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MIDWEST SUPERCONDUCTIVITY CONSORTIUM

1993 Progress Report

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Midwest Superconductivity Consortium

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SUMMARY

The mission of the Midwest Superconductivity Consortium, MISCON, is to advance the science and understanding of high T_c superconductivity.

During the past year, twenty-seven (27) projects produced over one hundred thirty-five (135) talks and one hundred twenty-six (126) publications. Four (4) Master's Degrees and five (5) Doctor's of Philosophy Degrees were granted to students working on MISCON projects.

Group activities and interactions involved two (2) MISCON group meetings (held in July and January); the first MISCON Workshop held in July; sixteen (16) external speakers; sixty-four (64) collaborations (with universities, industry, Federal laboratories, and foreign research centers); and twenty-three (23) exchanges of samples and/or measurements.

Research achievements this past year focused on understanding the effects of processing phenomena on structure-property interrelationships and the fundamental nature of transport properties in high-temperature superconductors.

In the synthesis and processing area: new low-temperature routes for processing bulk and thin film materials were developed; understandings of crystallization, grain growth and texture development in solidified melts and deposited thin films were broadened; important effects of substitutions, second phases, texture alignments, modulated microstructures and composite and microlaminate structures on superconducting properties were characterized; and, processing routes for improving the density and texture of tubular shielding structures were explored.

In the area of transport phenomena: theories for universal conductivity at superconductor-insulator transitions, flux-lattice melting transitions, the electrodynamics and thermodynamics of vortex motion, electromagnetic wave dissipation, and Josephson current densities through insulating barriers were advanced; important experimental techniques for measuring magneto-transmission and reflections of mm microwaves, vortex correlation fluctuations, magnetic penetration depths, the softening of in-plane phonon modes, flux pinning by complex defects

and interfaces, weak-link behaviors, and reproducible sub-energy-gap structures were studied.

The following are examples of notable achievements by MISCON investigators during the year:

- YBCO processed by the solid-liquid melt growth (SLMG) process form textured 123 phase with fine (ca 100nm) 211-phase precipitates. These samples exhibit extremely good low temperature flux pinning properties. Argonne National Laboratory has filed a patent application for this process. (P. McGinn, University of Notre Dame, E. Kvam, Purdue University, and D. Shi, Argonne National Laboratory).
- A formalism which for the first time makes fully microscopic calculations of the mixed state has been developed and is being applied to calculations of the microwave conductivity. (A. H. MacDonald and S. M. Girvin, Indiana University).
- The flux-lattice melting temperature of single-crystal YBCO has been calculated without any adjustable parameters, in excellent agreement with experimental results. (D. G. Stroud, Ohio State University).
- Superconducting junction arrays, consisting of 300x300 proximity-coupled, weak-link junctions fabricated of Ag/YBa₂Cu₃O₇ on SrTiO₃ substrates, have been fabricated and characterized. These junctions exhibit a Kosterlitz-Thouless-type transition in the superconducting state. (J. C. Garland, Ohio State University).
- Some key superconducting characteristics for BSCCO have been extracted from the theory of thermal fluctuations of vortices in layered superconductors. These properties include the temperature dependencies of the penetration depth, λ_{ab} , the upper critical field, H_{c2} , and the Ginzberg-Landau parameter, κ . (J. R. Clem and V. G. Kogan, Iowa State University).
- The first direct measurement of a vortex lattice in a superconducting niobium film was demonstrated by measuring NMR transitions in an

atomic beam directed across the surface of the film. (G. Lafyatis and T. Lemberger, Ohio State University).

- The thermal decomposition of 124 leads to the eventual formation of 211, Cu_2BaO_2 , and other phases under a three-step process. In contrast to earlier work, the decomposition of 124, per se, takes place in one step with a characteristic activation energy. (D. V. Baxter, K. G. Caulton, and M. H. Chisholm, Indiana University).
- The first direct determination of the magnetic penetration depth was made for an oxygen-depleted YBCO film. The results reveal that the penetration depth increases with oxygen depletion, but that its temperature dependence is unchanged, consistent with d-wave superconductivity. (T. R. Lemberger, Ohio State University).
- A three-tunnel capacitor model for single-electron tunneling was successfully applied to explain the highly non-linear I-V characteristics obtained with $\text{TlBa}_2(\text{Ca}_{0.8}\text{Y}_{0.2})\text{Cu}_2\text{O}_7$ films. (M. W. McElfresh and R. G. Reifenberger, Purdue University).
- A new, direct method has been developed for analyzing magnetic relaxation data. With this method it is now possible to determine the dependence of the pinning potential, $U(m)$, of the magnetic induction, B , as well as to see the effects of oxidation-induced pinning centers on $U(m)$. (W. B. Yelon and J. W. Farmer, University of Missouri).
- Two vortex phase transitions have been observed for Tl-2212. The lower temperature transition corresponds to a vortex-glass transition while the higher temperature transition corresponds to a pancake-vortex coupling transition. (M. W. McElfresh and R. G. Reifenberger, Purdue University).
- Measurements of 2-dimensional ^{89}Y NMR in $\text{YBa}_2\text{Cu}_3\text{O}_7$ to probe vortex dynamics reveal that in fields of several Tesla, vortices do not make spatial jumps of distances comparable to the lattice spacing. (C. Pennington, Ohio State University).

- The first Raman scattering studies of the phonon modes of $\text{YBa}_2\text{Cu}_4\text{O}_8$ (Y124) under pressure have been made. The mode Grüneisen parameters of the phonons present in both Y124 and Y123 scale with their bulk moduli. However, the chain modes that are Raman allowed only in Y124 are anomalously different. (M. Chandrasekhar, University of Missouri).
- Improvements have been made to a leadless, nondestructive microwave technique for characterizing high-temperature superconductors in the presence of a sustained dc magnetic field (0-7 Tesla). It is now possible to infer with reasonable agreement microwave surface impedance directly from the data. (W. J. Tomasch and J. K. Furdyna, University of Notre Dame).
- For YBCO with 211 additions, the enhancement of the critical current through flux pinning has been found to depend on the size of the 211 particles. However, the pinning seems to be induced more by extended defects (dislocations and CuO layer stacking faults) associated with the particles rather than by the particles themselves. (E. Kvam, Purdue University).

PROGRAM OVERVIEW

The Midwest Superconductivity Consortium, MISCON, in the fourth year of operations further strengthened its mission to advance the science and understanding of high T_c superconductivity. The goals of the organization and the individual projects continue to reflect the current needs for new knowledge in the field and the unique capabilities of the institutions involved. Group efforts and cooperative laboratory interactions to achieve the greatest possible synergy under the Consortium continue to be emphasized. Industrial affiliations coupled with technology transfer initiatives were expanded. Activities of the participants during the past year achieved an interactive and high level of performance. The number of notable achievements in the field contributed by Consortium investigators increased.

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-seven (27) research projects and thirty-eight (38) principal investigators. The research projects involve seven (7) undergraduate students, fifty-seven (57) graduate students and twelve (12) postdoctoral associates. In the past year, these participants have published sixty-three (63) papers. Nine (9) more papers are in press and an additional fifty-four (54) have been submitted. Further, the participants have given over one hundred thirty-five (135) talks or conference presentations. During this past year, four (4) Master's Degrees and five (5) Doctor's of Philosophy degree were granted to students working on MISCON projects.

Group activities and interactions with others were again a major activity under the Consortium. MISCON group meetings were held in January and July. A two day schedule for each meeting provided ample opportunity for the desired interactions to take place. Based upon these meetings the Program Committee reexamined the goals and programmatic research and made desirable program changes.

In addition to the group meetings, a workshop entitled "Type-II Superconductors: Basic Properties, Measurements, and Selected Advanced Topics", was held on July 8-9, 1993, to provide a tutorial on leading theories and experimental developments in transport behavior. Outstanding speakers from both within and outside MISCON participated. Underwriting support was provided by Quantum Design and Lake Shore Cryotronics, Inc., two of MISCON's Affiliates.

Coupled with the group meetings and workshop, the participants were very active in cooperative interactions with MISCON Affiliates and other organizations. Among these activities were sixteen (16) external speakers, sixty-four (64) collaborations, twenty-three (23) exchanges of samples and/or measurements, and one (1) gift of equipment from industry. The number of actively participating industrial Affiliates increased by 3 (from 8 to 11) with the addition of Bellcore, Lake Shore Cryotronics, Inc., and The Weizmann Institute of Science. Additional affiliations are pending.

Group activities are fostered by three programs: first, a seminar exchange promotes interaction within and between the groups; second, a programmatic exchange facilitates the use of special capabilities by all

participants; finally, a special capital equipment competition addresses group needs as the primary criterion. Cost sharing realized over \$234K worth of equipment, that was selected to provide new capabilities to the consortium, with less than \$118K of MISCON funds invested. One (1) equipment gift was received from industry.

Industrial affiliations and technology transfer activities were expanded during the year. Nine (9) written agreements and two (2) equipment access agreements were formalized this year with eleven (11) different industry and national laboratory groups. Seven (7) additional formal agreements are pending. Such interactions make all participants more aware of industry's needs for new knowledge and the current state of the technology.

PEER REVIEW

In accordance with MISCON procedures all fourth-year proposals and new proposals are reviewed by an independent external peer review panel. The 1993 peer review was conducted by nine outstanding experts in the field of high- T_c superconductivity. Project renewal decisions were then based on the results of this peer review and the 1992 DOE/OPA review. Two projects were directed to be phased out based on low scores in both reviews, and two projects were significantly redirected to refocus the work on those elements given higher marks by the reviewers. The mean score for the remaining projects was near the midpoint between "very good" and "excellent", representing a significant improvement in the overall quality of the program.

In addition to the fourth-year reviews, six new project proposals were peer reviewed. Of these, four scored sufficiently high to justify funding for 1993/94. These were funded at a reduced level for the first year for a total of \$212,628.

Finally, two projects were voluntarily withdrawn; for one the goals had been completed. These changes in research projects are indicated in Appendix I.

The process of peer review will continue to be the principal means within MISCON for continuous improvement of project quality, productivity and synergy and for dynamic renewal of project compositions within the two main program thrusts.

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 the 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 the research goals within the mission of the Consortium, two general programmatic areas of research 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. In addition to cooperative research programs in these areas, the Consortium encourages proposals for studies of new materials which can be expected to exhibit useful high-temperature superconductivity.

Area 1: New and Improved High T_c 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 that control these properties. Such properties include both thermodynamic and kinetic information about superconducting and normal-state phases. Processing variables encompass those necessary for optimizing synthesis and processing procedures for materials properties control. 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: High T_c Superconductor Transport Properties: Controlling/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).

RESEARCH PROGRAM

Titles of the projects within the two principal research program areas are given in Appendix I, along with industrial affiliations of the principle investigators for each project. A major emphasis during the past year was to increase the number of affiliations with other organizations. Eight (8) out of twenty-seven (27) projects now involve formalized working agreements. Those affiliations covered by formalized agreements are also indicated in Appendix I.

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. Formal affiliations are noted by an asterisk.

Area 1: New and Improved High T_c Superconducting Materials: Phase Relations, Reactions, Synthesis and Processing

Low Temperature Routes to Processing of High-Temperature Superconductors

***David V. Baxter, Kenneth G. Caulton, and Malcolm H. Chisholm.
Indiana University
Advanced Technology Materials, Inc.****

The objectives of this research project are:

- 1. To elucidate the mechanisms through which molecular precursors are transformed into superconducting materials during the CVD process;*
- 2. To study the phase transformations in the YBCO system; and*
- 3. To use this knowledge to improve the design of new generations of precursors.*

The gas handling system for our Remote Plasma Enhanced Chemical Vapor Deposition (RPECVD) reactor has been completed. Preliminary studies of the process pumping capability, plasma generator, and mass spectrometry system (including differential pumping) reveal that these various subsystems all perform as expected.

Thermal decomposition studies of 124 show a three-step process leading to the eventual formation of 211, Cu_2BaO_2 and other phases. In contrast to earlier work we find that the decomposition of the 124 phase

takes place in one step, and that the associated process is consistent with an activation barrier of 2.7eV/particle.

We have completed our characterization of compounds of barium and copper coordinated by a new class of ligand and the addition of a donor base. This work has been submitted for publication. Molecular modeling graphics, based on our structure determinations, has given us the means to select and synthesize a new improved copper-containing precursor. The compound Cu(B)₂ is promising with regard to its volatility without the necessity of added donor bases, and thus this theme will be emphasized.

Study of Compositional Modulation in High-T_c Superconductor Structures and Its Influence on their Superconducting Properties.

K. M. Choudhary and S. T. Ruggiero
University of Notre Dame

The objectives of this project are to study the fabrication and characterization of HTSC composites, multilayers, modulated structures, thin films, and other useful structures employing the following specific approaches:

- 1. Development of newly discovered ErBaCuO compounds;*
- 2. Productions of HTSC/AMnO₃ multilayers; and*
- 3. Introduction of controlled defects to pin flux and thereby increase J_c.*

Results during the year include:

- Orthorhombic-DyMnO₃ thin films were synthesized by molecular beam epitaxy. This is another classic example of metastable phase synthesis by MBE. In a bulk form, the orthorhombic phase of DyMnO₃ can only be prepared under high pressure.
- Epitaxial orthorhombic-DyMnO₃(110)/Er₁Ba₂Cu₃O_{7-δ}(001) and orthorhombic-DyMnO₃(110)/Er₅Ba₇Cu₁₂O_y(001) thin film heterostructures on LaAlO₃(100) substrates were successfully grown.

Therefore, the feasibility of fabricating DyMnO₃(110)/Er₁Ba₂Cu₃O_{7- δ} (001) superlattices has been demonstrated.

- In comparison with the Er₁Ba₂Cu₃O_{7- δ} (001) thin films, the surface smoothness of the [001] oriented new Er₅Ba₇Cu₁₂O_y high-temperature superconductor thin films was found to be better. Furthermore, the transport properties of the Er₅Ba₇Cu₁₂O_y(001) and Er₁Ba₂Cu₃O_{7- δ} (001) thin films were found to be similar. These results suggest that the Er₅Ba₇Cu₁₂O_y(001) thin films may have potential for applications in superconductor electronics.

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

P. J. McGinn

University of Notre Dame

Argonne National Laboratory*

The goal for this project is to investigate the microstructural dependence of J_c in zone-melt-textured YBCO so as to optimize its microstructure and improve its properties and processability.

Studies were performed on Y₂BaCuO₅ (211) and liquid (L=3BaCuO₂:2CuO) to study the effect of additions of BaSnO₃ and PtO₂ on the coarsening behavior of 211 particles in the liquid above the peritectic temperature of YBa₂Cu₃O_{6+x} (123) and the magnetic properties after melt texturing.

Some key results are:

- The solid-liquid melt growth (SLMG) process for producing textured 123 with fine (~100nm) 211 has been developed. Samples processed by this route exhibit extremely good low temperature flux pinning properties. A patent application has been filed by Argonne National Laboratory.

- Studies have shown that although additions of BaSnO₃ and PtO₂ both reduce the coarsening of 211, PtO₂ does so much more effectively. The PtO₂ additions refine 211 by altering the 211/liquid interfacial energy and/or Y diffusivity, and not by acting as heterogeneous nucleation sites as reported in some studies in the literature. BaSnO₃ additions are found to not be inert in the melt as reported by others.
- It has been found that PtO₂ additions lead to an increase in the defect density in textured 123, and it is this change in the defect level which appears to be the source of the enhanced pinning and higher J_c observed with PtO₂ (or Pt) additions.

***Growth of Single Crystals and/or Textured Specimens of High-T_c
Superconductors using Oxygen Seeding***

Patrick K. Gallagher

The Ohio State University

The objective of this research project is to demonstrate the efficacy of oxygen seeding for the growth of single crystal or highly textured YBa₂Cu₃O₇ (123).

Several techniques for oxygen seeding have been tried. Although the success has been limited, it is encouraging and indicates that preferred nucleation and growth based on seeding with oxygen is a viable technique for YBCO (123). Preliminary studies also indicate that it can also be achieved in the BSCCO system.

***Processing of Textured Superconducting Oxide/Noble Metal
Microlaminates***

Ken H. Sandhage

The Ohio State University

P. J. McGinn

University of Notre Dame

Intermagnetics General Corporation*

Ribbon Technology Corporation*

The objective of this research program is to produce fracture-tough, high J_c superconducting composites consisting of thin layers of superconducting oxide alternating with thin layers of noble metal.

Research accomplishments include:

- Attempts to melt texture $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ on Ag substrates (or in a silver crucible) in a reduced oxygen partial pressure at temperatures below the Ag melting point resulted in consumption of the Ag by the peritectic liquid.
- A 90 wt% Ag/10 wt% Pd alloy is only minimally attacked by the peritectic liquid. Successful melt texturing of $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}$ at temperatures below 955°C in an alloy crucible has been performed. This suggests that texturing of microlaminates is possible.
- While chemically-homogeneous metallic precursor tapes have been produced by spinning molten Y-Ba-Cu-Ag alloys, it is difficult to obtain melt-spun ribbons with flat surfaces. However, dense, chemically-uniform precursor tapes have been produced by hot rolling of mechanically-alloyed $\text{YBa}_2\text{Cu}_3\text{Ag}_{46}\text{Pd}_{4.7}$ powder inside a silver tube.
- 200 micron thick $\text{YBa}_2\text{Cu}_3\text{Ag}_{46}\text{Pd}_{4.7}$ tapes can be completely oxidized within ≈ 7 hours at 400°C in oxygen, suggesting that the synthesis of microlaminates of $\text{YBa}_2\text{Cu}_3\text{O}_{7-y}/\text{Ag-Pd}$ within reasonable times is possible.

***Anisotropic Grain Growth and Isothermal Grain Alignment of Bulk,
Superconducting Oxides***

Ken H. Sandhage

The Ohio State University

American Superconductor Corp.*

The goals of this research program are:

- 1. To understand the influence of various processing parameters (temperature, composition, oxygen partial pressure) on the grain growth of superconducting oxides; and*
- 2. To tailor the growth of superconducting oxide grains to allow for isothermal grain alignment.*

Results during the year include:

- The thermodynamic stability of $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_y$ thick films exposed to elevated oxygen fugacities [$f(\text{O}_2) = 1 - 750 \text{ atm}$] and temperatures ($500-900^\circ\text{C}$) has been determined. Heat treatment at sufficiently high oxygen fugacities results in solid-state decomposition of the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_y$ -type compound into the $\text{Bi}_2(\text{Sr,Ca})_2\text{Cu}_1\text{O}_y$ -type compound, an alkaline earth bismuthate ($\approx \text{Bi}_9\text{Sr}_{11}\text{Ca}_5\text{O}_y$), and CuO . The temperature at which such decomposition occurs decreases with increasing oxygen fugacity (e.g., $<500^\circ\text{C}$ at $f(\text{O}_2) = 750 \text{ atm}$).
- An enhanced degree of grain alignment has been observed in $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_y$ thick films that have been decomposed and then re-formed by a two-stage, solid-state heat treatment consisting of:
 - ◆ a 5 hour anneal at 880°C at an oxygen fugacity of 115 atm, followed by
 - ◆ a 24 hour anneal at 860°C in pure oxygen at 1 atm pressure.The resulting $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_y$ films were also more dense than films that were exposed to a single heat treatment at 860°C in 1 atm oxygen for up to 120 hours.

- Bulk $(\text{Pb,Bi})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+y}$ -type specimens (produced from nitrate-pyrolyzed powder provided by American Superconductor Corporation) have also been found to undergo solid-state decomposition at elevated oxygen pressures. The decomposition reaction for this compound is still being determined.

Pair Breaking Phenomena in the $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Ni}_y\text{O}_4$ Systems:

Experiment and Theory

J. M. Honig and J. Spalek

Purdue University

The two questions being addressed by this project are:

- 1. What is the influence on T_c of Ni substitutions for Cu as a function of the Sr concentration in $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Ni}_y\text{O}_{4+\delta}$?*
- 2. What are the electron states and real space pairing of a statistical spin liquid (SSL) in which double occupancies of the same quasiparticle level are not allowed?*

We have investigated the properties of an electron assembly in solids in which the charge carrier interactions are so strong that the double occupancy of states, usually considered in setting up the statistics of the standard electron gas, is no longer possible. A totally new theoretical treatment of the strongly interacting system has been set up and applied to high T_c superconductors. A rationalization has been provided of the experimental trends showing not only how T_c changes with doping of these superconductors but also how the superconducting gap changes with temperature. Both sets of predictions are in very good accord with experiment.

Together with a second group at the University of Kentucky we have initiated a program of studies concerning the heat capacity anomalies at the onset of superconductivity in $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Ni}_y\text{O}_4$. The substitution of nickel for copper in the parent compound leads to a drastic decrease in the critical temperature, T_c .

***Processing and Texture Development in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Films Synthesized
from Metallo-Organic Precursors***

***Gerald L. Liedl and Arden L. Bement, Jr.
Purdue University***

The objectives of this research project are:

- 1. To achieve rapid thermal processing of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) films on suitable substrates employing metallo-organic precursors; and*
- 2. To understand and control the development of film orientation by varying the process parameters.*

The Metallo-Organic Decomposition (MOD) technique was utilized in the fabrication of YBCO films with preferred orientation on single crystal (100) MgO and (100) SrTiO_3 substrates. Rapid thermally processed Y-rich films (870-980°C) exhibited a metallic behavior in the normal state with superconducting onset between 80-85K and maximum orthorhombic peak splitting.

For films deposited on (100) MgO substrates, c-axis texturing is observed in all films fired above 930°C in an oxygen atmosphere. At higher temperatures ($\geq 945^\circ\text{C}$) there is a tendency for in-plane preferential orientation in addition to the c-axis texture. Epitaxial film growth has been observed in films fired at $\geq 960^\circ\text{C}$ in reduced oxygen pressures.

For films deposited on (100) SrTiO_3 substrates, strontium interdiffusion and second phase formation (complex barium titanium oxide) is observed at firing temperatures $> 940^\circ\text{C}$ in an oxygen atmosphere. Epitaxial films, free of secondary phases, have been obtained by firing at 930°C in reduced oxygen pressure.

***High Temperature Superconducting Tubes for Magnetic Shielding
Applications***

K. P. Trumble, M. W. McElfresh, and K. J. Bowman

Purdue University

Quantum Magnetism*

Los Alamos National Laboratory*

The objectives of this research project are:

- 1. To develop processes for fabricating superconductivity shield tubes;*
- 2. To characterize the texture and properties of the processed tubes;
and*
- 3. To investigate the effects of annealing conditions on the
superconducting properties of BSCCO-silver composites.*

Results during the year include:

- BSCCO tubes processed by centrifugal slip casting have been produced consistently. The slurries used in centrifugal slip casting of these tubes have been optimized.*
- Microstructure characterization using optical microscopy shows the higher alignment of BSCCO particles in centrifugally slip casting of tubes (five times that of a random sample) compared to that achieved by cold-pressing (50 MPa) the same powder. Compared to the cold-pressed sample, centrifugal slip casting produces 15 to 20% higher fired density and 30% higher J_c .*
- We have recently shown that the vortex-glass phase transition of the grain boundary is significantly reduced with respect to that of the bulk. This reduction may be a result of oxygen depletion, which we also recently showed will push the vortex-glass transition to lower temperature and fields. The field dependence of the weak-link behavior is consistent with these results.*

Study of Naturally Modulated High T_c Superconducting Compounds

H. Sato

Purdue University

The objective of this project is to use controlled changes in the natural crystal structure modulation of the high-temperature superconductors to understand superconductivity and guide improvements of materials.

In order to answer the question "Why in Bi-compounds are reliable data limited to the right hand side of the universal curve?" a paper "Structural Stability of Bi-based Cuprates" has been written. The conclusion is that Bi-based compounds are not structurally stable without doping of oxygen or lead atoms in the Bi-O layer and, hence, are only stable with sufficient concentration of O ions.

Bi-compounds consist of the Perovskite block, which includes the CuO_2 layer and the Rocksalt block representing the Bi-O layer. If the mismatch of these two types of blocks becomes too large, the crystal becomes unstable.

For the measure of the stability of the Perovskite structure, the tolerance factor, t , is generally used. This is defined for a Perovskite ABO_3 as

$$t = \frac{\text{A-O}}{\sqrt{2}(\text{B-O})} ,$$

where the bond length A-O and B-O are taken to be the sum of the ionic radii of cation and oxygen. In perovskite, the structure is stable if $0.8 < t < 0.9$. In Bi-compounds Bi is taken for "A" and Cu is taken for "B". Even for Bi-compounds, $t=0.80$ is found to be the limit for the stability. Without extra oxygen doping in the Bi-O layer, t is found to be ~ 0.78 . Extra oxygen atoms increase the Bi-O bond length. Based on this, without the doping of Pb, the minimum amount of extra oxygen required for stabilizing the $n=2$ compound or to make $t \geq 0.80$ is estimated to be $\delta_{\min} \sim 0.08-0.1$. It is apparent from this stability relation, that the existence of Bi-compounds is limited to the right hand side of the universal relation. The result also shows clearly that the mismatch of the Rocksalt block and the Perovskite block is key to determine the stability of this compound. Here,

the charge reservoir Bi-O layer is found to provide all extra charges to the superconducting CuO_2 layers created by nonstoichiometry.

**Area 2: High T_c Superconductor Transport Properties:
Controlling/Limiting Factors**

***Quantum and Statistical Mechanics of High T_c Superconductors and Flux
Line Liquids***

**A. H. MacDonald and S. M. Girvin
Indiana University**

The objectives of this project are:

- 1. To clarify how superconductivity coexists with very intense magnetic fields at low temperatures in the limit when the effects of Landau quantization becomes important;*
- 2. To investigate the quantum phase diagram of superconductivity in two-dimensional systems (e.g., thin films) in the presence of magnetic fields and/or disorder; and*
- 3. To numerically simulate how columnar defects pin vortices in the high T_c superconductors.*

Results during the year include:

- We have delineated the phase diagram describing the transition region between normal and Abrikosov lattice states of anisotropic superconductors in a magnetic field by performing Monte Carlo simulations of the Lawrence-Doniach model.
- We have developed a formalism which makes fully microscopic calculations of mixed state properties possible for the first time and are applying it to calculations of the microwave conductivity.
- We have, for the first time, solved microscopic models for the magnetic field dependence of the upper critical field in the case of non s-wave superconductors.

- We have performed Monte Carlo calculations which establish that the superconducting vortex glass state does not occur at finite temperature in the limit of 2D films with point disorder.

Thermally Activated Flux Motion and Anisotropy in High-Temperature Superconductors

J. R. Clem and V. G. Kogan

Iowa State University

AT&T Bell Labs*

The objective of this project is to develop a quantitative theory of the relationship between the anisotropy of high-temperature superconductors and their susceptibility to thermally-activated fluxuation and other possible dissipative processes, in order to set theoretical limits on their critical current densities.

Starting with the theory of thermal fluctuations of vortices in layered superconductors, which we had developed during the previous year with MISCON support, we were able to analyze the magnetization data on $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ in order to extract some key superconducting characteristics of this material, including the temperature dependencies of the penetration depth, λ_{ab} , the upper critical field, H_{c2} , and the Ginzburg-Landau parameter, κ .

If fluctuations are ignored, use of the mean-field theory to analyze the data yields a puzzling, unphysical increase of $H_{c2}(T)$ as T approaches T_c . Including fluctuations in the theory, however, resolves this problem and leads to a more reasonable temperature dependence for the experimentally-determined values of $H_{c2}(T)$ near T_c .

Electrical and Optical Investigations of Pristine and Doped $\text{YBa}_2\text{Cu}_4\text{O}_8$

Meera Chandrasekhar

University of Missouri-Columbia

The objective of this project is to study the role of Zn and Fe doping in $\text{YBa}_2\text{Cu}_4\text{O}_8$ (Y124). The first experiment is to study the softening of the in-plane phonon modes at T_c via Raman scattering for different dopant

concentrations of Fe and Zn, thereby establishing whether the effect of the weak links is a minimum at a critical nominal concentration, as in Y123.

Results during the year include:

- A study of the phonon modes in $\text{YBa}_2\text{Cu}_4\text{O}_8$ (Y124) was conducted using Raman scattering under hydrostatic pressure (up to 100 kbar) at 13K. These are the first studies of these materials under pressure. We have accurately determined and compared the mode Grüneisen parameters for six different phonon modes, including those associated with various vibrations either in the Cu-O planes or in the Cu-O chains. A marked difference can be observed between the behavior of these chain and plane modes. The mode Grüneisen parameters of the phonons present in both the $\text{YBa}_2\text{Cu}_4\text{O}_8$ and the more conventional superconductor $\text{YBa}_2\text{Cu}_3\text{O}_7$ (Y123) scale with their bulk moduli, while the chain modes that are Raman allowed only in $\text{YBa}_2\text{Cu}_4\text{O}_8$ are anomalously different.
- A study of the phonon anomalies in pristine and Zn-doped Y124 was conducted at atmospheric pressure. In Y123 materials the frequencies of the in-plane phonon modes exhibited a softening at T_c that is attributed to mixing with electronic excitations across the superconducting gap. In Y124 materials, the several phonons (not just the in-plane) exhibit such anomalies.
- A study of the shifts in the phonon modes was conducted in Y124. The high-frequency, chain-associated mode shifts very rapidly with pressure, while the other modes shift to lower frequencies. The Raman-frequency shifts in most materials are usually small and extend to higher frequencies. As such, this behavior in Y124 is rather unusual.

Neutron Diffraction and Defect Studies of High T_c Superconductors

W. B. Yelon and J. W. Farmer

University of Missouri-Columbia

The major current objective of this project is to model current-voltage characteristics, critical currents, phase boundaries, and other properties in granular and otherwise disordered high- T_c superconductors, principally using networks of Josephson junctions.

Results during the year include:

- In collaboration with Ames Lab, we have developed a better understanding of the behavior of Nd-rich 1-2-3 compounds ($\text{Nd}_{1+x}\text{Ba}_{2-x}\text{Cu}_3\text{O}_{7+y}$). The similarities between this and oxygen deficient Y123 are related to the addition of excess oxygen on the anti-chain sites and the filling of holes.
- The collaboration with S.K. Malik has resulted in three publications on related Pr compounds, which, while non-superconducting, may be useful in making practical devices and in improving the critical current density. A new structure has been found, and work is underway to prepare further related compounds both with Pr and other rare earths.
- An important new collaboration has begun with the University of Kansas and Midwest Superconductivity, Inc. (Lawrence KS) to characterize Tl-based compounds. This group is preparing devices (especially thin films and bulk shielding) through the use of a novel synthesis route which gives better material than conventional processes.
- We developed a new, direct method for analyzing magnetic relaxation data. This method gives both the slope and second derivative of the pinning potential, $U(m)$. With the new method it is possible to map $U(m)$ in detail and determine the dependence of $U(m)$ on B , the

magnetic induction, as well as to clearly see the effects of radiation-induced pinning centers on $U(m)$.

- We have proposed a simple, one parameter model of the dependence of the critical current on B . The model accounts for the qualitative shape of hysteresis curves in both weak and strong pinning systems and can be used to explain the change of shape of hysteresis curves after the introduction of pinning centers with irradiation.

***Microwave and Optical Studies of High-Temperature Superconductors:
Flux-Lattice Dynamics, Crystal Anisotropy, Flux Pinning and Photo-
Modulated Superconductivity***

H. A. Blackstead

University of Notre Dame

This project studies transport properties of high-temperature superconductors, in particular field-induced changes in the microwave resistance, to derive information on flux lattice dynamics, crystal anisotropy and flux pinning.

We have recently concluded field and temperature-dependent, surface resistance measurements on superconducting, polycrystalline, Hg-Ba-Ca-Cu-O. We found that several samples provided to us contained multiple phases, including primarily $\text{HgBa}_2\text{CaCu}_2\text{O}_{6+\delta}$ (two layer) and $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+\delta}$ (three layer) phases. A small amount of a third phase, most likely $\text{HgBa}_2\text{Ca}_3\text{Cu}_4\text{O}_{10+\delta}$, was also detected. With variation of the angle Ψ between the applied field and current density, the low temperature data exhibit large, flux-flow resistivity which varies approximately as $\sin^2(\Psi) + a(B)$. For low temperatures, $a(B)$ is a relatively small isotropic field dependent contribution. At high temperatures, the dominant field and temperature dependent response is attributed to the isotropic phase-slip resistivity losses in intra-granular defects. For temperatures just below the transition temperature of the 2-layer phase, very small flux-flow is evidenced. This result is consistent with a large effective H_{c2} , suggesting a "dirty-limit" value of H_{c2} . The interesting features of the data required significant revisions of applicable theory. This

has led to the development of a theory which merges the simpler approach we have previously employed, with the sophisticated Coffey-Clem theory.

Superconducting Quantum Structures

A. E. Miller, B. Das, and

S. Bandyopadhyay

University of Notre Dame

The objective of this project is to fabricate lateral surface superlattices (two dimensional periodic arrays of quantum dots) of the maximum temperature superconductor BKBO.

The fabrication requires the generation of a two dimensional template that acts as a host for the quantum dots. This template is a regular, periodic hexagonal arrangement of ultrasmall pores that form in the anodized layer on Al.

We have successfully completed the first phase of this research, namely setting up the anodizing equipment with the necessary controls. Several test runs have been made to standardize the anodization process. Anodized Al has been produced that show the desired pore formation.

We are now poised to enter the second phase which is backfilling the pores with the superconducting materials of interest.

Transport Properties of YBCO Thin Films

S. T. Ruggiero

University of Notre Dame

The objective of this project is to understand and control the electronic properties of YBCO thin films; in particular:

- 1. To study critical-current enhancement by induced-defect generation, and*
- 2. To investigate the far-infrared responsivity of step-edge YBCO devices.*

Results during the year include:

- We have successfully reconfigured our deposition system to focus our effort, with an emphasis on YBCO film growth and step etching. We have verified the ability to produce good thin films, now far more efficiently, with step etching in the same chamber.
- FIR diode laser tests are proceeding with one laser in hand. Our completed system will have the ability to do both unique mixing (at 25 μm l) and time-domain (<300 ps) experiments.

Far-Infrared and Microwave Magneto-Dissipation in High- T_c Superconductors

W. J. Tomasch and J. K. Furdyna

University of Notre Dame

NIST*

TRW Superconductivity Research*

The objectives of this research project are:

- 1. To study the dynamic properties of the flux lattice in highly anisotropic high temperature superconductors; and*
- 2. To utilize laser and microwave magneto reflection and transmission measurements to obtain quantitative determinations of the important material parameters that are of basic interest and appropriate for high frequency applications.*

Results during the year include:

- We have developed a leadless, nondestructive microwave technique for quantitative evaluation of high temperature superconductors in the presence of substantial dc magnetic fields (0-7 tesla). Recent improvements enable us to infer the microwave surface impedance directly from the data. This avoids an intermediate step involving use of some specific theory of the mixed state. We are now able to numerically solve Maxwell's equations for the electromagnetic field

distributions in the sample chamber. This is a potentially important factor impacting our accurate determination of the surface impedance.

- Analysis of magneto transmission and reflection measurements on a 1800 angstrom thick YBCO (123) film, supplied by TRW, Inc., have yielded realistic material parameters.

High T_c Superconducting Composites, Arrays and Crystals

J. C. Garland

The Ohio State University

The objectives of this project are:

- 1. To develop high- T_c machinable Ag/YBCO bulk composites with superconducting fractions ranging from 10 percent to 100 percent;*
- 2. To develop high- T_c Ag/YBCO weak links and fabricate two-dimensional (2-D) Josephson Junction arrays; and*
- 3. To prepare BSCCO single crystals and understand the effects of interplane vortex interactions.*

Results during the year include:

- We have developed machinable bulk superconducting Ag/YBa₂Cu₃O₇ composites whose resistive transition temperatures were those of pure YBa₂Cu₃O₇. By systematically varying the superconductor volume fraction over the entire percolation range (0.16-0.9), several high- T_c composite materials were synthesized for low-current applications, including superconducting shielding enclosures, high-Q tuned cavities and bonding materials.
- We have fabricated and characterized Ag/YBa₂Cu₃O₇ superconducting weak link junctions and arrays on SrTiO₃ substrates. Each weak link junction consisted of a 5 μ m-wide high- T_c film overlaying at right angles to a 0.5 μ m-wide silver line.

Measurements of the zero-field resistive transitions and current-voltage characteristics showed that our two-dimensional arrays, which contained 300×300 proximity-coupled weak link junctions, exhibited a Kosterlitz-Thouless-type transition to the superconducting state.

- Our six-contact-lead measurements of the zero-field resistive transition of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ single crystals showed that, with decreasing temperature, a bulk zero-resistance state is established via Josephson coupling of the CuO bilayers, followed by a Kosterlitz-Thouless-type transition in the bilayers. In the temperature interval ($\sim 2\text{K}$) bounded by the two transition temperatures, our "flux-transformer" experiments yielded a pronounced peak in the secondary voltage, which was suppressed by external magnetic fields. We associate this structure with the out-of-plane Josephson coupling of thermally-excited vortices and antivortices.

Atomic Beam Studies of Vortex Lattices at Superconductor Surfaces
Gregory Lafyatis and Thomas Lemberger
The Ohio State University

The long-term goals of this work is to measure vortex correlation functions at the surface of superconductors by developing a new atomic beam technique and to use this technique to study the behavior of the vortex lattice in high- T_c materials.

Results during the year include:

- In the late spring (May 10) we accomplished our first benchmark goal for this project: we saw a vortex lattice in a sputtered superconducting niobium film.
- In analyzing and modelling our results, we discovered that our signal strength is sensitive to the penetration depth of the sample and that by examining our signal strength as a function of temperature,

(surprisingly) we could determine the penetration depth of our samples.

- The most important improvement in the past half-year is our description of the individual vortices. We now use the London model description of Marchetti, extended to include the finite thickness of our sample.
- The power and potential of this new technique depend on our signal detection sensitivity. By cooling an avalanche photodiode down to liquid nitrogen temperature we are able to achieve a sensitivity between a factor of two and a factor of one hundred better than the best devices that are currently on the market. For our experiment, it should soon result in a factor of thirty increase in sensitivity.

Device-Related Properties of Doped $\text{YBa}_2(\text{Cu}_{1-x}\text{M}_x)\text{O}_{7-\delta}$ Films

***Thomas R. Lemberger
The Ohio State University***

The objective of this project is to develop a better understanding of transport properties of superconductors through measurements of the kinetic inductance and Bernoulli potential in YBCO films.

Results during the year include:

- We demonstrated that the size and temperature dependence of the magnetic penetration depth measured in films of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ agrees in large measure with earlier surprising and controversial measurements on crystals. Differences between our films and crystals are quantitatively explained as resulting from weak disorder in a d-wave superconductor, thus supporting the conclusion from the crystal work that pure YBCO is a d-wave superconductor.
- We demonstrated that oxygen depletion from pure YBCO films increases the magnetic penetration depth without affecting its dependence on T/T_c . This is consistent with d-wave

superconductivity and the popular opinion that oxygen depletion changes the concentration of superconducting charge carriers without adding substantial disorder to the important CuO plane bilayers.

- We demonstrated that replacing a few percent of Cu with Ni or Zn in YBCO films increases the penetration depth dramatically and alters its dependence on temperature. These effects are consistent with estimates for the behavior of d-wave superconductors, assuming that doping introduces disorder without affecting the concentration of superconducting carriers.

NMR Studies of Vortex Dynamics in High T_c Superconductors

***Charles Pennington
The Ohio State University***

The objective of this project is to make NMR measurements on several high T_c samples with the goal of finding situations favorable to the detection and characterization of vortex motion.

We are investigating several types of high T_c materials, using several nuclear species as probes. Highlights of our research on the use of NMR to explore vortex dynamics in high T_c superconductors are:

- We measured ^{205}Ti NMR linewidths in single crystal 2201 and observed indications of possible decoupling of vortices in adjacent CuO_2 planes.
- We used ^{89}Y 2D NMR on $\text{YBa}_2\text{Cu}_3\text{O}_7$ powder to demonstrate that at 9 Tesla and 20-90K the correlation time for vortex jumps of a size comparable to the vortex lattice spacing is much greater than 10ms.
- In ^{89}Y NMR measurements of Powder $\text{YBa}_2\text{Cu}_3\text{O}_7$ our experiments yield a simple conclusion; namely, that in fields of several Tesla, vortices do not make frequent spatial jumps of distances comparable to the lattice spacing.

- In ^{205}Tl NMR measurements of 2201 Single Crystals anomalies in ^{205}Tl line shapes at low magnetic fields suggest that vortices in adjacent plane become decoupled at higher temperatures. The position of a vortex current loop in one plane becomes completely uncorrelated with that of the vortex in an adjacent plane. As a result, the magnetic fields produced by vortex current loops in adjacent planes add in an incoherent manner, and NMR and μSR linewidths are much narrower than would be expected.

Dynamical Properties of Josephson-coupled Systems: Application to High-Temperature Superconductors

David G. Stroud

The Ohio State University

This project is intended to study the structures of various high T_c superconductors, their defects, the correlations between their defects and physical properties, and the control of these defects.

During the past several months, we have succeeded in calculating the flux-lattice melting temperature of single-crystal $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ without any adjustable parameters, in excellent agreement with the experimental results of Safar, et al, over a field range from about 10^4 to 1.5×10^5 Oe (H||c).

Besides obtaining the flux lattice melting curve, we have begun to obtain some properties of the two phases near the transition. First, it appears that there is a *single* phase transition, characterized by the simultaneous onset of long-range order in both the c direction and the ab plane.

Secondly, we find that the transition in the *pure* case is characterized by the onset of a finite superfluid density component in the c direction, but not in the ab plane. This corresponds, not to a flux line liquid, but rather to a flux lattice which is unpinned and free to slide in the ab plane.

Transport Properties of High T_c Superconductors

G. F. Giuliani

Purdue University

The objectives of this project are:

- 1. To advance the theory of Josephson junctions and the flux dynamics in Type-II superconductors; and*
- 2. To characterize the transport properties of artificially manufactured Josephson junctions as a means of better understanding the Josephson effort in layered superconducting structures.*

Our research efforts have led to a number of interesting and fundamental results:

- We have developed a theory of the effect of an applied magnetic field, H_{ext} , on the critical current, J_c , of a bulk layered superconductor. We believe that our results provide an understanding for some of the interesting transport properties recently observed in high T_c (bulk) cuprates.
- We have studied the effect of an applied magnetic field, H_{ext} , on the critical current, I_c , of a single Josephson junction. The occurrence of an interesting cancellation phenomenon between the effects of the Meissner current and that associated with vortex currents has been demonstrated and analyzed in detail.
- We have studied the general problem of a Josephson junction with thin superconducting electrodes. In this case field penetration can occur in the form of Pearl vortices and the dependence $I_c(H_{ext})$ can differ greatly from the usual "Fraunhofer" relationship characterizing homogeneous field penetration.
- We developed a theory of the current-voltage characteristic of a Josephson junction in the presence of randomly distributed Abrikosov vortices in the superconducting electrodes. We have found

that for finite bias voltage, propagating electromagnetic waves display a broad spectrum of wavelengths. Moreover the amplitude of these waves is found to increase as the bias is decreased.

- We have calculated the Josephson current for a S-I-S junction taking into account the effect of the interaction between Cooper pairs and phonons in the insulating barrier region. We show that in the limit of $\omega\tau \gg 1$ (where ω is here a characteristic phonon frequency and τ is the semiclassical barrier crossing time) the critical current can drastically change. In particular we have established that when the screening length is much larger than the barrier thickness the critical current can actually increase with respect to the case of negligible barrier-electron-phonon interaction.
- We have investigated the spatial dependence of $v_n(r)$, the normal current in the vicinity of a moving vortex. This investigation provides insight into the appropriate boundary conditions to be used in a realistic modeling of the intermediate region which characterizes the immediate vicinity of a moving vortex core in a superfluid.

Structural Defects and Interfaces in High T_c Superconducting Compounds

Eric P. Kvam

Purdue University

The objectives of this project are:

1. *To examine the microstructure, and in particular, the extended defect and intercrystalline boundary structures of textured bulk polycrystals and epitaxial thin films (including bicrystals) of $YBa_2Cu_3O_7$; and*
2. *To correlate these microstructural aspects with transport property characteristics.*

In materials with 211 additions, it has been found that the enhancement of critical currents through flux pinning depends on the size of the 211 particles. The pinning seems to be induced by other extended defects (dislocations and CuO layer stacking faults) associated with the particles, rather than directly by the particles themselves.

Another aspect which has been identified is the existence of very small precipitates, apparently of the 211 phase. These precipitates are in the 30 to 100nm size range, and thus may be associated with magnetic pinning of flux lines.

In the calculation of the flux pinning by dislocations in 123 materials, we have shown that screw components of dislocations should have no strain-related effects on the flux lines, although the edge components may be significant contributors to pinning. Pinning effects related to dislocation cores, on the other hand, appear to be the other way around, at least for the special case of spiral growth-related screw dislocations. Such dislocations should have very larger Burgers vectors, and consequently very large normal-state cores, in which the flux lines could be readily trapped.

Intrinsic and Induced Weak Link Behavior in YBa₂Cu₃O_{7-δ} Films

M. W. McElfresh and R. G. Reifenberger

Purdue University

IBM Thomas J. Watson Research Center*

Lake Shore Cryotronics*

Quantum Magnetics*

The Weizmann Institute of Science*

The objectives of this project are:

- 1. To fabricate and characterize high-temperature superconducting thin films; and*
- 2. To optimize material properties through a better understanding of the order parameter and weak-link behavior in high-temperature superconductors.*

Results during the year include:

- We observed evidence for a two vortex-phase transitions in Tl-2212. The lower temperature transition corresponds to a vortex-glass transition and the higher temperature transition to a pancake-vortex-coupling transition.
- The magnetic phase diagram for grain boundaries in polycrystalline YBCO showed that the vortex-glass transition is strongly reduced at the boundary. Also, we observed a reduction in T_c at the grain boundary of a bicrystal film.
- We measured the magnetic phase diagram of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ as a function of δ , showing that the vortex-phase transition moves down and broadens with δ , while the melting transition does not broaden but merely tracks the change in T_c .
- We explained the anomalous reduction in magnetic-relaxation rate after a transport current is removed from a thin film and reported detailed analytical calculations of the demagnetization effects on thin film samples.
- We reported the frequency dependence of the vortex-glass transition by magnetotransport and showed that it is frequently independent for over five orders of magnitude in frequency.
- We identified the fine structure in the density of states data for YBaCuO high T_c films. The fine structure observed compares favorably with a theoretical model proposed by Tachiki, et al.
- We observed a single electron tunneling behavior in layered, high T_c $\text{TlBa}_2(\text{Ca}_{0.8}\text{Y}_{0.2})\text{Cu}_2\text{O}_7$ at 10K. By successfully applying a three-tunnel capacitor model for single electron tunneling, we were able to explain the highly non-linear I-V characteristics obtained from $\text{TlBa}_2(\text{Ca}_{0.8}\text{Y}_{0.2})\text{Cu}_2\text{O}_7$ films.

- We realized that layered materials of the type commonly studied by MISCON make attractive materials for fabricating 1-D arrays of tunnel-capacitors. Such arrays are one essential building block for the next generation of nanoelectronic devices.

Vortices in Anisotropic Superconductors

Paul Muzikar

Purdue University

The objectives of this project are to study vortex lattices and their instabilities in an effort to find minimum energy configurations and to study the pinning of a vortex line to a defect in a two-dimensional superconducting sheet.

Finding the configuration of vortex lines which minimizes the London free energy turns out to be a nontrivial task for anisotropic superconductors. We have found a surprising result: when the average field $\vec{B}$ is not parallel to a crystalline symmetry axis, a lattice of vortex lines parallel to $\vec{B}$ is not necessarily the configuration of lowest free energy. When the anisotropy is high enough, a configuration consisting of a set of vortex lines parallel to $\hat{c}$, plus a set of lines parallel to $\hat{a}$, and producing the same average $\vec{B}$, can have a lower free energy. We have made microscopic calculations of the penetration depth, λ , at $T = 0$, as a function of impurity scattering; we find significant differences between s-wave and d-wave order parameters.

MISCON TALKS and PRESENTATIONS

January 1993 - December 1993

1. **Kenneth G. Caulton**, Talk at West Virginia University, April 1993.
2. **Malcolm H. Chisholm**, Talk at the Gordon Research Conference on Chemical Reactions at Surfaces, Ventura, CA, March 1993.
3. "Numerical Simulations of Vortex Glass Dynamics", **S. M. Girvin**, Aspen Winter Meeting on Collective Dynamics in Disordered Systems, Aspen, CO, January 9, 1993.
4. "The Universal Conductivity at the Zero-Temperature Superconductor-Insulator Transition in Two Dimensions: Monte Carlo Calculation", Min-Chul Cha and **S. M. Girvin**, 2nd CTP Workshop on Statistical Physics, Seoul National University, Seoul, Korea, January 13-15, 1993.
5. "Quantum and Statistical Mechanics of High-Temperature Superconductors", **S. M. Girvin**, MISCON Meeting, Columbia, MO, January 28, 1993.
6. "Just What is Superconductivity Anyway?", **S. M. Girvin**, Indiana State University, Terre Haute, IN, March 17, 1993.
7. "I-V Characteristics of High Temperature Superconductors with Correlated Defects", Mats Wallin and **S. M. Girvin**, Proc. NATO ASI: Phase Transitions and Relaxation in Systems with Competing Energy Scales, Geilo, Norway, April 13-23, 1993.
8. "Vortex Glass Transition with Columnar Defects", **S. M. Girvin**, University of Minnesota, Minneapolis, MN, April 20, 1993.
9. "Universal Conductivity of a 2D Disordered Boson Model at the Field-Tuned Superconductor-Insulator Transition", Min Chul Cha and **S. M. Girvin**, Bull. Am. Phys. Soc. **38**, 526, 1993.
10. "Vortex Glass Transition with Columnar Defects", **S. M. Girvin**, University of Illinois, Urbana, IL, May 7, 1993.
11. "Vortex Glass Transition with Columnar Defects", **S. M. Girvin**, Stanford University, Stanford, CA, May 13, 1993.
12. "Quantum and Statistical Mechanics of Vortices", **S. M. Girvin**, MISCON Meeting, University of Notre Dame, South Bend, IN, July 7, 1993.

13. "Just What is Superconductivity Anyway?", **S. M. Girvin**, University of Texas, Austin, TX, September 29, 1993.
14. "The Zero-Temperature Two-Dimensional Vortex Glass Transition", Ross A. Hyman, **S. M. Girvin**, Mats Wallin, A. Peter Young, and Matthew P. A. Fisher, 21st Midwest Solid State Theory Meeting, Detroit, MI, October 3-4, 1993.
15. "Just What is Superconductivity Anyway?", **S. M. Girvin**, University of Kansas, Lawrence, KS, October 25, 1993.
16. "Superconductors in Magnetic Fields", **A. H. MacDonald**, Atlantic Undergraduate Physics Conference, Antigonish Nova Scotia, February 1993.
17. "Superconductivity in Extremely Strong Magnetic Fields", **A. H. MacDonald**, University of Kentucky, April 1993.
18. "Superconductivity in Extremely Strong Magnetic Fields", **A. H. MacDonald**, University of Illinois, April 1993.
19. "Superconductors in Magnetic Fields", **A. H. MacDonald**, University of Louisville, April 1993.
20. "Vortex-lattice Melting", **A. H. MacDonald**, MISCON Workshop on Type-II Superconductors, Notre Dame University, July 1993.
21. "Two-Dimensional Vortex Lattice Melting", Jun Hu and **A. H. MacDonald**, Conference on the Statics and Dynamics of Vortices, Eugene, OR, August 1993.
22. "Vortex-lattice Melting in 2D Superconductors", **A. H. MacDonald**, Florida State University, October 1993.
23. "Vortex-lattice Melting in 2D Superconductors", **A. H. MacDonald**, University, of Florida, October 1993.
24. "Thermal Fluctuations and Flux Lattice Melting of Superconducting Films", Jun Hu and **A. H. MacDonald**, Bull. Am. Phys. Soc, **28**, 635, 1993.
25. "Vortices in Layered Superconductors, I and II", **John R. Clem**, Experimental Workshop on High-Temperature Superconductors and Related Materials, Centro Atomico Bariloche, San Carlos de Bariloche, Argentina, January 11-12, 1993.

26. "Fundamentals of Vortex Structure in High-Temperature Superconductors", **John R. Clem**, SC Global 93-International Superconductor Applications Convention, San Jose, CA, February 2, 1993.
27. "The Layered High-Temperature Superconductors: Why Is Their Ability to Carry Supercurrent Limited by Quasi-two-dimensionality?", **John R. Clem**, Physics Colloquium, University of California, Davis, CA, February 23, 1993.
28. "Effects of Anisotropy and Layering in the High-Temperature Superconductors", **John R. Clem**, IVth International Bar-Ilan Conference on Frontiers in Condensed Matter Physics, Bar-Ilan University, Ramat-Gan, Israel, March 18, 1993.
29. "Vortex Structure of the High-Temperature Superconductors: 2D Pancake Vortices and Josephson Strings", **John R. Clem**, Berkeley, CA, March 31, 1993.
30. "Vortex Structure of the High-Temperature Superconductors: 2D Pancake Vortices and Josephson Strings", **John R. Clem**, Condensed Matter Physics Seminar, Oregon State University, Corvallis, OR, April 28, 1993.
31. "High-Temperature Superconductivity Update", **John R. Clem**, Annual Advisory Review of Exploratory Research, Electric Power Research Institute, Palo Alto, CA, May 5, 1993.
32. "Theory of ac Losses in Type-II Superconductors, Including the High-Temperature Superconductors", **John R. Clem**, EPRI/ASC Workshop on Bismuth Cuprate Superconducting Wires and Tapes, Half Moon Bay, CA, May 19, 1993.
33. "Vortex Structure of the High-Temperature Superconductors: 2D Pancake Vortices and Josephson Strings", **John R. Clem**, Condensed Matter Physics Seminar, University of California, Los Angeles, CA, June 9, 1993.
34. "Vortex Structure of the High-Temperature Superconductors: 2D Pancake Vortices and Josephson Strings", **John R. Clem**, Conductus, Sunnyvale, CA, June 17, 1993.
35. "Vortices in Highly Anisotropic Superconductors", **John R. Clem**, Tutorial Lecture, Midwest Superconductivity Consortium, Notre Dame, IN, July 9, 1993.

36. "Anisotropic Superconductors, Fundamentals of Vortices in Layered Superconductors: I, II, III, and IV", **John R. Clem**, Tutorial lectures, NATO Advanced Study Institute on Vortices in Superfluids, Cargese, Corsica, France, July 21-22, 1993.
37. "2D Pancake Vortices in a Finite Stack of Superconducting Layers", **John R. Clem**, Euroconference on Coherence and Phase Transitions in Superconductors and Mesoscopic Structures, Institute for Scientific Interchange, Villa Gualino, Torino, Italy, September 28, 1993.
38. "Conference Summary", **John R. Clem**, Euroconference on Coherence and Phase Transitions in Superconductors and Mesoscopic Structures, Institute for Scientific Interchange, Villa Gualino, Torino, Italy, September 29, 1993.
39. "Entropy Effects in the Mixed State of Layered Superconductors", **Vladimir G. Kogan**, 2nd International Conference on High-Tc Superconductivity, Eilat, Israel, January 4, 1993.
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41. "Role of Vortex Fluctuations in Determination of Penetration Depth from Magnetization for Layered Superconductors", J. H. Cho, D. C. Johnston, **V. G. Kogan**, M. Ledvij, and A. Yu. Simonov, APS March Meeting, Seattle, WA, March 23, 1993.
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44. "Images of the Vortex Lattice Near Extended Twin Boundaries in YBa₂Cu₃O_{7- δ} ", P. L. Gammel, C. A. Duran, D. J. Bishop, **V. G. Kogan**, M. Ledvij, and A. Yu. Simonov, APS March Meeting, Seattle, WA, March 25, 1993.
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46. "Vortices in Superconductors", **Vladimir G. Kogan**, Summer School on Vortices in the Four States of Matter, Institute for Nonlinear Studies, UCSD, LaJolla, CA, June 21-23, 1993.
47. "Vortex Entropy in Layered Superconductors", **Vladimir G. Kogan**, Tutorial Lecture, Midwest Superconductivity Consortium Workshop, Notre Dame, IN, July 9, 1993.
48. "Vortex Interactions and the Flux-line Lattice", **Vladimir G. Kogan**, **Workshop** on Statics and Dynamics of Vortices in Superconductors, Eugene, OR, August 3, 1993.
49. "Hydrostatic Pressure Studies of the LO Phonon Modes in the Raman Spectra of the Bulk High-Temperature Superconductor $\text{YBa}_2\text{Cu}_4\text{O}_8$ and the Effects of Doping", M. S. Boley, **Meera Chandrasekhar**, H. R. Chandrasekhar, Y. Wu, and P. Boolchand, AIRAPT/APS Conference, June 28-July 2, 1993.
50. "Raman Scattering Studies of Yb-124 Single Crystals and Y-124 Superconductor Samples under High Pressure", D. J. Payne, E. M. Baugher, R. J. Thomas, M. S. Boley, **M. Chandrasekhar**, H. R. Chandrasekhar, B. Dabrowski, Y. Wu, and P. Boolchand, Midwest Solid State Conference, September 24-25, 1993.
51. "High Pressure Optical Spectroscopy in Superconductors and Semiconductors", **M. Chandrasekhar**, Condensed Matter Seminar, Washington University, St. Louis, September 28, 1993.
52. "Critical Current Enhancement by Neutron Irradiation of Rapidly Textured $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ ", M. J. Kramer, **J. W. Farmer**, S. R. Arrasmith, and R. W. McCallum, IEEE Trans. on Superconductivity, 1993.
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56. "Field and Temperature Dependent Surface Resistance in High Temperature Superconductors", **H. A. Blackstead**, M. I. T. Lincoln Lab, November 5, 1993.
57. "Growth Morphologies of [001], [100] and [010] Oriented $\text{Er}_5\text{Ba}_7\text{Cu}_{12}\text{O}_y$ High-Temperature Superconductor Thin Films on Various Substrates", **K. M. Choudhary**, P. Seshadri, and M. Black, Thirteenth North American Molecular Beam Epitaxy Conference, Stanford, CA, September 13-15, 1993.
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68. "Synthesis and Properties of $\text{YBa}_2\text{Cu}_3\text{O}_7$ with ZrO_2 or MgO by Anionic Oxidation-Reduction", Siyoung Choi and **Patrick K. Gallagher**, Am. Ceram. Soc. An. Meeting, Cincinnati, OH, April 20, 1993.
69. "Inter-Plane Josephson Coupling of Thermally Excited Vortices in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-\delta}$ ", Y. M. Wan, S. E. Hebboul, D. C. Harris, and **J. C. Garland**, Bull. Am. Phys. Soc. **38**, 224, 1993.
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79. "Properties of Films of High-Temperature Superconductors", **T. R. Lemberger**, Ohio State University, October 1993.
80. "Infrared Reflectance and Penetration Depth of Doped Oxide Superconductors", **T. R. Lemberger**, University of Florida, November 1993.
81. "Stability of Bi-Sr-Ca-Cu-O Thick Films at Elevated Oxygen Pressures", **K. H. Sandhage** and D. H. Chmielewski, Workshop on Phase Equilibria of High- T_c Superconductors, Santa Fe, NM, June 4, 1993.
82. "The Influence of Elevated Pressure Annealing on the Stability of $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_y$ ", D. H. Chmielewski and **K. H. Sandhage**, TMS/ASM Fall Meeting, Pittsburgh, PA, October 18, 1993.
83. "High Temperature Physical Chemistry Involved in the Processing of Bulk Superconducting Oxide Wires/Tapes", **K. H. Sandhage**, IAP Research, Inc., Dayton, OH, November 18, 1993.
84. "Dynamical Properties of Josephson Junction Arrays: I. Shapiro Steps in Josephson Junction Arrays", **David Stroud**, CTP Workshop on Statistical Physics, Seoul, South Korea, January 13, 1993.
85. "Dynamical Properties of Josephson Junction Arrays: II. Bose Glass Transition in Josephson Junction Arrays, and Behavior of Underdamped Arrays", **David Stroud**, CTP Workshop on Statistical Physics, Seoul, South Korea, January 14, 1993.
86. "Dynamics of Josephson Networks", **David Stroud**, General Colloquium, Georgia Institute of Technology, Atlanta, GA, February 24, 1993.
87. "I-V Characteristics and Phase Transitions in Model High Temperature Superconductors with Columnar Defects", K. H. Lee, **D. Stroud**, and **S. M. Girvin**, APS March Meeting, Seattle, WA, March 1993.

88. "Resistive Steps in Josephson Junction Arrays", Wenbin Yu, K. H. Lee, and **D. Stroud**, APS March Meeting, Seattle, WA., 1993.
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92. "Weak-Coupled Superconductors", **David Stroud**, Condensed Matter Seminar, University of Wisconsin, Madison, WI, November 4, 1993.
93. "Orientation Texture in YBCO Films Synthesized from Amorphous Precursors", Chandra Venkatraman and **Gerald L. Liedl**, TMS Annual Meeting.
94. "Transport Properties of High T_c Superconductors", **G. F. Giuliani**, Midwest Superconductivity Consortium January Meeting, Columbia, MO, January 1993.
95. "Critical Current in a Lateral Josephson Junction between Layered Superconductors", **G. F. Giuliani**, APS March Meeting, Seattle, WA, March 1993.
96. "Critical Current of a Josephson Junction in Layered Superconductors", **G. F. Giuliani**, APS March Meeting, Seattle, WA, March 1993.
97. "Cahotic Vortex Penetration in Layered Superconductors", **G. F. Giuliani**, International Centre for Theoretical Physics, Scuola Normale Superiore, Pisa, Italy, June 1993.
98. "Antiparallel Spin Correlations in the Landau Theory of Fermi Liquids", **G. F. Giuliani**, Symposium in Honor of John J. Quinn, Brown University, Providence, Rhode Island, September 1993.
99. "Critical Current of a Josephson Junction and Layered Superconductor with Anisotropic Vortices", M. Fistul, Argonne National Laboratory, Chicago, IL, June 1993. (**Giuliani Group**)
100. "Interaction of a Long Josephson Junction with Abrikosov Vortices", M. Fistul, APS March Meeting, Seattle, WA, March 1993. (**Giuliani Group**)

101. "Properties of the $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Ni}_y\text{O}_4$ System", **J. M. Honig**, Midwest Superconductivity Consortium January Meeting, Columbia, MO, January 1993.
102. "Real Space Pairing of Heavy Fermion Materials and High T_c Superconductors", **J. M. Honig**, Midwest Superconductivity Consortium January Meeting, Columbia, MO, January 1993.
103. "Why Solids Undergo the Trauma of Metal Insulator Transitions", **J. M. Honig**, Superconductor Applications Association, San Jose, CA, February 1-3, 1993.
104. "Effect of Fluorination on $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$ Superconductors", **J. M. Honig**, Department of Chemistry, San Jose State University, San Jose, CA, February 4, 1993.
105. "The Trauma of Phase Transitions in Solids", **J. M. Honig**, Eastern Kentucky Section of the American Chemical Society, Richmond, KY, February 9, 1993.
106. "Single Crystal Growth and Characterization of Electrical Properties in Transition Metal Oxides", **J. M. Honig**, Department of Chemistry, Eastern Kentucky University, Richmond, KY, February 10, 1993.
107. "The Trauma of Phase Transitions in Solids", **J. M. Honig**, Department of Physics, University of Kentucky, Lexington, KY, February 11, 1993.
108. "Electron Correlation Phenomena in Selected Transition Metal Oxides", **J. M. Honig**, International Conference on Magnetism, Poznań, Poland, June 21-24, 1993.
109. "Electron Correlation Phenomena in Selected Transition Metal Oxides", **J. M. Honig**, Conference on Electron Correlation Phenomena, Białystok, Poland, June 28-30, 1993.
110. "Correlation Effects in Electrical Transport Properties in Inorganic Transition Metal Compounds", **J. M. Honig**, Meeting on Current Topics in Solid State Chemistry, Indian Institute of Science, Bangalore, India, December 14-17, 1993.
111. "Correlation Effects in Electrical Transport Properties in Inorganic Transition Metal Compounds", **J. M. Honig**, Regional Research Laboratory Thiruvananthapuram, India, December 20, 1993.
112. "Application of Statistical Spin Liquid Concept to High-Temperature Superconductivity", K. Byczuk and **J. Spałek**, International Conference on Magnetism, Poznań, Poland, 1993.

113. "Strongly Correlated Fermions at Low Temperatures", **J. Spałek**, J. Karbowski, W. Wojcik, European Physical Society Condensed Matter Division Conference, Regensburg, Germany, March 29 - April 2, 1993.
114. Invited seminar at the University of Illinois at Chicago, Department of Physics, Chicago, IL, **J. Spałek**, September 20, 1993.
115. "Texture Development in YBa₂Cu₃O_{7-δ} Films Synthesized from Metallo-Organic Precursors", Chandra Venkatraman and **Gerald L. Liedl**, 95th ACerS Annual Meeting, Cincinnati, OH, April 18-22, 1993.
116. "Effect of Processing Parameters on Texture Development in YBa₂Cu₃O_{7-δ} Films Synthesized from Metallo-Organic Precursors", Chandra Venkatraman and **Gerald L. Liedl**, MRS 1993 Fall Meeting, Boston, MA, November 29-December 3, 1993.
117. "Correlation of Magnetic and Transport Behavior in YBaCuO Thin Films", **M. W. McElfresh**, IVth International Conference on Frontiers in Condensed Matter Physics, Bar-Ilan University, Ramat-Gan, Israel, March 1993.
118. "Magnetic Order in the Frustrated 2D Heisenberg Antiferromagnet: La_{2-x}Sr_xNiO_{4+δ}", M. Darwin, **M. McElfresh**, P. Metcalf, **J. Honig**, and B. Crooker, APS March Meeting, Seattle, WA, March 1993.
119. "Irreversibility Line in YBaCuO Thin Films: Correlation of Transport and Magnetic Behavior", J. Deak, **M. McElfresh**, **John R. Clem**, Zhidong Hao, M. Konczykowski, R. Muenchausen, S. Foltyn, and R. Dyne, APS March Meeting, Seattle, WA, March 1993.
120. "Reduction of T_c at YBCO Bicrystal Thin Film Grain Boundaries", A. Lewicki, Shi Li, M. Darwin, C. Kovach, J. Deak, Lifang Hou, and **M. McElfresh**, APS March Meeting, Seattle, WA, March 1993.
121. "Effect of Transport Currents on the Critical State in YBCO Thin Films", M. Darwin, J. Deak, L. Hou, **M. McElfresh**, E. Zeldov, and **John R. Clem**, APS March Meeting, Seattle, WA, March 1993.
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124. "Effect of Transport Currents on the Critical State in YBCO Thin Films", **M. W. McElfresh**, CISE Laboratories, Milan, Italy, June 1993.
125. "Effect of Transport Currents on the Critical State in YBCO Thin Films", **M. W. McElfresh**, Orsay University, Orsay, France, June 1993.
126. "Magnetic Properties of Superconductors: The Basics", Workshop on "Type II Superconductors: Basic Properties, Measurements, and Selected Advanced Topics", **M. W. McElfresh**, University of Notre Dame, Notre Dame, IN, July 8-9, 1993.
127. "Properties of the Irreversibility Line: An Update", **M. W. McElfresh**, Invited Presentation at Los Alamos National Laboratory, Los Alamos, NM, August 11, 1993.
128. "Properties of the Irreversibility Line: An Update", **M. W. McElfresh**, Invited Presentation at Sandia National Laboratory, Albuquerque, NM, August 12, 1993.
129. "Formation of Tetragonal $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ from an Undercooled Melt", J. R. Olive, W. H. Hofmeister, R. J. Bayuzick, G. Carro, J. P. McHugh, R. H. Hopkins, M. Vlasse, R. Weber, P. Nordine, and **M. McElfresh**, MRS 1993 Fall Meeting, Boston, MA.
130. "Vortices in Anisotropic Superconductors", G. Preosti, Argonne National Laboratory, November 1993. (**Muzikar Group**)
131. "Texture and Microstructure in Ceramics", **K. J. Bowman**, Riso National Laboratory, Denmark, June 24, 1993.
132. "Texture in Ceramic Materials", **K. J. Bowman**, Proceedings of the Tenth International Conference on Texture of Materials, Clausthal, Germany, Sept. 1993.
133. "Texture and Microstructure in Ceramic Materials", **K. J. Bowman**, Case Western, Cleveland, OH, Sept. 14, 1993.
134. "Preferred Orientation of BSCCO Via Centrifugal Slip Casting", G. Steinlage, **K. P. Trumble**, **K. J. Bowman**, S. Li, and **M. McElfresh**, TMS Meeting, Indianapolis, IN, January 11, 1993.

135. "Structural Stability of $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{O}_{2n+4}$ Compounds: A Study on the Effect of Cation Doping and Oxygen Non-Stoichiometry", H. Zhang and H. Sato, MRS Fall Meeting, Boston, MA, Dec. 1, 1993.

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2. "The Universal Conductivity at the Zero-temperature Superconductor-insulator Transition in Two Dimensions: Monte Carlo Calculation", Min-Chul Cha and **S. M. Girvin**, in Proc. 2nd CTP Workshop on Statistical Physics: KT Transition and Superconducting Arrays, ed. by D. Kim, J.S. Chung, and M.Y. Choi (Min Eum Sa Co., Seoul, 1993), p. 225-239.
3. "Quantum Mechanics and Superconductivity in a Magnetic Field", **A. H. MacDonald**, Hiroshi Akera, and M. R. Norman, Aust. J. Phys. **46**, 333-344, 1993.
4. "Two-Dimensional Vortex Lattice Melting", Jun Hu and **A. H. MacDonald**, Phys. Rev. Lett. **71**, 432-435, 1993.
5. "Theory of Microwave Transmission and Reflection in Type-II Superconductors in the Mixed State", Mark W. Coffey and **John R. Clem**, Phys. Rev. B **48**, 342-350, 1993.
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12. *"Observation of a Novel Vortex Structure Driven by Magnetic Interactions Near a Sawtooth Twin Boundary in YBa₂Cu₃O_{7- δ} ", P. L. Gammel, C. A. Durán, D. J. Bishop, **V. G. Kogan**, M. Ledvij, A. Yu. Simonov, J. P. Rice, and D. M. Ginsberg, Phys. Rev. Lett. **69**, 3808-3811, 1992.
13. "Layered High-T_c Superconductors in an AC Field", A. Yu. Simonov, Physica C **211**, 455-466, 1993. (**Clem, Kogan Group**)
14. "Transport, Structural and Magnetic Properties of the Single-copper-oxygen Layer Bi₂Sr_{2-x}La_xCuO_y System", A. E. Schlögl, J. J. Neumeier, J. Diederichs, C. Allgeier, J. S. Schilling, and **W. Yelon**, Physica C **216**, 417-431, 1993.
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21. "Current and Angular-Dependent Transport in the Mixed State of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ ", **H. A. Blackstead**, *Solid State Communications* **87**, 35-39, 1993.
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32. "Effective Flux-Creep Activation Energy and Anisotropy in a $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ Single Crystal", M. E. Smith, Donglu Shi, S. Sengupta, and Z. Wang (**McGinn Group**), *Applied Superconductivity* **1,1/2**, 151-156, 1993.
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35. "Flux Pinning in Hot Isostatically Pressed $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ ", D. J. Miller, S. Sengupta, J. D. Hettinger, D. Shi, K. E. Gray, A. S. Nash, and K. C. Goretta (**McGinn Group**), *Appl. Phys. Lett.* **61**, 23, 2823-2825, 1992.
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54. "Identifying the Loss of Critical Current Density in $\text{YBa}_2\text{Cu}_3\text{O}_7$ Thin Films", J. Deak, **M. McElfresh**, **John R. Clem**, Zhidong Hao, M. Konczykowski, R. Muenchausen, S. Foltyn, and R. Dye, Phys. Rev. B **47**, 8377-8380, 1993.
55. "Density-of-States Fine Structure in the Tunneling Conductance of Y-Ba-Cu-O Films: A Comparison Between Experiment and Theory", T. G. Miller, **M. McElfresh**, and **R. Reifenberger**, Phys. Rev. B **48**, 7499-7504, 1993.
56. "Effect of Flux Creep on the Temperature Dependence of the Current Density in Y-Ba-Cu-O Crystals", J. R. Thompson, Yang Ren Sun, L. Civale, A. P. Malozemoff, **M. W. McElfresh**, A. D. Marwick, and F. Holtzberg, Phys. Rev. B **47**, 14440-14447, 1993.
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60. "Effect of Transport Currents on the Critical State of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Thin Films", M. Darwin, J. Deak, L. Hou, **M. McElfresh**, E. Zeldov, **John R. Clem**, and M. Indenbom, Phys. Rev. B **48**, 13192-13195, 1993.
61. "Enhancement of T_c in $\text{YBa}_2\text{Cu}_3\text{O}_7$ by Chemical Substitution in Bulk and Thin Film Materials: Implications for the Upper Critical Magnetic Field", J. J. Neumeier, **M. W. McElfresh**, Lifang Hou, and A. Lewicki, Applied Superconductivity **1**, 1279-1288, 1993.
62. "Minimum Energy Vortex Configurations in Anisotropic Superconductors", G. Preosti and **Paul Muzikar**, Phys. Rev. B **48**, 9921-9924, 1993.
63. "Structural Stability of Bi-Based Cuprates", Huanbo Zhang and **Hiroshi Sato**, Physica C **214**, 265-271, 1993.

(Accepted for Publication)

1. "Anisotropic Superconductors: Fundamentals of Vortices in Layered Superconductors", **John R. Clem**, to appear in the Proceedings of the NATO Advanced Study Institute.
2. "X-ray Diffraction Studies of Epitaxy in Orthorhombic-DyMnO₃/Er₁Ba₂Cu₃O_{7- δ} Thin Film Heterostructures on LaAlO₃(100) Substrates", P. Seshadri and **K. M. Choudhary**, to appear in Physica C.
3. "Growth Morphologies of (001), (100) and (010) Oriented Er₅Ba₇Cu₁₂O_y High-Temperature Superconductor Thin Films on Various Substrates", **K. M. Choudhary**, P. Seshadri, and M. Black, to appear in J. Vacuum Sci. and Technology B.
4. "Effects of the C-axis Resistive Transition Width on the Secondary Voltage of Bi₂Sr₂CaCu₂O_{8-y}", Y. M. Wan, S. E. Hebboul, D. C. Harris, and **J. C. Garland**, to appear in Physica B.
5. "DC Magnetization of Random Y₁Ba₂Cu₃O_{8- δ} /Ag Bulk Composites", C. L. Ash, D. C. Harris, J. J. Calabrese, and **J. C. Garland**, to appear in Physica B.
6. "Fabrication and Measurements of High T_c Weak Links", S. T. Herbert, S. E. Hebboul, and **J. C. Garland**, to appear in Physica B.
7. "Irreversibility Line in YBaCuO Thin Films: Correlation of Transport and Magnetic Behavior", J. Deak, **M. McElfresh**, **John R. Clem**, Zhidong Hao, M. Konczykowski, R. Muenchausen, S. Foltyn, and R. Dye, accepted by Phys. Rev. B.
8. "The Penetration Depth and Impurity Scattering in Unconventional Superconductors: T = 0 Results", Heesang Kim, Gianfranco Preosti, and **Paul Muzikar**, accepted.
9. "Preferred Orientation of BSCCO via Centrifugal Slip Casting", Greg Steinlage, Ryan Roeder, **Kevin Trumble**, **Keith Bowman**, Shi Li, and **Mike McElfresh**, accepted by J. Materials Research.

(Submitted for Publication)

1. "Synthesis, Structural Characterization, Thermolysis and Volatility Study of Tricarbomethoxymethanate Complexes of Copper (II) and Barium(II)", **David A. Baxter, Kenneth G. Caulton**, Wen-Chung Chiang, **Malcolm H. Chisholm**, Vincent F. DiStasi, Sylvain G. Dutremez, James D. Martin, and William E. Streib, submitted.
2. "Synthesis and Structural Characterization of $\text{Cu}[\text{CH}_3\text{C}(\text{O})\text{CHC}(\text{NCH}_2\text{CH}_2\text{OCH}_3)\text{CH}_3]_2$, a Volatile β -Ketoiminate Complex Suitable for Copper Metal MOCVD", **David A. Baxter, Kenneth G. Caulton**, Wen-Chung Chiang, **Malcolm H. Chisholm**, Vincent F. DiStasi, Sylvain G. Dutremez, and Kirsten Folting, submitted.
3. "Correlations in Two-Dimensional Vortex Liquids", Jun Hu and **A. H. MacDonald**, submitted.
4. "Bound Electron Pairs in Two Dimensions at Quantizing Magnetic Fields", H. Aker, **A. H. MacDonald**, and D. Yoshioka, submitted.
5. "The Superconductor-insulator Transition in 2D Dirty Boson Systems", Mats Wallin, Erik S. Sørensen, **S. M. Girvin**, and A. P. Young, submitted.
6. "Universal Conductivity in the Boson Hubbard Model in a Magnetic Field", Min-Chul Cha and **S. M. Girvin**, submitted.
7. "Magnetization and Transport Currents in Thin Superconducting Films", E. Zeldov, **John R. Clem**, **M. McElfresh**, and M. Darwin, submitted.
8. "Hysteretic ac Losses and Susceptibility of Thin Superconducting Disks", **John R. Clem** and Alvaro Sanchez, submitted.
9. "Effects of Anisotropy and Layering in the High-Temperature Superconductors", **John R. Clem**, submitted to Physica A.
10. "Structural and Magnetic Properties of Intermediate Oxygen Stoichiometry $\text{PrBa}_2\text{Cu}_3\text{O}_x$ ", S. K. Malik, **W. B. Yelon**, J. J. Rhyne, W. J. James, Ram Prasad, K. Adhikary, and N. C. Soni, submitted.
11. "Hole Filling, Charge Transfer and Superconductivity in $\text{Nd}_{1+x}\text{Ba}_{2-x}\text{Cu}_3\text{O}_{7+\delta}$ ", M. J. Kramer, S. I. Yoo, R. W. McCallum, **W. B. Yelon**, H. Xie, and P. Allenspach, submitted to Physica C.

12. "Catastrophic Quenching of Superconductivity in Melt-Textured $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ with Second Phase Additions", **H. A. Blackstead**, D. B. Pulling, and **P. J. McGinn**, submitted to Applied Physics Letters.
13. "Spin Glass Prepared States and the Resistive Transitions of High-Temperature Superconductors", **H. A. Blackstead** and J. C. Phillips, submitted.
14. "High Field Temperature Dependent Transport in Polycrystalline Tl-Ba-Ca-Cu-O ", **H. A. Blackstead** and G. A. Kapustin, submitted.
15. "Flux-Flow and Phase-Slip Resistivity in Two Phase Polycrystalline $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_{1.7}\text{Ca}_2\text{Cu}_3\text{O}_x$ ", **H. A. Blackstead**, D. B. Pulling, and **H. Sato**, submitted.
16. "Synthesis of DyMnO_3 Thin Films on $\text{LaAlO}_3(100)$ Substrates by Molecular Beam Epitaxy and Characterization of Their Growth Orientation", **K. M. Choudhary**, P. Seshadri, C. Venkatraman, submitted to Journal of Crystal Growth.
17. "Synthesis of DyMnO_3 Thin Films on $\text{LaAlO}_3(100)$ Substrates by Molecular Beam Epitaxy and Characterization of Their Growth Orientation", **K. M. Choudhary**, P. Seshadri, C. Venkatraman, submitted to Phys. Rev. B.
18. "Crystal Structure of $\text{Er}_5\text{Ba}_7\text{Cu}_{12}\text{O}_y$ Thin Film High-Temperature Superconductor", **K. M. Choudhary**, P. Seshadri, and J. Bae, submitted to Physical Review Letters.
19. "Critical Current Density and Microstructure of Melt-Processed $\text{YBa}_2\text{Cu}_3\text{O}_x$ with PtO_2 Additions", C. Varanasi, **P. J. McGinn**, V. Pavate, and **E. P. Kvam**, submitted to Physica C.
20. "Considerations in the Processing of Long Lengths of Melt Textured $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ Wires", **P. J. McGinn**, C. Varanasi, D. Balkin, submitted to Proceedings of the TMS Symposium entitled *Processing of Long Lengths of Superconductors*, ed. by U. Balachandran, A. Goyal, and E.W. Collings, (TMS, 1994).
21. "The Effect of Er 211 Additions on the Microstructure and Magnetic Properties of Zone Melt Textured Y_{123} ", David K. Balkin and **Paul J. McGinn**, submitted to Superconductor Science and Technology.
22. "An Alternate Method to Introduce Fine Y_2BaCuO_5 Precipitates into $\text{YBa}_2\text{Cu}_3\text{O}_x$ With Enhanced Flux Pinning", C. Varanasi, S. Sengupta, and **P. J. McGinn**, submitted to Applied Superconductivity.

23. "Y₂BaCuO₅ Particle Coarsening During Melt Processing of YBa₂Cu₃O_{7-x}", C. Varanasi and **P. J. McGinn**, submitted to Journal of Electrical Materials.
24. "Flux Pinning Associated with Y₂BaCuO₅ Precipitates in Melt-Processed YBa₂Cu₃O_x", S. Sengupta, Donglu Shi, J. S. Luo, V. R. Todt, Z. Wang, C. Varanasi, **P. J. McGinn**, U. Balachandran, and K. C. Goretta, submitted
25. "A Comparison of PtO₂ and BaSnO₃ Additions on the Refinement of Y₂BaCuO₅ and Magnetization of Textured YBa₂Cu₃O_{6+x}", C. Varanasi, M. A. Black, and **P. J. McGinn**, submitted to Superconductor Science & Technology.
26. "Effects of Oxygen Partial Pressure on the Crystallization of Amorphous Bi-Sr-Ca-Cu-O and Bi-Sr-Ca-Cu-O + Ag", M. J. Kramer, L. Margulies, S. R. Arrasmith, K. W. Dennis, J. C. Lang, **P. K. Gallagher**, and R. W. McCallum, submitted.
27. "An Atomic Beam Study of a Superconductor's Magnetic Vortex Lattice", Samuel Dapore-Schwartz, Nathan G. Woodard, and **Gregory P. Lafyatis**, submitted to Phys. Rev. Lett.
28. "Photon Counting Using a Large Area Avalanche Photodiode Cooled to 100K", Nathan G. Woodard, Eric G. Hufstedler, and **Gregory P. Lafyatis**, submitted.
29. "Crossover in Temperature Dependence of Penetration Depth $\lambda(T)$ in YBa₂Cu₃O_{7- δ} Films", JuYoung Lee, Kathleen Paget, and **Thomas R. Lemberger**, submitted to Phys. Rev. Lett.
30. "Infrared Reflectance of YBa₂(Cu_{1-x}Ni_x)₃O_{7- δ} Films", J.-T. Kim, M. J. Sumner, E. R. Ulm, and **T. R. Lemberger**, submitted.
31. "Magnetic Penetration Depth in Doped YBa₂(Cu_{1-x}M_x)₃O₇ Films", Eric R. Ulm, Jin-Tae Kim, **Thomas R. Lemberger**, Steve R. Foltyn, and Xindi Wu, submitted.
32. "Vortex Correlations in the Superconducting Transition of YBa₂(Cu_{1-x}Al_x)₃O_{7- δ} Films in High Magnetic Fields", Dimitrios G. Xenikos, Jin-Tae Kim, and **Thomas R. Lemberger**, submitted to Phys. Rev. Lett.

33. "Thermal Stability of Tl-Ba-Ca-Cu-O High- T_c Superconductors", **Ken H. Sandhage** and **Patrick K. Gallagher**, to appear in *Thallium-Based High-Temperature Superconductors*, editors Allen M. Hermann and J. V. Yakhmi.
34. "Flux Lattice Melting, Flux Pinning, and Superfluid Density Tensor of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ ", R. Šášik and **D. Stroud**, submitted to Phys. Rev. Lett.
35. "Magnetic Field Dependence of the Critical Current of a Layered Superconductor", Mikhail V. Fistul and **Gabriele F. Giuliani**, submitted.
36. "Two-impurity Anderson Model: Results of a Perturbative Expansion in U ", Giuseppe E. Santoro and **Gabriele F. Giuliani**, submitted.
37. "Critical Current of a Josephson Junction in Layered Superconductors", Mikhail V. Fistul and **Gabriele F. Giuliani**, submitted.
38. "Two-impurity Anderson Model: Some Exact Results Within Fermi Liquid Theory", Giuseppe E. Santoro and **Gabriele F. Giuliani**, submitted.
39. "Critical Current of a Lateral Josephson Junction for Layered Superconductors", Mikhail V. Fistul and **Gabriele F. Giuliani**, submitted.
40. "Reclassification of Early Transition Metal Oxides: Absence of True Mott-Hubbard Materials", J.-H. Park, L. H. Tjeng, J. W. Allen, R. Claessen, C. T. Chen, P. Metcalf, and H. R. Harrison, submitted. (**Honig Group**)
41. "Paramagnetism, Antiferromagnetism and Superconductivity in La_2NiO_4 ", J. V. Acrivos, M. Chen Lei, C. Jiang, H. Nguyen, P. Metcalf, and **J. M. Honig**, submitted.
42. "Melting Curve of Condensed ^3He as a Mott-Hubbard Localization Boundary for He Atoms: Elementary Analysis and Comparison with Experiment", **J. Spałek**, submitted.
43. "Application of Statistical Spin Liquid Concept to High-Temperature Superconductivity", K. Byczuk and **J. Spałek**, submitted.
44. "Interorbital Pairing for Heavy Fermions and Universal Scaling of Their Basic Characteristics", J. Karbowski and **J. Spałek**, submitted.

45. "High-Temperature Superconductor as a Paired State of Statistical Spin Liquid", K. Byczuk and **J. Spałek**, submitted to Phys. Rev. B.
46. "Strongly Correlated Fermions at Low Temperatures", **J. Spałek**, K. Byczuk, J. Karbowski, and W. Wójcik, submitted to Physica Scripta.
47. "Dislocation-Induced Flux Pinning Through Strain Interactions in YBa₂Cu₃O₇", **E. P. Kvam** and V. Pavate, submitted to Physica C.
48. "Texture Development in YBa₂Cu₃O_{7-δ} Films Synthesized from Metallo-organic Precursors", C. Venkatraman, submitted. (**Liedl, Bement Group**)
49. "Synthesis of YBa₂Cu₃O_{7-δ} Films from Metallo-Organic Precursors", C. Venkatraman and **G. L. Liedl**, submitted to J. Am. Ceram. Soc.
50. "Mechanism of Development and Control of Orientation Texture in YBa₂Cu₃O_{7-δ} Films Fabricated From Metallo-Organic Precursors", C. Venkatraman and **G. L. Liedl**, in preparation.
51. "Temperature Range for Critical Scaling Behavior in YBCO Thin Films", J. Deak, M. J. Darwin, and **M. McElfresh**, submitted.
52. "Evidence for Two Continuous Vortex Phase Transitions in Tl₂Ba₂CaCu₂O₇ Thin Films", J. Deak, **M. McElfresh**, D. W. Face, and W. L. Holstein, submitted to Phys. Rev. B Rapid Comm.
53. "Low-Temperature Electronic Properties of the La_{n+1}Ni_nO_{3n+1} (n = 2, 3 and ∞) System: Evidence for a Crossover from Fluctuating valence to Fermi Liquid-like Behavior", K. Sreedhar, **M. McElfresh**, D. Perry, D. Kim, P. Metcalf, and **J. M. Honig**, submitted.
54. "Single Electron Tunneling in TlBa₂(Ca_{0.8}Y_{0.2})Cu₂O₇ Thin Films at 10K", T. G. Miller, **R. Reifenberger**, **M. McElfresh**, D. W. Face and W. L. Holstein, submitted.

MISCON THESES

January 1993 - December 1993

M. S. DEGREES

1. Cynthia Smotzer, M. S. Thesis, Department of Physics, Indiana University, 1993. **(Baxter Group)**
2. "Neutron Studies on High Tc Superconductors and Permanent Magnets", H. Xie, M. S. Thesis, University of Missouri-Columbia, August 1993. **(Yelon, Farmer Group)**
3. Mark McClorey, M. S. Thesis, Department of Physics, University of Notre Dame, June 1993. **(Tomasch, Furdyna Group)**
4. "Crystal Growth and Characterization of the Nickel Sulfide, Heazlewoodite", Patricia A. Metcalf, M. S. Thesis, Department of Chemistry, Purdue University, August 1993. **(Honig Group)**

DOCTORATE DEGREES

1. Vincent DiStasi, Doctor of Philosophy, Department of Physics, Indiana University, December 1993. **(Baxter Group)**
2. "Studies of the Effects of Processing and Chemical Substitutions on the Microstructure and Properties of Melt Textured YBa₂Cu₃O₇", David Balkin, Doctor of Philosophy, Department of Engineering, University of Notre Dame, December 1993. **(McGinn Group)**
3. "Millimeter Microwave Properties of High-Temperature Superconductors", Eric K. Moser, Doctor of Philosophy, Department of Physics, University of Notre Dame. **(Tomasch, Furdyna Group)**
4. "Investigation of Transport Properties of Conventional and High Tc Superconducting Weak Link Devices", Steven T. Herbert, Doctor of Philosophy, Department of Physics, Ohio State University, August 1993. **(Garland Group)**
5. "Experimental Studies on Penetration Depth in YBa₂Cu₃O_{7-δ} Superconductors", Ju Young Lee, Doctor of Philosophy, Department of Physics, Ohio State University, December 1993. **(Lemberger Group)**

APPENDIX I
RESEARCH PROGRAM LISTING

Area I: New and Improved High T_c Superconducting Materials: Phase Relations, Reactions, Synthesis and Processing

PI	Univ	Title	Funding	Affiliations	Students & Professionals	Status
D. V. Baxter K. G. Caulton M. H. Chisholm	IU	Low Temperature Routes to Processing of High-Temperature Superconductors	105,000	Advanced Technology Materials, Inc.	Vincent DiStasi Wen Chung Chiang Cynthia Smotzer Dr. Ziling Xue Dr. Sylvain Dutremez	Ph.D. awarded 1993 Ph.D. anticipated 1994 M.S. awarded 1993 Professional Professional
K. M. Choudhary*ND S. T. Ruggiero		Study of Compositional Modulation in High Temperature Superconductor Structures and Its Influence on their Superconducting Properties	carry over		Chungling Zhong P. Seshadri Jewen Bae	Ph.D. anticipated 1995 Ph.D. anticipated 1994 Left MSE Program 8/93
P. J. McGinn	ND	Microstructural Dependence of Critical Current Density in Melt Textured YBa ₂ Cu ₃ O _{6+x} Superconductors	129,948		David Balkin Suvankar Sengupta Varanasi Chakripani Hai-feng Yang J. Kirksey Chan Joong Kim	Ph.D. awarded 12-93 Ph.D. anticipated 5-94 Ph.D. anticipated 8-94 Ph.D. anticipated 5-97 Technician Postdoctoral Associate
P. K. Gallagher**	OSU	Growth of Single Crystals and/or Textured Specimens of High-T _c Superconductors using Oxygen Seeding	47,115		Siyoung Choi Thawli Iwagoshi	Ph.D. anticipated 6-94 Ph.D. anticipated 1994
K.H. Sandhage P.J. McGinn	OSU ND	Processing of Textured Superconducting Oxide/Noble Metal Microlaminates	90,000	Intermagnetics General Corp Ribbon Technology Corporation	S. Vilayannur Marc Black	Ph.D. anticipated 1-96 Ph.D. anticipated 5-95
K. H. Sandhage	OSU	Anisotropic Grain Growth and Isothermal Grain Alignment of Bulk, Superconducting Oxides	100,390		Yong-Yi Shi David Chmielewski Holly Miron	Left Univ. 7-93 M.S. anticipated 6-94 M.S. anticipated 6-95

*Project Withdrawn

**New Project

PI	Univ	Title	Funding	Affiliations	Students & Professionals	Status
J. M. Honig J. Spaček	PU	Pair Breaking Phenomena in the La _{2-x} Sr _x Cu _{1-y} Ni _y O ₄ Systems. Experiment and Theory	83,366		P. Metcalf K. Sreedhar P. Metclaf	M.S. awarded 8-93 Postdoctoral Associate Professional
G.L. Liedl A.L. Bement, Jr.	PU	Processing and Texture Development in YBa ₂ Cu ₃ O _{7-δ} Films Synthesized from Metallo-Organic Precursors	121,917		C. Venkatraman S. Mansour D. Perry	Ph.D. anticipated 1994 Professional Professional
K.P. Trumble M.W. McElfresh K.J. Bowman	PU	High Temperature Superconducting Tubes for Magnetic Shielding Applications	116,500	Quantum Magnetism/ Quantum Design	Shi Li Greg Steinlage N. Medendorp Darin Aldrich Chad Peterson Amy Trissler Timothy Brent	Ph.D. anticipated 1996 M.S.E. anticipated 5-94 M.S.E. anticipated 1995 B.S.E. awarded 5-93 B.S.E. awarded 5-93 B.S.E. awarded 5-93 B.S.E. anticipated 5-94
H. Sato*	PU	Study of Naturally Modulated High T _c Superconducting Compounds	carry over		H. Zhang J.G. Chen	Ph.D. anticipated 1994 Postdoctoral Researcher
Area II: High T_c Superconductor Transport Properties: Controlling/Limiting Factors						
A. H. MacDonald S. M. Girvin	IU	Quantum and Statistical Mechanics of High T _c Superconductors and Flux Line Liquids	90,000		Jun Hu Yong Wang Ross Hyman Hirosaki Akera Mats Wallin	Ph.D. anticipated 1994 Ph.D. anticipated 1995 Ph.D. anticipated 1995 Visiting Scientist Visiting Scientist
J. R. Clem* V. G. Kogan	ISU	Thermally Activated Flux Motion and Anisotropy in High-Temperature Superconductors	carry over	AT&T Bell Lab	Maamar Benkraouda Andrew Y. Simonov	Ph.D. anticipated 1994 Postdoctoral Fellow
Meera Chandrasekhar	UM- Col	Electrical and Optical Investigations of Pristine and Doped YBa ₂ Cu ₄ O ₈	71,400		Dale Payne	Ph.D. anticipated 1996

*Project Withdrawn

PI	Univ	Title	Funding	Affiliations	Students & Professionals	Status
W. B. Yelon J. W. Farmer	UM-Col	Neutron Diffraction and Defect Studies of High T_c Superconductors	70,000		H. Xie	M.S. awarded 8-93
H. A. Blackstead	ND	Microwave and Optical Studies of High-Temperature Superconductors: Flux-Lattice Dynamics, Crystal Anisotropy, Flux Pinning and Photo-Modulated Superconductivity	114,000		Ann Klunzinger Peder Beeli D.B. Pulling	Graduate Student Graduate Student Professional Specialist
A. E. Miller** B. Das S. Bandyopadhyay	ND	Superconducting Quantum Structures	69,986		Duofeng Yue Gautam Banerjee	Ph.D. anticipated 1994 Postdoctoral Associate
S. T. Ruggiero**	ND	Transport Properties of YBCO Thin Films	49,000		Chunling Zhong	Graduate Student
W. J. Tomasch* J. K. Furdyna	ND	Far-Infrared and Microwave Magneto-Dissipation in High-Temperature Superconductors	carry over	NIST TRW Superconductivity Research	E.K. Moser Mark McClorey	Ph.D. awarded 8-93 M.S. awarded 6-93
J. C. Garland	OSU	High T_c Superconducting Composites, Arrays and Crystals	118,605		S.T. Herbert Y.M. Wan John Markus Matt Trawick Sergio Ammirata C. Ash S.E. Hebboul D.C. Harris Hu Jong Lee	Ph.D. awarded 8/93 Ph.D. anticipated 1994 Ph.D. anticipated 1996 Ph.D. anticipated 1996 Ph.D. anticipated 1997 M.S. anticipated 1994 Professional Postdoctoral Associate Visitor
G. P. Lafyatis T. R. Lemberger	OSU	Atomic Beam Studies of Vortex Lattices at Superconductor Surfaces	73,500		S. Dapore-Schwartz Harold Haughlin	Ph.D. anticipated 1994 Ph.D. anticipated 1996
T. R. Lemberger	OSU	Device-related Properties of Doped $YBa_2(Cu_{1-x}M_x)_3O_{7-\delta}$ Films	62,000		Ju Young Lee Eric Ulm Jack Kessler	Ph.D. awarded 1993 Graduate Research Asst. Graduate Research Asst.

*Project Withdrawn

**New Project

PI	Univ	Title	Funding	Affiliations	Students & Professionals	Status
C. Pennington	OSU	NMR Studies of Vortex Dynamics in High T_c Superconductors	57,642		Charles Recchia	Ph.D. anticipated 1996
D. G. Stroud	OSU	Dynamical Properties of Josephson-Coupled Systems: Application to High-Temperature Superconductors	63,000		Ki Ho Lee Roman Sasik Eric Roddick Wenbin Yu	Postdoctoral Researcher Postdoctoral Researcher Student Student
G. Giuliani	PU	Transport Properties of High- T_c Superconductors	70,000		Mikhail V. Fistul	Postdoctoral Researcher
E. P. Kvam	PU	Structural Defects and Interfaces in High T_c Superconducting Compounds	205,000		D.S. Linehan V. Pavate T.J. Brent J.T. Dawley L.B. Williams D.L. Perry	M.S. anticipated 1994 M.S. anticipated 1994 B.S. anticipated 1994 B.S. anticipated 1994 B.S. anticipated 1994 Professional
M. W. McElfresh R. G. Reifenberger	PU	Intrinsic and Induced Weak Link Behavior in $YBa_2Cu_3O_{7-\delta}$ Films	117,736	IBM Thomas J. Watson Research Center Lake Shore Cryotronics Quantum Magnetica Weizmann Institute of Science	Tom Miller Lifang Hou James Deak Michael J. Darwin Patti Metcalf	Ph.D. anticipated 1994 Ph.D. anticipated 1996 Ph.D. anticipated 1994 Ph.D. anticipated 1996 Professional
P. Muzikar** **New Project	PU	Vortices in Anisotropic Superconductors	46,527		Heesang Kim G. Preosti	Ph.D. anticipated 1994 Ph.D. anticipated 1996

APPENDIX II

Cooperative Laboratory Interactions January 1993 - December 1993

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
SEMINAR AND GUEST SPEAKERS		
James D. Jorgensen Argonne National Laboratory	Guest Speaker at Group Meeting	Columbia, MO
Dean E. Peterson Los Alamos National Laboratory	Guest Speaker at Group Meeting	Columbia, MO
AT&T Bell Labs	Invited Seminar Speaker	Vladimir Kogan Iowa State University
Dr. Paul Muzikar Purdue University	Invited Seminar Speaker	Purdue University
Dr. David Gaskell Purdue University	Invited Seminar Speaker	Purdue University
Dr. C. J. van der Beek Argonne National Laboratory	Invited Seminar Speaker	Purdue University
Dr. David G. Stroud Ohio State University	Invited Seminar Speaker	Purdue University
Dr. Tom Lemberger Ohio State University	Invited Seminar Speaker	Indiana University
M. V. Indenbom Institute of Solid State Physics Russian Academy of Science, Moscow, Russia	Invited Seminar Speaker	Purdue University

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
Martin Nikolo St. Louis University St. Louis, MO	Invited Seminar Speaker	Purdue University
Allen Goldman University of Minnesota	Guest Speaker at Group Meeting and Workshop Speaker	University of Notre Dame
Valerii Vinokur Argonne National Laboratory	Workshop Speaker	University of Notre Dame
Masaki Suenaga Brookhaven National Laboratory	Workshop Speaker	University of Notre Dame
Marko Ledvij Iowa State University	Workshop Speaker	University of Notre Dame
Alex Gurevich University of Wisconsin-Madison Madison, Wisconsin	Workshop Speaker	University of Notre Dame
Alvaro Sanchez Universitat Autònoma de Barcelona Spain	Workshop Speaker	University of Notre Dame
Hugo Safar AT&T Bell Labs	Workshop Speaker	University of Notre Dame
Boris Amonzon Russian Scientific Center Moscow, Russia	Invited Seminar Speaker	Purdue University
Dr. A. Gurevich University of Wisconsin-Madison Madison, Wisconsin	Invited Seminar Speaker	Purdue University
Dr. Milind N. Kunchur Oak Ridge National Laboratory Oak Ridge, Tennessee	Invited Seminar Speaker	Purdue University

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION****PROGRAMMATIC EXCHANGE PROGRAM**

Jewan Bae
Choudhary Group
University of Notre Dame

Measurements of Transport Properties

M. McElfresh Lab
Purdue University

Dimitri Xenikos
Lemberger Group
Ohio State University

Use of Laser Ablation System

M. McElfresh Lab
Purdue University

Mike Darwin, Jim Deak, and Shi Li
McElfresh Group
Purdue University

Discussions on Setting up and Maintaining
Electromagnetically Shielded Room

S. Ruggiero Lab
University of Notre Dame

Parthasarathy Seshadri
Choudhary Group
University of Notre Dame

Study of the crystal structure of $\text{Er}_5\text{Ba}_7\text{Cu}_{12}\text{O}_y$
thin films on various substrates

G. L. Liedl Lab
Purdue University

Chakrapani Varanasi
University of Notre Dame

Perform TEM Work

E. Kvam Lab
Purdue University

CO-OP EFFORTS/COLLABORATIONS

Daniel Arovas
UCSD
San Diego, CA

Discussions on Microscopic and
Macroscopic Properties

A. H. MacDonald
S. M. Girvin
Indiana University

John Berlinsky
McMaster

Discussions on Microscopic and
Macroscopic Properties

A. H. MacDonald
S. M. Girvin
Indiana University

Min-Chul Cha
University of Kentucky

Field-tuned Superconductor-insulator
Transition

A. H. MacDonald
S. M. Girvin
Indiana University

David Stroud
Ohio State University
Columbus, OH

Vortex Glass Simulations

A. H. MacDonald
S. M. Girvin
Indiana University

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
A. Peter Young UCSC	Vortex Glass Transition in 2D	A. H. MacDonald S. M. Girvin Indiana University
Matthew P. A. Fisher UCSB	Collaborative Research	A. H. MacDonald S. M. Girvin Indiana University
Michael Norman Argonne National Lab Argonne, IL	Microscopic Study of Superconductors in High Fields	A. H. MacDonald S. M. Girvin Indiana University
M. J. Kramer Iowa State University	Collaboration	W. B. Yelon J. W. Farmer University of Missouri-Col
M. A. Kirk Argonne National Laboratory	Collaboration	J. W. Farmer University of Missouri-Col
P. Allenspach University of California San Diego, CA	Collaboration	W. B. Yelon University of Missouri-Col
J. J. Neumeier Los Alamos National Laboratory	Collaboration	W. B. Yelon University of Missouri-Col
J. Schilling Washington University St. Louis, MO	Collaboration	W. B. Yelon University of Missouri-Col
J. Diederichs Washington University St. Louis, MO	Collaboration	W. B. Yelon University of Missouri-Col
W. J. James University of Missouri-Rolla	Collaboration	W. B. Yelon University of Missouri-Col
J. J. Rhyne University of Missouri-Columbia	Collaboration	W. B. Yelon University of Missouri-Col

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

J. Z. Wu
University of Kansas

Collaboration

W. B. Yelon
University of Missouri-Col

Y. Xin
Midwest Superconductivity, Inc.
Lawrence, KS

Collaboration

W. B. Yelon
University of Missouri-Col

K. W. Wong
University of Kansas and
Midwest Superconductivity, Inc.
Lawrence, KS

Collaboration

W. B. Yelon
University of Missouri-Col

P. Dai
Oak Ridge National Laboratory

Collaboration

W. B. Yelon
University of Missouri-Col

R. W. McCallum
Iowa State University

Collaboration

W. B. Yelon
University of Missouri-Col

J. M. Honig
Purdue University

Collaboration

W. B. Yelon
University of Missouri-Col

J. D. Dow
Arizona State

Collaboration

H. Blackstead
University of Notre Dame

Dr. Donglu Shi
Argonne National Lab

Joint Project

P. J. McGinn
University of Notre Dame

Rich Fletcher
Wright Patterson AFB

Collaboration on Transport and
Microwave Properties

S. T. Ruggiero
University of Notre Dame

Parthasarathy Seshadri
University of Notre Dame

YBCO Superconductor Multilayers

S. T. Ruggiero
University of Notre Dame

D. Rudman
NIST
Boulder, CO

Thin Film YBCO

S. T. Ruggiero
University of Notre Dame

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Beth Baumert
Westinghouse
Pittsburgh, PA

Collaboration on YBCO Step-edge Studies

S. T. Ruggiero
University of Notre Dame

Peter Rosenfeld
Advanced Fuel Research
W. Hartford, Conn.

Exchange of FAR/Josephson Junction Results

S. T. Ruggiero
University of Notre Dame

Greg Hey-Shipton
Lincoln Bourne
Superconductor Technologies, Inc.

YBCO Film Preparation and also
Contributions to edited work "Superconductor
Devices Handbook"

S. T. Ruggiero
University of Notre Dame

Mike McElfresh
Purdue University

Loan of Equipment
for Low-temperature Experiments

S. T. Ruggiero
University of Notre Dame

Steve Schwarzbek
Claire Pettiette-Hall
TRW Space and Technology
Redondo Beach, CA

YBCO Thin Film Collaborations

W. J. Tomasch
University of Notre Dame

Mark Coffey
NIST
Boulder, CO

YBCO Thin Film Collaborations

W. J. Tomasch
University of Notre Dame

John R. Clem
Ames Lab
Iowa State University

Comparisons of Microwave Data

W. J. Tomasch
University of Notre Dame

M. J. Kramer
Iowa State University

Collaborations

P. Gallagher
Ohio State University

Gordon Roesler
NRL

Collaborations

G. Lafyatis
Ohio State University

J. Garland
Ohio State University

Collaborations

G. Lafyatis
Ohio State University

Rutherford Backscattering Facility
Cornell University

Improvement of the Stoichiometry
of Codeposited Films

T. R. Lemberger
Ohio State University

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

A. H. MacDonald
S. M. Girvin
Indiana University

Discussions on vortices

T. R. Lemberger
Ohio State University

D. Stroud
Ohio State University

Interpretations of Data

T. R. Lemberger
Ohio State University

Dr. Bart Riley
American Superconductor Corp.

Collaborative Experiments

K. Sandhage
Ohio State University

Brian Maple
University of California
San Diego, CA

Collaboration on Transport and Magnetic
Properties

D. Stroud
Ohio State University

Dr. Ki Il. Lee
Syracuse University

Collaboration

D. Stroud
Ohio State University

M. McElfresh Group
Purdue University

Weak Link Properties of Grain Boundaries
in BSCCO and YBCO

G. Giuliani
Purdue University

M. McElfresh Group
Purdue University

Critical Transport of Junctions Artificially
Manufactured out of Narrow Channels

G. Giuliani
Purdue University

C. Broholm
Johns Hopkins University

Collaborative Research

J. Honig
Purdue University

T. Rosenbaum
University of Chicago

Collaborative Research

J. Honig
Purdue University

J. Brill
University of Kentucky

Collaborative Research

J. Honig
Purdue University

P. Eklund
University of Kentucky

Collaborative Research

J. Honig
Purdue University

J. Aeppli
AT&T Bell Laboratories

Collaborative Research

J. Honig
Purdue University

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J. Acrivos
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Collaborative Research

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C. Stassis
Iowa State University

Collaborative Research

J. Honig
Purdue University

J. W. Farmer
University of Missouri-Columbia

Collaborative Research

J. Honig
Purdue University

W. Yelon
University of Missouri-Columbia

Collaborative Research

J. Honig
Purdue University

Dr. U. Balachandran
Argonne National Lab

Collaboration on joint project

E. Kvam
Purdue University

Tom Lemberger
Ohio State University

Discussions on penetration depth
calculations

P. Muzikar
Purdue University

Dr. Jim Eckstein
Varian Research Laboratories
Palo Alto, CA

Collaborations

R. Reifengerger
M. McElfresh
Purdue University

Dean Peterson
Los Alamos National Lab
Los Alamos, NM

Collaborations

K. Trumble
Purdue University

Jon Martens
Conductus

Collaborations

K. Trumble
Purdue University

Alan Kleinsasser
IBM T.J. Watson Research Center
Yorktown Heights, NY

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Purdue University

John Neumeier
Los Alamos National Lab
Los Alamos, NM

Collaborations

M. McElfresh
Purdue University

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Ross Muenchausen
Los Alamos National Lab
Los Alamos, NM

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M. McElfresh
Purdue University

Dean Face
DuPont Central Research
Wilmington, DC

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Purdue University

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Iowa State University
Ames, IA

Collaborations

M. McElfresh
Purdue University

Mike McHenry
Carnegie-Mellon University
Pittsburgh, PA

Collaborations

K. Trumble
Purdue University

SAMPLE EXCHANGE/COLLABORATIONS

P. Boolchand
University of Cincinnati

Sample Exchange

M. Chandrasekhar
University of Missouri-Col

B. Dabrowski
Argonne National Lab

Sample Exchange

M. Chandrasekhar
University of Missouri-Col

J. Schilling
Washington University

Experiment on Pressure Dependencies
of Raman modes in Ti 2201

M. Chandrasekhar
University of Missouri-Col

T. Venkatesan
University of Maryland

Discussion of collaboration

M. Chandrasekhar
University of Missouri-Col

S. Bandyopadhyay
University of Notre Dame

Collaboration

M. Chandrasekhar
University of Missouri-Col

Dr. Xiao Ping Jiang
Morris Research, Inc.
Berkeley, CA

Sample Exchange/Joint Project

P. J. McGinn
University of Notre Dame

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Prof. Robert Snyder
Alfred University

Sample Exchange/Joint Project

P. J. McGinn
University of Notre Dame

Dr. Jeffrey A. Eastman
Argonne National Laboratory

Characterizing Structures using SEM, TEM

A.E. Miller, B. Das,
& S. Bandyopadhyay
University of Notre Dame

Dr. Richard Ricker
NIST
Gaithersburg, Maryland

Anodization and Fabrication of Templates

A.E. Miller, B. Das,
& S. Bandyopadhyay
University of Notre Dame

NIMET Industries, Inc.

Technology Transfer and Adaptation of the
Anodization Process

A.E. Miller, B. Das,
& S. Bandyopadhyay
University of Notre Dame

Dr. Meera Chandrasekhar
University of Missouri-Columbia
Columbia, MO

Possible Collaboration on Examination of
Structures with Raman Spectroscopy

A.E. Miller, B. Das
& S. Bandyopadhyay
University of Notre Dame

Howard A. Blackstead
University of Notre Dame

$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-y}$ Samples

J. C. Garland
Ohio State University

Charles Pennington
Ohio State University

$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-y}$ Samples

J. C. Garland
Ohio State University

Thomas R. Lemberger
Ohio State University

Ag/YBa₂Cu₃O₇ Arrays

J. C. Garland
Ohio State University

Dale Van Harlingen
University of Illinois
Urbana-Champaign

$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8-y}$ Samples

J. C. Garland
Ohio State University

Charles Pennington
Ohio State University

Single Crystals of YBa₂Cu₃O_{7- δ}

G. Lafyatis
Ohio State University

Steve Foltyn and Xindi Wu
Los Alamos National Lab

Laser Ablated Films of YBCO

T. R. Lemberger
Ohio State University

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Mike McElfresh
Purdue University

Laser Ablated Films of YBCO
Drawings for Substrate Heater

T. R. Lemberger
Ohio State University

Julia Phillips
AT&T Bell Labs

Films of pure YBCO for comparison

T. R. Lemberger
Ohio State University

P. Gallagher
Ohio State University

Use of Lab for Fabrication of Powder
Precursors

T. R. Lemberger
Ohio State University

Brian Maple
University of California-San Diego
San Diego, CA

Powder and Single Crystal samples of
 ^{17}O -enriched $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$

C. Pennington
Ohio State University

James Garland
Ohio State University

Single Crystals of BSSCO (2212)

C. Pennington
Ohio State University

Alan Hermann
University of Colorado

Single Crystals of TiBaCuO (2202)

C. Pennington
Ohio State University

INDUSTRIAL CONTACTS

AT&T Bell Labs
Dr. D. Bishop

Discussions on Experimental
Results

V. G. Kogan
Iowa State University

Dr. K. W. Wong
Midwest Superconductors, Inc.
Lawrence, KS

Industrial Affiliate Discussions

W. B. Yelon
J. W. Farmer
University of Missouri-Col

Dean Face
DuPont

Industrial Affiliate Discussions

S. T. Ruggiero
University of Notre Dame

Dr. David Rudman
High Temperature Superconductors
NIST
Boulder, CO

Industrial Affiliate Discussions

S. T. Ruggiero
University of Notre Dame

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Lincoln Bourne
Greg Hey-Shipton
Superconductor Technologies
Santa Barbara, CA

Industrial Affiliate Discussions

S. T. Ruggiero
University of Notre Dame

Beth Baumert
Westinghouse Science and Technology Center
Pittsburgh, PA

Industrial Affiliate Discussions

S. T. Ruggiero
University of Notre Dame

National Nanofabrication Facility
Cornell University
Ithaca, NY

Sample Fabrication

J. C. Garland
Ohio State University

Mike Tomsic
Plastronic, Inc.
Troy, OH

Industrial Affiliate Discussions

K. Sandhage
Ohio State University

Dr. C. E. Oberly
Wright Patterson Air Force Base

Informal Collaboration with
goal of Formal Affiliate Agreement

E. Kvam
Purdue University

INDUSTRIAL AFFILIATES

Advanced Technology Materials, Inc.
John Steinbeck
Danbury, CT

Written Agreement

K. G. Caulton
Indiana University

AT&T Bell Labs
Dr. David J. Bishop
Murray Hill, NJ

Written Agreement

J.R. Clem, V.G. Kogan
Iowa State University

Bellcore
Dr. R. Ramesh
Red Bank, NJ

Written Agreement

E. Kvam, M. McElfresh
Purdue University

IBM Thomas J. Watson Research Center
Dr. Stuart Bermon
Yorktown Heights, NY

Written Agreement

M. W. McElfresh
Purdue University

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
Intermagnetics General Corporation Dr. Pradeep Haldar Guilderland, NY	Equipment Access	K. Sandhage, P. McGinn Ohio State University University of Notre Dame
Lake Shore Cryotronics, Inc. B. C. Dodrill Westerville, OH	Written Agreement	MISCON Researchers
National Institute of Standards and Technology Dr. Robert A. Kamper and Dr. M. W. Coffey	Written Agreement	W. J. Tomasch University of Notre Dame
Quantum Magnetics Dr. Ronald E. Sager and Dr. Barry Lindgren San Diego, CA	Written Agreement	M. W. McElfresh Purdue University
Ribbon Technology Corporation Dr. Tom Gaspar	Equipment Access	K. Sandhage, P. McGinn Ohio State University University of Notre Dame
TRW Superconductivity Research Stephen M. Schwarzbek Redondo Beach, CA	Written Agreement	W. J. Tomasch University of Notre Dame
Dr. Elia Zeldov The Weizmann Institute of Science Rehovot, Israel	Written Agreement	M. W. McElfresh Purdue University
FOREIGN INTERACTIONS		
Hiroshi Akera Hokkaido University Japan	Studying Pair Tendencies in the Extreme Strong Magnetic Field Limit and Visit	A. H. MacDonald S. M. Girvin Indiana University
Mats Wallin KTH Stockholm, Sweden	Joint Project and Visit	A. H. MacDonald S. M. Girvin Indiana University

COMPANY/CONTACT	ACTIVITY	MISCON PI/LOCATION
A. E. Schlögl University of Munich Munich, Germany	Collaboration	W. B. Yelon University of Missouri-Col
C. Allgeier University of Munich Munich, Germany	Collaboration	W. B. Yelon University of Missouri-Col
R. Sieburger University of Munich Munich, Germany	Collaboration	W. B. Yelon University of Missouri-Col
S. K. Malik Tata Inst. for Fundamental Research Bombay, India	Collaboration	W. B. Yelon University of Missouri-Col
H. Jahns Tata Inst. for Fundamental Research Bombay, India	Collaboration	W. B. Yelon University of Missouri-Col
R. Prasad Bhabha Atomic Research Center	Collaboration	W. B. Yelon University of Missouri-Col
K. Adhikary Bhabha Atomic Research Center	Collaboration	W. B. Yelon University of Missouri-Col
N. C. Soni Bhabha Atomic Research Center	Collaboration	W. B. Yelon University of Missouri-Col
VIP, Inc India	Anodized Samples	A. E. Miller University of Notre Dame
IIT Bombay, India	Anodized Samples	A. E. Miller University of Notre Dame
G. Lander Euratom, Karlsruhe	Collaborative Research	J. Honig Purdue University

COMPANY/CONTACT**ACTIVITY****MISCON PI/LOCATION**

Dr. Marcin Konczykowski
Ecole Polytechnique
Palaiseau, France

Joint Projects and Visits

M. W. McElfresh
Purdue University

Eli Zeldov
The Weizmann Institute of Science
Rehovot, Israel

Collaboration

M. W. McElfresh
Purdue University

Yosi Yeshurun
Bar-Ilan University
Ramat-Ganz, Israel

Collaboration

M. W. McElfresh
Purdue University

APPENDIX III

ORGANIZATION

January 1, 1992 - December 31, 1993

<u>Name</u>	<u>Location</u>	<u>Telephone Number</u>
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C. COMMITTEES

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