## Research Activity: Experimental Condensed Matter Physics

Division: Materials Sciences and Engineering
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## Portfolio Description:

The portfolio consists of a broad-based experimental program in condensed matter and materials physics research emphasizing electronic structure, surfaces/interfaces, and the discovery of new materials. It includes the development and exploitation of advanced experimental techniques and methodology. The objective is to provide the understanding of the physical phenomena and processes underlying the properties and behavior of advanced materials. The portfolio includes specific research thrusts in magnetism, semiconductors, superconductivity, materials synthesis and crystal growth, and photoemission spectroscopy. The portfolio addresses well-recognized scientific needs, including understanding magnetism and superconductivity; the control of electrons and photons in solids; understanding materials at reduced dimensionality, including the nanoscale; the physical properties of large, interacting systems; and the properties of materials under extreme conditions.

## Unique Aspects:

The research on magnetism and magnetic materials has more emphasis and direction than in other federally supported programs. It focuses on hard magnet materials, such as those used for permanent magnets and in motors, and on exchange biasing, such as used to stabilize the magnetic read heads of disk drives. The Experimental Condensed Matter Physics (ECMP) activity continues to support research on electronically complex materials, an area that impacts a wide range of other topics including superconductivity, magnetoresistivity, low-dimensional electron systems, and magnetism including topics such as exchange bias and spin-polarized electron transport. The integrated photovoltaics program, consisting of research from this portfolio and technology from EE and EPRI, is both successful and a model for such integration. The combined projects in superconductivity comprise a concerted and comprehensive energy-related basic research program. The DOE laboratories anchor the efforts and maintain the integration with the EE developmental efforts. The LANL thermoacoustics program is unique, both scientifically and technologically. This work led to an R&D-100 award in 1999 and aspects are being developed commercially. The 100 T multi-shot magnet, under construction at LANL, is a multidisciplinary project in many different areas of materials design, materials research and high power systems. Two major areas research will be pursued upon completion of the magnet in 2005 which include magnetic field induced phase transitions in addition to nano-quantization and quantum size effect. The ECMP activity also has unique thrusts in photovoltaics and in photoemission investigations of superconductors. It is a source of new materials scientists through strong programs at LANL, SNL, Ames, ANL, BNL and Stanford**.** Internationally, the ECMP activity holds a position of world leadership in the areas of magnetism, superconductivity, materials characterization, and nanoscale science. It is dominant in photoemission characterization of cuprate superconductors. New, exciting areas launched within this activity in photonic band gap materials, 2-D electron systems, magnetic superconductors and quasicrystals are now pursued worldwide. Enhanced efforts are ongoing to generate high quality single crystals of new materials at Ames, ANL, BNL, ORNL and SSRL.

## Relationship to Others:

This activity supports the National Academy of Science's Solid State Sciences Committee, which in turn serves as a coordinating mechanism nationally. Within DOE, the activity is coordinated through the Energy Materials Coordinating Committee. The ECMP activity interacts with the BES Condensed Matter Theory and Neutron and X-Ray Scattering activities. Research in photovoltaics is coordinated with the Chemical Sciences, Geosciences and Biosciences Division and with the Photovoltaics Technology Division of EE. The activity also supports projects jointly with DP, FE, EE/RE and EPRI. In the areas of magnetism, superconductivity, and research on the control of electrons and photons in solids, this activity provides more support than the National Science Foundation's Condensed Matter Physics program.

## Significant Accomplishments:

The ECMP activity has a long history of accomplishments dating back to the 1950's and the first neutron scattering experiments at the Oak Ridge National Laboratory. Notable accomplishments include the discovery of ion channeling and the development of the field of ion implantation; the discovery of metallic and strained-layer superlattices; the establishment of the field of thermoacoustics and thermoacoustic refrigeration and heating; the invention of Z-contrast scanning transmission electron microscopy; the theoretical and predictive basis for photonic band gap materials; the tandem photovoltaic cell which holds the record for efficiency; the observation of stripes in superconductors; and, the invention of a Josephson junction scanning tunneling microscope and the first observation of superconductivity in a magnetically doped semiconductor ($PtSb_2$ with ~1% Yb). In addition, the activity has supported much of the seminal work in the fields of high temperature superconductors and quasicrystals, efforts now pursued worldwide.

## Mission Relevance:

This activity provides direct research assistance to the technology programs in EE (photovoltaics, superconductivity, power sources, thermoacoustics), FE (thermoacoustics), and DP (photoemission, positron research, and electronic and optical materials). In addition, it supports, more fundamentally, several DOE technologies and the strategically important information technology and electronics industries through its results in the fields of semiconductor physics, ion implantation and electronics research; the petroleum recovery efforts of FE and the clean-up efforts of EM through research on granular materials and on fluids; the OTT through research on advanced materials and magnets; energy conservation efforts through research on ion implantation, ultra-hard materials, superconductivity, thermoelectrics, and power source component materials; and DP through research on advanced laser crystals and weapons-related materials.

## Scientific Challenges:

Among the immediate on-going scientific challenges are: the solution of the mechanism for high temperature superconductivity; the understanding of “stripes” in correlated electron systems; the understanding of novel quantum effects and of “emergent phenomena,” that is, new phenomena that emerge when the complexity of a system grows with the addition of more particles; the development of a very high-magnetic field research program to exploit the 100T and 60T magnets at LANL; research in nanoscale science; low-temperature physics; and the continued development of a materials synthesis and crystal growth capability in this country. Quality materials lie at the heart of quality measurements: a thrust to develop a core competence in the synthesis of new materials and the growth of crystals is underway and it will continue to be a priority. High-magnetic-field research coupled with low temperature physics led to the discovery of the quantum Hall effect and to the general area of novel quantum effects. The availability of very high magnetic fields over useable time scales, as will be afforded by the new magnets at LANL, offers the promise of both increasing the fundamental understanding of matter and of observing the effects of very high magnetic fields on materials properties. This will undoubtedly lead to the discovery of new and exciting physics. Similarly, low temperature physics continues to be important for the advancement of physics by providing the experimental conditions necessary to observe phenomena such as BEC, the quantum Hall effect, and superconductivity. Developing and understanding matter and materials at the nano- and subnanoscale is a critical need because electronic, optical, and magnetic devices continue to shrink in size. Ballistic transport in quantum wires exceeding 5 μm in length may provide the basis for quantum computing.

## Funding Summary:

**Dollars in Thousands**

| FY 2003 | FY 2004 | FY 2005 Request |
|---|---|---|
| 37,205 | 40,500 | 42,449 |

| Performer | Funding Percentage |
|---|---|
| DOE Laboratories | 77% |
| Universities | 23% |

These are percentages of the operating research expenditures in this area; they do not contain laboratory capital equipment, infrastructure, or other non-operating components.

ORNL has the largest single program in the portfolio, comprising approximately 22% of the overall effort. ANL is second at 18%, followed by, in order, 9% at LBNL, 8% at Ames, and 7% BNL. Of particular note are: (1) the integrated and successful research (this activity) and technology (EE) program in photovoltaics at NREL; (2) LBNL with its world-class collection of “electronics” research, including molecular electronics based upon carbon species; and (3) LANL, where the thermoacoustics effort with joint funding from FE shows promise as a commercial technology, the project on photoemission spectroscopy of actinides has joint funding with DP, and the 100T magnet project. The forty-nine currently active university grants are distributed among forty universities in twenty-seven states and Puerto Rico. Included are one HBCU and one HSI.

## Projected Evolution:

The Experimental Condensed Matter Physics activity will include further work at the nanoscale; the development of a very high magnetic field research program; and continued development of the materials synthesis and crystal growth thrust. The portfolio can be expected to continue thrusts in electronic structure, new materials, surfaces/interfaces, and experimental techniques. For example, sum frequency generation is a new technique that is now being used to probe the electronic and vibrational structure of chiral molecules on surfaces. Femtosecond time-resolved magnetooptical, tehahertz and x-ray diffraction techniques will be used to study the coupled dynamics of charge carriers along with the associated lattice deformations in high temperature superconductors, colossal magneto-resistance manganites and charge density wave conductors. The subtopics also will be the similar, e.g., magnetism, low dimensional electron systems, and new materials. Low temperature physics and superconductivity both are important. Low temperature physics underlies several other areas of opportunity and presents issues of its own. Superconductivity, specifically high temperature superconductivity, continues to be a potentially revolutionizing technology. The goal for the former is to augment the investment in low temperature physics when possible. In superconductivity, the goal is to identify the most pressing scientific issues and ensure the level of effort is consistent with the priorities. New investigations in the Casimir force will be initiated. The attractive force between two surfaces in a vacuum predicted over 50 years ago, could affect everything from micromachines to unified theories of nature.