2001 Annual Report

Center for Superconductivity Research

University of Maryland
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DIRECTOR'S MESSAGE

The Center for Superconductivity Research (CSR) at the University of Maryland conducts interdisciplinary research in the fields of superconductivity, magnetism, ferroelectricity, the synthesis and characterization of advanced electronic materials, and the development of scanning probe microscopies. Our research impacts technology in areas such as communications, digital and analog electronics, medical instrumentation, and computers. The experimental and theoretical research programs at CSR are carried out by approximately 30 scientists and engineers of whom 12 are also teaching faculty members of the Department of Physics, Electrical Engineering, Chemistry, or Materials Engineering. Approximately 30 graduate students are working on their research dissertation projects with members of the CSR faculty. A significant number of undergraduate students and visiting scientists also participate in research projects.

One important goal of the CSR is to train students with the expertise necessary to make contributions to advancing technology in the State of Maryland and elsewhere in the United States. The CSR provides a unique interdisciplinary education that gives our students a diversity of experimental skills as well as a broad and flexible perspective of how scientific knowledge can be used to impact technological development. Our Ph.D. and M.S. graduates have found rewarding positions with industry, government laboratories, and universities.

Our faculty were recognized by several awards during the past year. R. Ramesh received a Humboldt Senior Scientist Award for his research achievements in ferroelectrics, as well as an award for Outstanding Achievement in Ferroelectrics, 2000 at the Annual International Symposium on Integrated Ferroelectrics. I. Takeuchi received an NSF Career Award for Combinatorial Investigation of Functional Metal Oxide Thin Films and an ONR Young Investigator Award for Combinatorial Investigation of Novel Magnetic Shape Memory Alloys. C. Lobb was recognized by the University of Maryland College Park as a year 2000-2001 Distinguished Scholar-Teacher.

This year, external federal support of CSR research programs was about $2.9 million, a significant sum in today's competitive environment. In addition, some of our faculty are an important part of a Maryland collaboration which was recently awarded a prestigious NSF Materials Research Science and Engineering Center (MRSEC). This $10 million, 5 year, grant will support our research efforts in magnetic and ferroelectric thin film oxides and the development of novel scanning probe microscopies. We are continuing to explore joint science and technology programs with industry and government laboratories. We have programs in progress with NIST (Gaithersburg), NASA (Lewis), NRL, Brookhaven, LPS, Argonne, Telcordia, Motorola, Lucent, Seagate, Radiant Technologies, and Neocera. Neocera is a small Maryland company, founded by one of our faculty, that develops and sells products based on thin film electronic materials and scanning probe microscopy. Several of our patents have been licensed to Neocera for product development; some royalties have already been returned to the University and the inventors.

The research programs in CSR encompass a wide range of interdisciplinary areas: fundamental physical properties of novel superconductors, ferromagnets and ferroelectrics; thin film preparation, characterization and device structures of complex oxide materials; properties and technology of Josephson junction arrays, SQUIDS, and single electron charging effect devices; dynamical properties of vortices in superconductors; physics and technology of giant magnetoresistive oxides; physics of mesoscopic metals; development of scanning microwave microscopy and other novel scanning probes of materials; development of solid state quantum computers; and
synthesis of new materials with novel electronic properties. Details of this research can be found in the publication list starting on page 9 of this report.

Some highlights of CSR Research in FY 2001 are:

• An understanding of the physics of the electron-doped high temperature superconductors (HTSC), e.g. Pr$_{2-x}$Ce$_x$CuO$_4$ (PCCO), is a topic of considerable scientific interest. The CSR has played a leading role in research on these materials in the past. Last year we discovered an anomalous, normal state, energy gap in the ab plane tunneling spectra of optimally doped PCCO at temperature above $T_c$ and at magnetic fields above $H_{c2}$. The cause of this gap must be ultimately connected to the fundamental physics of the electron-doped HTSC. However, its relation to the superconducting gap and the “pseudogap” found in underdoped hole-doped cuprates is yet to be determined.

• The nature of the charge-ordered (CO) state and its “melting” in a magnetic field found in various manganese oxides is a problem of fundamental interest. Two years ago we discovered from low temperature specific heat measurements, an anomalous excitation associated with the CO state in La$_{0.5}$Ca$_{0.5}$MnO$_3$. Last year we found that this excitation is present in another CO system, Pr$_{1-x}$Ca$_x$MnO$_3$. Moreover, a magnetic field sufficient to induce a resistive and magnetic transition from the CO state to the ferromagnetic metal state, i.e “melting”, does not completely remove the anomalous specific heat excitation. This suggests that the CO state is not completely destroyed in the “melting” magnetic field and the physics of this transition is more subtle than previously believed.

• Using femto-second pair breaking spectroscopy, the photon energy dependence of the Cooper pair breaking rate for optimal doped YBCO ($T_c$=90K), oxygen depleted YBCO ($T_c$=60K) and Zn doped YBCO ($T_c$=40K) has been measured. The optimal doped and oxygen depleted YBCO exhibit similar behavior with a sharp resonant triplet around 1.5eV, while the Zn doped YBCO shows a red-shift (~20 meV) of the triplet. These observations support the electronic phase separation model of high-$T_c$ superconductivity.

• Thin films of the recently discovered superconductor, MgB$_2$, were deposited on SrTiO$_3$ and Al$_2$O$_3$ substrates by pulsed laser deposition, and subsequent in-situ or ex-situ annealing approaches. The resulting films show a $T_c$ of 39 K for ex-situ anneal, and ~20-25 K for in-situ anneal.

• The pulsed laser deposition process was optimized for the case of double perovskite (Sr$_x$FeMoO$_6$) films. High quality films are obtained only at a laser energy density about 2.5 J/cm$^2$, very low (~1 x 10$^{-7}$ Torr) background pressure and a substrate temperature close to 1000 C. These films are expected to be useful for room temperature CMR devices.

• Direct experimental evidence was found for changes in the ultrafast (less than picosecond) incoherent lattice fluctuations at the ferromagnetic phase transitions in two layered CMR manganites, and at the superconductivity transition in the high-$T_c$ LSCO system. These fluctuations appear to play an important role in the high-$T_c$ and CMR phenomena, but their exact role is yet to be determined.

• We demonstrated device quality (low defect and low interface state density) epitaxial AlN on SiC via a recrystallization process. The improved interface between AlN dielectric and SiC by recrystallization is useful for high-temperature and high power electronic devices.
• We conducted a systematic study of ZnMgO metal-oxide wide band gap semiconductors for the fabrication of UV and solar blind optoelectronic detectors. Prototype devices were designed, fabricated, and tested. A patent on this topic was filed.

• Prior to the high-\(T_c\) era, it was generally believed that a type-II superconductor in a magnetic field would have a small, but non-zero, linear resistance due to the thermally activated motion of vortices. This view was challenged a few years after the discovery of the cuprate superconductors by the theoretical work that predicted a “vortex glass” phase with zero resistance. Although an enormous number of experimental papers have been published in support of this theory, a new theory has recently proposed a “window-glass” scenario, which predicts a non-zero resistance. CSR researchers have argued that their new experimental evidence, as well as the many other papers in the literature, are, in fact, in favor of non-zero resistance. Further work will be needed to see which theoretical view is correct.

• Our near-field scanning microwave microscope has been used for quantitative imaging of dielectric constant, tunability, and ferroelectric polarization of thin films and single crystals. This microscope is unique in giving micron scale dielectric information at high frequencies. This information is useful for assessing technological applications of dielectric and ferroelectric thin films.

• In collaboration with CSR and MRSEC researchers, R. Ramesh’s group continues to carry out pioneering research in the field of multicomponent oxide thin films and heterostructures. In the area of ferroelectric thin films, they have demonstrated the ability to control point defects. Their work on nanoscale electric force microscopy of ferroelectric thin films has created a significant international excitement. A new area of research, based on spontaneous self-assembled oxide nanostructures has been initiated.

• R. Ramesh’s group continues to be active in creating new intellectual property based on the oxide thin film work ongoing. Five patent disclosures have been filed with the Office of Technology Liaison.

• S. Das Sarma’s work on Goldstone mode, Josephson effect, and neutral superfluidity in bilayer quantum hall systems was highlighted in the Search and Discovery section of Physics Today in its May 2001 issue in the context of related experimental observation of Das Sarma’s predictions. In general Das Sarma’s theoretical work on bilayer quantum coherence and quantum phase transitions has been highly cited, and has been influential in motivating experimental and theoretical work on the subject.

The past year has been another productive one for the CSR. We have continued to establish an international reputation for the high quality of our research, both basic and applied. The research emphasis of the CSR is very much in tune with national goals and we expect that our future research will continue to make strong contributions to the science and technology of advanced electronic materials and to the economy of the state.

Richard L. Greene
Director
INVITED TALKS

Anlage, S.

Quantitative Imaging with the Near-Field Scanning Microwave Microscope, Progress in Electromagnetics Research Symposium, Cambridge, MA (July 13, 2000).

Imaging Microwave Intermodulation Fields in a Superconducting Microstrip Resonator, Applied Superconductivity Conference, Virginia Beach, VA (September 22, 2000).


Barbara, P.


Cerne, J.

The Infrared Hall Effect in YBCO Thin Films, APS March Meeting, Seattle, WA (March 14, 2001).

Das Sarma, S.

Spin Electronics and Spin Computation, International Conference on Spintronics, Cortona, Italy (July 2000).

Intersubband Spectroscopy in Infrared Detection, International Optical Society of America Conference on Integrated Photonic Research, Quebec City, Canada (July 2000).


Metal-Insulator Transitions, Aspen Summer Workshop, Aspen, CO (July 2000).


Metal-Insulator Transition, International LD-3 Conference, Gainsville, FL (March 2001).

2D Metal-Insulator Transitions, APS March Meeting, Seattle, WA (March 2001).

Quantum Transport, International Semiconductor Transport Theory Workshop, Maratea, Italy (June 2001).

Drew, H.D.

IR Hall Effect in YBCO, Workshop on Strongly Correlated Electron Systems, Trieste, Italy (July 2000).


IR Hall Effect in High Temperature Superconductors, Ohio State University, Columbus, OH (February 23, 2001).

Anomalous Proximity Effect in Underdoped YBa$_2$Cu$_3$O$_{6+x}$ Josephson Junctions, McMaster University, Ontario, Canada (April 2, 2001).

IR Transport in the Cuprates: One Tau, Two Tau's or Tau$^2$?, Rutgers University, New Brunswick, NJ (April 24, 2001).


IR Transport in the Cuprates: One Tau, Two Tau's or Tau$^2$?, Los Alamos Laboratories, Los Alamos, CA (June 22, 2001).

Eichhorn, B.


Zintl Chemistry, Georgetown University, Washington, DC (April 5, 2001).

Greene, R.

Electron-doped High-T$_c$ Superconductors - Are They Different?, Colloquium - IBM Almaden Research Center, San Jose, CA (November 10, 2000).

Status of Electron-doped Cuprates, ITP Workshop on High-T$_c$ Superconductors, University of California, Santa Barbara, CA (August 15, 2000).

Hu, X.


Lee, C.

Ultrafast Optics for Microwave Photonics, The 2nd Korea-Japan Joint Workshop on Microwave Photonics, Seoul, Korea (February 1, 2001)

Lobb, C.


Smaller, Faster, Cheaper: From Transistors to Artificial Microstructures, Distinguished Scholar-Teacher Lecture at the University of Maryland, College Park, MD (October 2000).

Lynn, J.W.

Spin and Charge Correlation in the Cubic Manganites, Workshop on CMR Manganites and Related Transition Metal Oxides, Telluride, CO (July 2000).

Spin Dynamics and Polaron Formation in CMR Manganites, Telluride Workshop, Telluride, CO (July 2000).

Charge Correlations in (La-Ca)MnO₃, Conference on Magnetism and Magnetic Materials, San Antonio, TX (January 2001).

Spin and Charge Correlation in Colossal Magnetoresistive Systems, Texas A&M University, College Station, TX (February 2001).

Magnetic Order and Superconductivity: Competition, Coexistence, and Carnage, Texas A&M University, College Station, TX (March 2001).


Magnetic Order and Superconductivity: Competition, and Coexistence, Louisiana State University, Baton Rouge, LA (May 2001).

Ramesh, R.

Defects in Ferroelectric Thin Films, MRS Fall 2000 Meeting Symposium, Hynes Convention Center, Boston, MA (November 2000).

Ferroelectrics for Microwave Communications, MRS Fall 2000 Meeting Symposium, Hynes Convention Center, Boston, MA (November 2000).
Sharma, R.P.

Evidence for Electronic Phase Separation in High Tc Cuprates and CMR Manganites, International Symposium on Physics in Local Lattice Distortions, AIST Tsukuba Research Center, Ibaraki, Japan (July 23, 2000).

Direct Evidence for Electronic Phase Separations in High Tc Cuprates and CMR Manganites, Third International Conference on Stripes and High Tc Superconductivity, University di Roma, “La Sapienza” Roma, Italy (September 30, 2000).

Smolyaninova, V.

Anomalous Specific Heat of Charge-ordered Manganese Oxides, University of Sherbrooke, Quebec, Canada (November 8, 2000).

Takeuchi, I.

Combinatorial Materials Research at the University of Maryland, Japan-US Workshop on Combinatorial Material Science and Technology, Maui, HI (October 1, 2000).


Combinatorial Approach to Materials Research, Naval Research Laboratory, Washington, DC (June 11, 2001).

Wellstood, F.

From the Lab to Industry: Commercialization of the Scanning SQUID Microscope, Georgetown University, Department Colloquium, Washington, DC (September 14, 2000).

High-Tc SQUID Microscope for Nondestructive Testing of Electronic Circuits, 13th International Symposium on Superconductivity, Tokyo, Japan (October 16, 2000).

Scanning SQUID Microscopy, Solid State Colloquium, University of California, Berkley, CA (May 7, 2001).


Yakovenko, V.

Overview of Transport Models in Cuprates, XII Workshop on Strongly Correlated Electron Systems, Trieste, Italy (July 2000).

Electron Edge States in Quasi-1D and Quasi-2D Systems, XII Workshop on Strongly Correlated Electron Systems, Trieste, Italy (July 2000).

Electrons on Edge, ETH, Zurich, Switzerland (January 2001).

Electron Edge States in Triplet Superconductors (TMTSF)$_2$ and Sr$_2$RuO$_4$, University of Geneva, Geneva, Switzerland (January 2001).

Electrons on the Edge, University of Fribourg, Fribourg, Switzerland (January 2001).

Theory of the Electron Edge States in the Quasi-One-Dimensional Organic Conductors of the (TMTSF)$_2$X Family, Delft Technical University, Delft, Netherlands (February 2001).

Electrons on the Edge, Laboratoire de Physique des Solides, Orsay, France (February 2001).

Electron Edge States in Quasi-One-Dimensional Organic Conductors, Harvard University, Cambridge, MA (March 2001).

Electrons on the Edge, Boston College, Boston, MA (March 2001).

Electron Edge States in Quasi-One-Dimensional Organic Conductors, Massachusetts Institute of Technology, Cambridge, MA (March 2001).

Electron Edge States in Quasi-One-Dimensional Organic Conductors, University of Chicago, Chicago, IL (April, 2001).

Zutic, I.

Spin Transmission Through Interfaces, APS March Meeting, Seattle, WA (March 2001).
PUBLICATIONS

Applied Physics Letters


Ultraviolet Photoconductivity Detector Based on Epitaxial \( \text{Mg}_{0.25}\text{Zn}_{0.75}\text{O} \) Thin Films, W. Yang, R.D. Vispute, S. Choopun, R.P. Sharma, T. Venkatesan, and H. Shen, 78, 2787 (2001).


Chemistry of Materials


Foundations of Physics


IEEE Transactions on Applied Superconductivity


Integrated Ferroelectrics


Inorganic Chemistry


International Journal of Modern Physics B

Microwave Electrodynamics of LowTc and High Tc Systems with Coexisting Superconductivity and Magnetism, L.V. Mercaldo, V.V. Talanov, S.M. Anlage, C. Attanasio, and L. Maritato, 14, 2920 (2000).

Journal of Applied Physics


Charge Correlation in La₇₋ₓCaₓMnO₃, J.W. Lynn, C.P. Adams, Y.M. Mukovskii, A.A. Arsenov, and D.A. Shulyatev, 89, 6846 (2001)
Journal of Electronic Materials


Journal of Low Temperature Physics


Journal of Magnetism and Magnetic Materials


Journal of Modern Physics B


Journal of Physics and Chemistry of Solids


Journal of Solid State Chemistry


MRS Internet Journal of Nitride Semiconductor Research


Physica B


Physica C

Microwave Electrodynamics of the Electron-Doped Cuprate Superconductors Pr_{2-x}Ce_xCuO_4+y and Nd_{2-x}Ce_xCuO_4+y, J.D. Kokales, P. Fournier, L.V. Mercaldo, V.V. Talanov, R.L. Greene, and S.M. Anlage, 341, 1655 (2000).

Microwave Electrodynamics of the Antiferromagnetic Superconductor GdBa_2Cu_3O_7-s, L.V. Mercaldo, V.V. Talanov, and S.M. Anlage, 341, 1675 (2000).


Saturation of the Phase Coherence Length at Low Temperatures in Pr_{1.95}Ce_{0.05}Cu_3, P. Fournier, C.J. Lobb, and R.L. Greene, 341, 1941 (2000).

Physical Review B


Emission Mossbauer Study of the Electronic Phases in La_{0.5}Ca_{0.5}MnO_3, V. Chechersky, A. Nath, C. Michel, M. Hervieu, K. Ghosh, and R.L. Greene, 62, 5316 (2000).


Anomalous Field-Dependent Specific Heat in Charge-ordered $Pr_{1-x}CaMnO_3$ and $La_{0.5}Ca_{0.5}MnO_3$, V.N. Smolyaninova, A. Biswas, X. Zhang, K.H. Kim, B-G. Kim, S-W. Cheong, and R.L. Greene, 62, R6093 (2000).


Strain-Induced Local Distortions and Orbital Ordering in Nd_{0.2}Sr_{0.8}MnO_3 Manganite Films, Q. Qian, T.A. Tyson, C.-C. Kao, W. Prellier, J. Bai, A. Biswas, and R.L. Greene, 63, 224424 (2001).


Physical Review Letters


Charge Ordering and Polaron Formation in $\text{La}_{0.7}\text{Ca}_{0.3}\text{MnO}_3$, J.W. Lynn, C.P. Adams, Y.M. Mukovskii, A.A. Arsenov, and D.A. Shulyatev, 85, 3954 (2000).


Science


Silicon Carbide and Related Materials


Solid State Electronics


Synthetic Metals

Comparison of Experimental Data and Theoretical Calculations for Electrical Resistivity and Hall Coefficient in Quasi-One-Dimensional Organic Conductor (TMTSF)$_2$PF$_6$, V.M. Yakovenko and A.T. Zheleznyak, 120, 1083 (2001).

Conference Proceedings


Books & Chapters in Books


SEMINARS

9/26/00  Professor Paul Siedel - Jena University, Germany
         Superconducting Magnetic Field Sensors Application

9/26/00  Ingrid Wilke - University of Hamburg
         The Dielectric Properties of YBCO_6.0 Investigated by Terahertz Pulse Propagation

10/2/00  Juergen Halbritter - Forschungszentrum Karlsruhe, Germany
         Pseudogap and Transport in HTS

1/12/01  Dr. Wilfred Prellier - Laboratoire CRISMAT-ISMRA, Caen, France
         Thickness Dependence of the Stability of the Charge-ordered State in Pr_{0.5}Ca_{0.5}MnO_3 Thin Films

2/8/01   Alan Dorsey - Department of Physics, University of Florida, Gainesville
         Liquid Crystal Phases in Quantum Hall Systems

2/23/01  Alexander Tselev - TU Dresden
         Cross-Beam Pulsed Laser Deposition in Vacuum: Preparation of Thin Films Metastable Solid Solution

4/18/01  Dr. Andres Felipe Santander Syro - Ecole Normale Superieure and Ecole Superieure de Physique et Chimie Industrielles, Paris, France
         Infrared Reflectivity of Underdoped to Overdoped Bi_2Sr_2CaCu_2O_{8+d} Thin Films: Energy Scales in the Normal and Superconducting States

5/7/01   Dr. Carlos Sa de Melo - Georgia Institute of Technology
         Magnetic Coupling in Nanometer Scale Ferromagnet/Superconductor Multilayers
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Sankar Das Sharma
Dennis Drew
Bryan Eichhorn
Michael Fuhrer
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