

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. $\text{Pr}_{2-x}\text{Ce}_x\text{CuO}_4$ (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 $\text{La}_{0.5}\text{Ca}_{0.5}\text{MnO}_3$. Last year we found that this excitation is present in another CO system, $\text{Pr}_{1-x}\text{Ca}_x\text{MnO}_3$. 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 ($T_c=90\text{K}$), oxygen depleted YBCO ($T_c=60\text{K}$) and Zn doped YBCO ($T_c=40\text{K}$) 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 ($\sim 20\text{ meV}$) 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_2O_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 $\sim 20\text{-}25\text{ K}$ for *in-situ* anneal.
- The pulsed laser deposition process was optimized for the case of double perovskite ($\text{Sr}_2\text{FeMoO}_6$) films. High quality films are obtained only at a laser energy density about 2.5 J/cm^2 , very low ($\sim 1 \times 10^{-7}\text{ Torr}$) 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