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