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Final Scientific Report

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Name of Recipient:

University of California, San Diego

Institute for Pure and Applied Physical Sciences

Project Title:

Acquisition of Single Crystal Growth and Characterization Equipment

Name of Principal Investigator:

M. Brian Maple

Contents

1 Scientific Report

1.1 Description of New Single-Crystal Growth Facility

1.1.1 Introduction

There is growing concern in the condensed matter community that the need for quality crystal growth and materials preparation laboratories is not being met in the United States. It has been suggested that there are too many researchers performing measurements on too few materials [see Physics Today, August 2007]. As a result, many user facilities are not being used optimally. The number of proficient crystal growers is too small. In addition, insufficient attention is being paid to the enterprise of finding new and interesting materials, which is the driving force behind much of condensed matter research and, ultimately, technology. While a detailed assessment of this situation is clearly needed, enough evidence of a problem already exists to compel a general consensus that the situation must be addressed promptly.

This final report describes the work carried out during the last four years in our group, in which a state-of-the-art single crystal growth and characterization facility was established for the study of novel oxides and intermetallic compounds of rare earth, actinide and transition metal elements. Research emphasis is on the physics of superconducting (SC), magnetic, heavy fermion (HF), non-Fermi liquid (NFL) and other types of strongly correlated electron phenomena in bulk single crystals. Properties of these materials are being studied as a function of concentration of chemical constituents, temperature, pressure, and magnetic field, which provide information about the electronic, lattice, and magnetic excitations at the root of various strongly correlated electron phenomena. Most importantly, the facility makes possible the investigation of material properties that can only be achieved in high quality bulk single crystals, including magnetic and transport phenomena, studies of the effects of disorder, properties in the clean limit, and spectroscopic and scattering studies through efforts with numerous collaborators. These endeavors will assist the effort to explain various outstanding theoretical problems, such as order parameter symmetries and electron-pairing mechanisms in unconventional superconductors, the relationship between superconductivity and magnetic order in certain correlated electron systems, the role of disorder in non-Fermi liquid behavior and unconventional superconductivity, and the nature of interactions between localized and itinerant electrons in these materials. Understanding the mechanisms behind strongly correlated electron behavior has important technological implications.

In the past, mosaic assemblages of small single crystals were usually prepared to facilitate neutron scattering, NMR, and μSR studies. These mosaics are inherently somewhat inhomogeneous and anisotropic, but were necessary because the aforementioned probes require sample surface areas of the order of 1 cm^2, a size much larger than many of the crystals that we were able to grow with the older techniques available in our laboratory. Currently, our facility is helping to fulfill two basic needs: the ability to synthesize large, high quality single crystals of compounds for which we were previously only able to grow small crystals, and the ability to make single crystals of compounds for which we previously lacked the facilities to grow any crystals at all. Even for smaller crystals, the Czochralski and optical floating zone furnaces have greatly enhanced our control of the doping concentrations, which in turn reduces composition uncertainty. This is immensely beneficial, as studies of doped flux-grown single crystals are often complicated by flux inclusions and non-uniform distribution of the dopant into clustered regions. In some systems, the effect is more pronounced at concentrations in the vicinities of quantum critical points, where dopant concentrations can be extremely inhomogeneous and crystals grow only to small size. These very compositions require the most scrutiny, often displaying the most dramatic and intriguing properties, such as NFL behavior. In turn, these properties are highly sensitive to small changes in chemistry at these concentrations. Crystals of certain stoichiometric compositions cannot be grown with sufficient quality without the equipment acquired under this grant. A representative example is Sr_2RuO_4, a *p*-wave superconductor that does not superconduct in flux-grown crystals; however, crystals grown in an optical floating zone furnace do exhibit superconductivity. Measurements such as magnetic susceptibility, magnetoresistance, pressure effects and thermal conductivity – all of which can be sensitive to material defects, grain boundaries, atomic defects, and crystallographic orientation – are currently performed on-site. We are also distributing samples to the many researchers with whom we maintain ongoing collaborations in neutron and x-ray scattering, spectroscopy, NMR, and other techniques. These investigations will help resolve presently open questions regarding the underlying nature of many interesting and often technologically useful phenomena.

Superconducting, magnetic and thermoelectric materials are key components in many technologies that are essential to modern society. Small amounts of disorder, chemical substitution or pressure can induce or destroy superconductivity or magnetism in many materials for reasons that are still not well understood. Further understanding of the fundamental mechanisms underlying electron correlations strengthens the ability to predict and design materials that will make superior superconductors, magnets or thermoelectrics, and creates conditions under which their properties will be of optimal utility. Consequently, the ability to more precisely study these effects will be of tremendous value. In the past, single crystal growth in this laboratory was achieved only via the flux growth process. Although this allows the growth of single crystals of some materials, such as $CeMIn_5$ and Ce_2MIn_8 (M = Co, Rh or Ir) using an indium flux, and some ternary skutterudites RT_4X_{12} (R = lanthanide, Th or U, T = Fe, Ru, or Os, and X = P, As or Sb) using either an antimony or tin flux, it cannot be used to grow many of the compounds in which current research interest lies. Furthermore, most of the single crystals grown by this method are too small for several important measurements, including neutron scattering, μSR, and some types of optical measurements. The flux growth method is further plagued with flux inclusion and significant time required to optimize the heating schedule. At present, the best method to grow single crystals of many transition metal oxides, including the high T_c oxides, is with a floating zone image furnace, while a multi-arc furnace coupled with a Czochralski crystal pulling system is ideal for intermetallic compounds. Image furnaces use parabolic mirrors to focus light from several halogen bulbs onto a heating region while a specially prepared sample is pulled through the hot zone. This method results in single crystals with diameters up to 1 cm and lengths up to 8 cm. Multi-arc furnaces can melt a sample using a typical arc method with the benefit that the multiple arcs insure an even heating area and thus uniform composition throughout the crystal. Coupled with the crystal pulling system, single crystals of 8 mm diameter by 8 cm lengths can be grown. By 2004, there were too few laboratories in the United States performing bulk single-crystal growth of strongly correlated electron materials. Most bulk single crystal samples of these compounds are still synthesized in Japan and Europe, as those regions have invested in the appropriate crystal growth equipment. At the same time, large growth in U.S. spectroscopy and scattering capability has lead to increasing domestic demand for large, high-quality single crystals for use in these experiments. During the period mentioned above, and with the economical resources provided by this grant, we are glad to report that we had established a domestic single-crystal growth capability that is already helping to meet this need.

1.1.2 Equipment Acquired During Grant Period

The upgraded single-crystal growth facility consists of three main pieces of equipment: an optical floating zone furnace, a tetra-arc furnace with Czochralski crystal puller and an x-ray diffractometer. Together, these three pieces of equipment are capable of producing and characterizing a broad spectrum of intermetallic and oxide compounds. Both classes of materials are central to the study of strongly correlated phenomena as they continue to provide new compounds demonstrating novel correlated electron phenomena.

This laboratory has over thirty years of experience in both producing and performing measurements on these materials. The new facility has been integrated into the existing laboratory, expediting commencement of the single crystal research program. The tetra-arc furnace with Czochralski crystal puller from Techno Search Corp. (model TCA5), which is already being used for the growth of high-quality intermetallic single crystals, consists of several parts. The main chamber of 208 mm internal diameter is built of stainless steel and is water-cooled to support maximum temperatures of 3000 °C. It has three viewing ports, one of which is complemented with a CCD camera that allows us to record videos of the growth. The power supply unit consists of five sources, four for melting (maximum current: 320 A) and one for gettering, and provides the stability required to insure even heating of the sample during crystal growth. Because the growth of high-quality single crystals requires a contamination free environment, a pumping system consisting of a compound turbomolecular pump (Osaka Vacuum Ltd., TG220F) and direct-drive oil sealed rotary pump (ULVAC KIKO, Inc., GVD-050A) is being used. This configuration is able to reach vacuums on the order of 10^{-6} mbar, although actual crystal growth is performed in an argon atmosphere. The furnace is coupled with a crystal puller capable of rotation speeds up to 20 rpm and pulling speeds up to 20 mm/hr. This system has been shown to reliably produce high-quality single crystals with diameters of 8 mm and lengths of 8 cm.

An optical floating zone furnace, also known as an image furnace, has been fully installed and used to produce high-quality transition metal oxide single crystals. The furnace and most of the ancillary equipment was acquired from NEC Machinery Corporation, including apparatus for proper sample preparation, which is very important for effective use of the image furnace. First, in order to make the feed rod, the mixture of desired materials is placed in a rubber tube, and pressed with a hydrostatic press to pressures up to 400 MPa (~ 4000 atm). The pressed rod is then sintered at 1200 °C, in order to give it a uniform sintered density. The sintered rod is then placed in the optical floating zone furnace, where ellipsoidal gold plated mirrors focus light from two halogen bulbs onto the rod. Temperatures up to 2100 °C are attainable under a variety of atmospheres and in pressures ranging from 5×10^{-5} torr to 9.9 bar. As the sintered rod is passed through the float zone, a single crystal is produced with dimensions of up to 8 mm in diameter and 9 cm in length. After the crystals are produced and their orientation is determined using the x-ray diffractometer, a diamond saw and fine polisher are used to give a final product ready to characterize via transport, magnetic susceptibility and other techniques.

A Bruker D8 Discover x-ray diffractometer has been installed to characterize samples grown by the Czochralski, flux, and optical floating zone methods. Unlike many single crystal x-ray diffractometers, this system is designed to measure reflected x-rays, which is essential for our application because single crystals grown in the tetra-arc and image furnaces will be too thick to measure in transmission. The x-ray source is a 2.2 kW Cu sealed tube powered by a Kristalloflex K780 generator. The system features a Hi-Star area detector with a 11.5 cm detector window on a multiwire proportional chamber, a highly efficient detector that will facilitate fast data collection while still achieving the resolution required for detailed crystallographic analysis. The sample mount is a 1/4-circle Eulerian cradle assembly with a 80 mm × 80 mm x-y scanning capability, and even larger samples can be accommodated. A video camera with an attached laser allows visual alignment of the sample. A PC, loaded with software capable of simultaneous diffractometer control and diffraction analysis, remotely runs the system. The software can automatically orient crystals, identify faces, recognize twinning or modulated structures, characterize texture, and solve full crystal structures, greatly reducing time spent on analysis. Moreover, the machine can perform 2D powder diffractometry, extending its utility to non-single-crystal applications. The diffractometer plays a critical role in the proposed facility: growth of high quality single crystals requires accurate characterization of samples. It is necessary to identify structural phases and chemical inhomogeneity to determine the growth conditions under which single crystals of desired compositions can be grown, which are currently established by trial and error. Even when optimal growth is achieved, superfluous secondary grains might be identified and removed. The D8 system has the ability to detect twinning and structural modulation, and quantify sample texture, providing a clear description of sample quality. While a full scan on an unknown crystal typically takes between two and three hours, the quick analysis has been essential to receiving efficient feedback to fine-tune sample growth procedures. Polycrystalline samples of $CeRu_2$ and $CeRhIn_5$ analyzed at Bruker demonstrated the system's ability to determine their purity and grain distribution. Once a single crystal is isolated, the diffractometer is used to perform detailed crystallographic analysis, providing a precise characterization of the single crystal. We can also determine the crystallographic orientation of the samples, facilitating studies of anisotropy in transport and magnetization, in addition to neutron scattering, μSR, and other measurements that are usually performed by our collaborators. In the future, it will be possible to upgrade the D8 system with an Oxford Helix closed-cycle cryogenic attachment that can cool the sample stage to 27 K and permit the determination of structural phase transitions below room temperature.

To expand our current facility for characterization of single crystal samples, we ordered a Spectrostat Continuous Flow ^{4}He Cryostat from Oxford Instruments. This system will be used to perform high-pressure diamond anvil cell magnetic susceptibility measurements on samples that we grow in our laboratory. We plan to measure the pressure dependence of T_c using the most nearly hydrostatic pressure medium available: helium. Superconducting transitions have been measured using ac magnetic susceptibility under such nearly hydrostatic conditions to pressures approaching 1 Mbar [Hamlin 06]. In the case of elemental lithium, helium pressure medium diamond anvil cell measurements [Struzhkin 02] revealed important features in the superconducting phase diagram that were obscured in the less hydrostatic resistivity measurements [Shimizu 02, Struzhkin 02]. These high-pressure experiments will reveal important information about the optimal conditions for high superconducting critical temperatures and will feed-back into our sample growth program by suggesting chemical substitutions which may lead to higher T_c values at ambient pressure.

The cryostat is fit with an axial window to allow *in situ* pressure measurement at low temperatures via the calibrated ruby scale [Chijioke 05]. The window flanges on such cryostats are usually made of indium, which becomes superconducting at low temperatures. The superconductivity of the window flange would cause problems for our sensitive ac magnetic susceptibility measurements. We therefore worked with Oxford Instruments to incorporate a special non-superconducting copper window flange which will not interfere with our ac magnetic susceptibility measurements. The cryostat is currently under construction at Oxford Instruments and we are awaiting the expected delivery in January 2009. Concurrently, we are setting up a space in our laboratory for the new cryostat. The cryostat will be mounted above a full sized optical bench making it possible to expand our facilities for optical characterization in the future.

We have recently acquired various components for the assembly of a custom ultra-high vacuum chamber for pulsed laser deposition (PLD) of thin films that is to be devoted to the growth of high quality single crystal actinide intermetallic compounds. The growth of good quality intermetallic films is often technically challenging, while the compounds of interest can be very sensitive to the defects often found in films. However, having developed techniques for reproducibly growing rare earth intermetallic thin films, we are now expanding our studies to actinide compounds. After the assembly and testing stages of the ablation chamber are completed, our PLD thin film growth facility will be capable of performing routine growths of actinide compounds that are of great interest to the condensed matter community, such as the heavy fermion superconductors UBe_{13}, UPt_3, URu_2Si_2, UPd_2Al_3, UNi_2Al_3, UGe_2, URhGe, and U_6Fe. The production of these thin films make possible studies of properties that cannot be performed on bulk materials, such as various spectroscopies, tunneling measurements, lattice strain studies, and critical current density measurements.

In order to characterize the complex single crystals grown in our facility in greater detail, we have acquired a specialized 7 tesla SQUID magnetometer that is capable of determining the response of the sample to an applied magnetic field in directions both parallel and perpendicular to the field direction and can map out the vector nature of this response in a full 360º range. By being able to perform these characterization measurements we can further monitor the quality of the grown single crystals. Furthermore, from these measurements we can now obtain additional vital information that can aid in determining how to adapt our growth procedures so as to produce the desired high quality single crystals.

1.1.3 Use and Upkeep of Facilities

This laboratory has distinguished itself by decades of effective materials preparation. Group members are all trained in crystal growth techniques and spend a large fraction of their time making samples. As a result, an experienced and capable research staff is already in place to oversee the facility. Operational costs are currently covered in part by research funding already acquired under other grants.

1.1.4 Project Activities

Despite having been studied for many years, most correlated f-electron materials are still not completely understood. A common concern raised in the investigation of novel electronic behavior is that of sample quality and how the quality affects the physical properties of interest. As discussed earlier in this document, questionable dopant and/or phase homogeneity is often present near compositions of interest, such as those at suspected quantum critical points (QCPs). Theories have been developed that take disorder into account or even invoke it as the fundamental cause, for example, of NFL behavior or flux pinning. Another obstacle to research is that physical properties in many systems are anisotropic, a condition that requires high quality single crystal specimens in order to measure the effects of anisotropy accurately, as they get directionally averaged in lower-quality samples. Considering the matters outlined above, we set up a state-of-the-art single crystal facility which allows us to control the preparation and investigation of single crystals of novel f-electron materials. The work carried out in this new facility is firmly based on years of well established precedent and helps to clarify important open questions about the nature of QCPs, NFL behavior and unconventional superconductivity, and the recently discovered new family of iron-based high temperature superconductors. Reviews of the recent history of this research have been provided in the proposals for this grant presented in 2004 and 2005.

During the period of time covered by this grant (2004 – 2008), we set up our new, improved, single crystal growth facility. We purchased three major pieces of equipment (the optical floating zone furnace or mirror furnace, the tetra-arc furnace and the D8 diffractometer), along with other systems and upgrades to older systems that enable us to continue with the flux-growth single crystal technique and to characterize the physical properties of the samples grown in this laboratory. An example of this complementary equipment is a new leak detection system, which was purchased and is frequently used to test the various high vacuum chambers of our furnaces and other equipment. Our new facility is now located in the newly constructed addition to Mayer Hall, the building housing the Physics Department at UCSD. Figures 1.1 and 1.2 show one of the rooms of the new facility, and the newly purchased equipment can be seen in the following figures.

Figure 1.1 – The new sample preparation laboratory. Several microscopes are used to work with the samples.

Figure 1.2 – The argon glove box serves to handle and store air sensitive materials.

Several experiments were carried out to test the new equipment, which also served as starting points to this new phase of our research program. The following paragraphs briefly describe some of the most important achievements made possible by the new materials synthesis and crystal growth facility.

Studies of the $URu_{2-x}Re_xSi_2$ system have resulted in a rich variety of types of behavior. First, there is a complicated T-H-P phase diagram for URu_2Si_2. Especially compelling is the existence of a hidden order parameter that seems to be responsible for a large entropy change [Schlabitz 84, Palstra 85, Maple 86] that cannot be explained by the small measured moment [Bourdarot 03, Suslov 03, Kim 03]. Pressure studies suggest a crossover to a true AFM state under applied pressure [Motoyama 03]. Nevertheless, the ordered phase is not understood and more single crystal studies of URu_2Si_2 are necessary. Re substitution exposes yet more complicated behavior, including AFM (spin density wave - SDW) and SC transitions driven to zero temperature with increasing x, the emergence of FM order at still higher x, and an NFL state in between [Dalichaouch 89, Bauer 05]. At present, it seems that a Griffiths-McCoy scenario may explain the NFL behavior because the T-dependence is not similar to that predicted for proximity to either FM or AFM (SDW) QCPs. However, neutron scattering measurements on single crystals with compositions at the FM and AFM (SDW) QCPs would help to determine the nature of the magnetic transitions and the energy and temperature dependence of the imaginary part of the dynamical susceptibility. Investigation of the effects of disorder would also contribute to understanding of the NFL properties. Studies of URu_2Si_2 system under pressure and in field would not only give more information about the QCPs, but could also shed light on the nature of the hidden order parameter at $x = 0$.

At the present moment, we have successfully grown in the tetra-arc furnace single crystals of $URu_{2-x}Re_xSi_2$ for Re concentrations of $x = 0$, 0.12 and 0.8. The ongoing project involves the participation of other investigators from various institutions: Jonathan Denlinger (Lawrence Berkeley National Laboratory), x = 0.8 for ARPES studies; Elizabeth Blackburn (U. Birmingham), x = 0, small angle scattering; Jeff Lynn (NIST), x = 0, neutron scattering under pressure; Pengcheng Dai (U. Tennessee and Oak Ridge National Laboratory) with various Re concentrations for neutron scattering; Jason Jeffries (Lawrence Livermore National Laboratory), x = 0, for high pressure measurements and TEM studies; Ali Yazdani (Princeton U.), x = 0, for STM studies. Besides the $URu_{2-x}Re_xSi_2$ doping study, we are currently working on the growth of UGe_2, URhGe and UCoGe single crystals.

Figure 1.3 – The tetra-arc furnace in its current location. The CCD camera mounted outside of one of the three window ports allows us to record the growth in a video. Videos can be viewed at our website (http://mbmlab.ucsd.edu/facility.html).

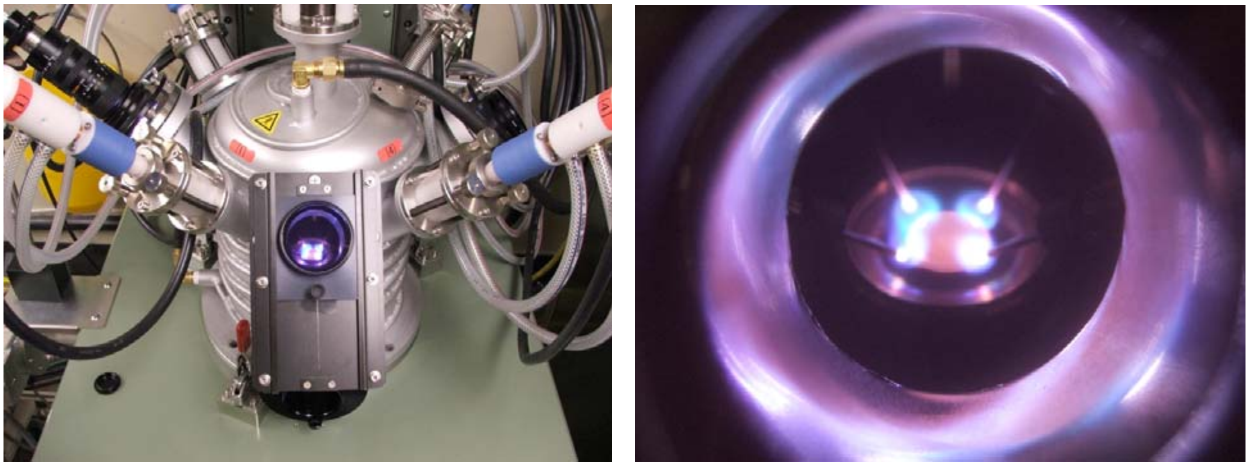

Figure 1.4 – (*Left*) The chamber of the tetra-arc furnace. (*Right*) Detail of the inside of the chamber during normal operation. The plasma created with the four electrodes gives a homogeneously heated sample.

High T_c superconductor single crystals grown with an optical floating zone furnace are desirable due to a greatly enhanced control of doping concentrations. Controlled, homogenous doping greatly reduces composition uncertainty. Studies with flux grown single crystals such as $Pr_xY_{1-x}Ba_2Cu_3O_{7-\delta}$ and $R_{2-x}Ce_xCuO_4$ (R = Nd, Pr, Sm, Eu) are complicated by a non-uniform distribution of dopant atoms into clustered regions. This also leads to difficulty in growth of materials with concentrations that are near the values where superconductivity is suppressed, as the stoichiometric molten flux is often inhomogeneous with respect to the dopant atoms. Electron-doped compounds have the largest anisotropy among the high temperature cuprate superconductors. We are engaged in an extensive effort to fabricate high-quality single crystals of the electron-doped compounds in order to study the anisotropic components of various superconducting and normal state properties. High-quality single crystals of $R_{2-x}Ce_xCuO_4$ (R = Nd, Pr, Sm) with various values of x were grown from a Cu-O flux. We were able to vary the T_c of these crystals from 7 K up to 25 K by varying the Ce and/or oxygen concentration. Magnetic measurements reveal that the Meissner fraction of the crystals is a maximum for maximum T_c and decreases monotonically as T_c is decreased. The crystals we have grown are used in different experiments in our laboratory here at UCSD, as well as in several collaborative efforts. The wide range of experiments that have been performed attest to the high quality of these crystals.

Titanium oxide (TiO_2) is a well-known compound for its ease of growth with the image furnace and it was therefore used as a test run to ensure the furnace was operational. Titanium oxide bulk single crystals were grown in the image furnace using the Traveling Solvent Floating Zone (TSFZ) method. The TSFZ method involves two pressed rods, a feed and a seed, where the feed rod is melted and resettled onto the seed rod, effectively growing the seed rod. Successful growths of TiO_2 were performed in both air and in pure argon flow.

Aluminum oxide (Al_2O_3) doped with trace amounts of chromium oxide (Cr_2O_3) single crystals, commonly known as *ruby*, was also grown in the image furnace using the TSFZ method mentioned before. A 2 cm long, 0.5 cm in diameter single crystal of ruby grown in our image furnace is shown in figure 1.6. Creating appropriate length pressed rods proved difficult as the

Al_2O_3 powder particles did not readily adhere to one another. Rod formation was improved with the acquisition of a new cold isostatic press, capable of pressures up to 60 kPsi.

NCCO ($Nd_{2-x}Ce_xCuO_4$) bulk single crystals were successfully grown in the image furnace using a modified TSFZ. The positions of the feed and seed were switched compared to other growths, a solvent pellet of mostly CuO was kept in the molten zone to reduce the melting point of NCCO and portions of the reflected light from the halogen bulbs were screened to create a steeper temperature gradient. NCCO was also grown in a mixture of pure argon and pure oxygen. Magnetization measurements performed in the SQUID magnetometer showed that the materials were superconductors with T_c = 20 K, which corresponds to the optimally doped region reported in the literature.

Figure 1.5 – (*Left*) The image furnace main chamber. (*Right*) Detail of one of the gold-plated mirrors.

Figure 1.6 – (*Left*) A photograph of an NCCO single crystal grown in the mirror furnace. (*Right*) A 2 cm long single crystal of *ruby*.

Following a recent report of superconductivity at 26 K in the compound $LaFeAsO_{1-x}F_x$, our group has been focused on an intense effort to discover new related superconductors based on P, Sb, or Bi, instead of highly toxic As. This effort has involved more than fifty growth attempts, each of which frequently results in several different types of crystals. Our Bruker D8 x-ray diffractometer has been invaluable in this research program by allowing us to rapidly identify interesting growth products. Our work on the superconducting compound LaFePO has recently been published [Hamlin 08]. Furthermore, we discovered two new phosphorus-based superconducting oxypnictides: PrFePO (T_c = 3.2 K) and NdFePO (T_c = 3.1 K) [Baumbach 08]. The short collection times required by the Bruker D8 diffractometer have allowed us to study nearly all of our many growth byproducts, leading us to identify a series of largely uninvestigated Fe-pnictide compounds. We are currently preparing a manuscript [Maple 08] on these materials which appear to exhibit a wide variety of magnetic, non-Fermi-liquid, and heavy fermion behavior.

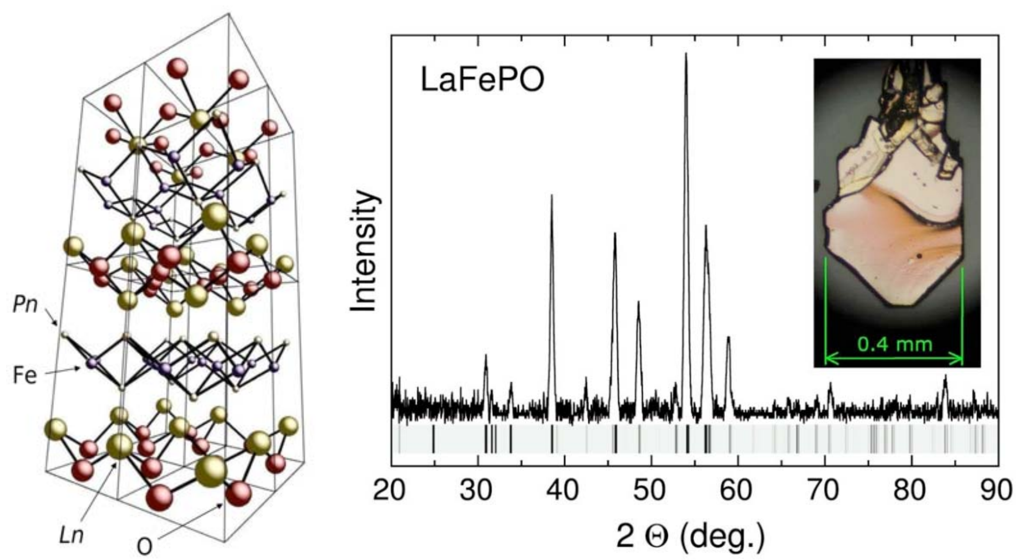

Figure 1.7 – (*Left*) Crystal structure for LnFePnO (Ln = lanthanide, Pn = pnictide) showing alternating Ln-O and Fe-Pn layers. (*Right*) Powder x-ray diffraction pattern of a LaFePO single crystal obtained in the laboratory with the new Bruker D8 diffractometer. The photograph shows a typical single crystal.

2 Products Developed Under Award

2.1 Scientific Publications

- Toni Feder, "US Condensed-Matter Community Grapples with Availability of Crystalline Samples," Physics Today, Volume 60, Issue 8, pp. 26-28 (2007). Photographs of single crystals of $URu_{2-x}Re_xSi_2$ and filled skutterudites grown in our laboratory are featured in this article.
- J. J. Hamlin, R. E. Baumbach, D. A. Zocco, T. A. Sayles and M. B. Maple, "Superconductivity in single crystals of LaFePO," Journal of Physics: Condensed Matter 20, 365220 (2008); arXiv:0812.0774.
- R. E. Baumbach, J. J. Hamlin, L. Shu, D. A. Zocco, N. Crisosto, and M. B. Maple, "Superconductivity in LnFePO (Ln = La, Pr, and Nd) single crystals," submitted to New Journal of Physics (2008).
- M. B. Maple *et al.*, manuscript in preparation for the Proceedings of the International Conference on Strongly Correlated Electron Systems, Buzios, Brazil, 2008.

2.2 Ph.D. Theses

Postdoctoral researchers, graduate students, and undergraduate students have been trained in the preparation and characterization of novel materials and the measurement of their physical properties as a function of temperature, pressure, and magnetic field. This program contributed to the education of undergraduate students by providing hands-on experience in the laboratory. Modern state-of-the-art equipment and techniques developed in this research program have been introduced into a condensed matter/materials science laboratory class at UCSD that the principal investigator helped develop and frequently teaches. Undergraduate students who participated in the proposed research include students who worked during the summer under the NSF-sponsored Research Experience for Undergraduates Program, UCSD students enrolled in independent study (Physics 199), and UCSD underrepresented minority students. Other outreach activities have included 15 laboratory tours for high school and undergraduate students, science demonstrations at local elementary schools, and popular lectures given by the principal investigator and group members.

- N. A. Frederick, "Superconductivity, Heavy Fermion Behavior, and Crystalline Electric Field Effects in the Filled Skutterudite Series $Pr(Os_{1-x}Ru_x)_4Sb_{12}$," (2005) *** Current position: Analyst at Independent Project Analysis, Inc.**

- W. M. Yuhasz, "A Study of Strongly Correlated Electron Behavior in the Filled Skutterudites," (2006). ***Current position: Postdoctoral research scientist at Iowa State University, Ames.**

- B. J. Taylor, "Evolution of vortex dynamics along the vortex-matter melting line in the high-T_c superconducting cuprates $Y_{1-x}Pr_xBa_2Cu_3O_7$ and $YBa_2Cu_3O_{6.5}$," (2006). ***Current position: Postdoctoral research physicist at the University of California, San Diego**

- D. A. Scanderbeg, “Thin Film Growth and Characterization of the Electron-Doped Superconductor $Sm_{2-x}Ce_xCuO_{4-y}$,” (2007). ***Current position: Postdoctoral researcher in radiology at the University of California, San Diego, Medical School.**

- J. R. Jeffries, “Correlated Electronic States Under Extreme Conditions,” (2007). ***Current position: Postdoctoral research physicist at Lawrence Livermore National Laboratory.**

- N. P. Butch, “The Search for Quantum Criticality near the Convergence of Hidden Order and Ferromagnetism,” (2008). ***Current position: Postdoctoral research physicist at University of Maryland.**

- T. A. Sayles, “Magnetism and Superconductivity in Pr-based Filled Skutterudite Arsenides,” (2008). *** Current position: Research scientist at Quantum Design.**

2.3 Students Who Conducted Research Under This Grant

Postdoctoral Researchers

Pei-Chun Ho	2001-2007
Johnpierre Paglione	2004-2007
Neil Frederick	2005-2006
Tatsuya Yanagisawa	2005-2007
William Yuhasz	2006-2007
Benjamin Taylor	2006-Present
James Hamlin	2008-Present
Lei Shu	2008-Present

Graduate Research Students

Neil Frederick	1999-2006
Benjamin Taylor	1999-2006
William Yuhasz	2000-2007
Daniel Scanderbeg	2000-2006
Nicholas Butch	2001-2008
Todd Sayles	2001-2008
Ryan Baumbach	2002-2008
Keith Chan	2005-2007
Diego Zocco	2005-Present
Columbine Robinson	2006-2007
Ashish Tripathi	2007
Colin McElroy	2007-Present
Kevin Huang	2008-Present
Jacob Stanley	2008-Present

Undergraduate Research Students

Columbine Robinson	2005-2006
Colin McElroy	2005-2007
Benjamin Yukich	2005-2007
Yong-Chan Kim	2005-2007
Patrick Johnson	2007
Christopher Lee	2007-2008
Eileen Gonzales	2007-Present

Research Experience for Undergraduates Students

Matthew W. Motley, Mark J. McClelland	2004
Zachery Dupre	2005
David Miller, Kevin Zielnicki	2006
Xiaoqian Zhang	2007
Nicole Crisosto	2008

Visiting Graduate Students

Kai Berggold	2004

Volunteer Students

Patrick Johnson	2004
Christopher Malotte	2004
Brian J. Maertz	2006
Keith Chan	2006
Patrick Johnson	2006
Chris Miles (M.I.T.)	2007
Nick Baker	2007
Kevin Huang	2007
Kristopher Konrath	2008
Ivy Lum	2008
Jennifer Duong	2008

2.4 Networks and Collaborations Fostered

In order to perform measurements that require specialized techniques or national facilities, we have collaborated with other researchers and their groups. Rare earth and actinide HF compounds, Kondo insulators, and NFL materials have been investigated in collaboration with several researchers. Regular collaborators include the following: F. Steglich and coworkers (Max Planck Inst., Dresden) have performed specific heat $C(T)$, thermal conductivity $\kappa(T)$, and thermal expansion $\alpha(T)$ measurements under pressure; S. K. Sinha (UCSD), J. W. Lynn (NIST), M. Aronson (U. Michigan), R. Osborn (ANL) and H. A. Mook, P. Dai, and V. Krishnamurthy (ORNL) carried out neutron scattering experiments; J. W. Allen (U. Michigan) and coworkers performed photoemission spectroscopy measurements; D. N. Basov and his group (UCSD) made infrared spectroscopy measurements; H. von Lohneysen, C. Pfleiderer and G. Goll (U. Karlsruhe) performed point – contact spectroscopy and C(T) measurements under pressure at low temperature; D. E. MacLaughlin (UC, Riverside) and T. Kohara (Himeji Inst. Tech., Japan) made NMR and μSR measurements; and L. J. Sham (UCSD) and D. L. Cox (UC, Davis) have lent theoretical support. S. Weir (LLNL) provided “designer diamond anvil” cells with embedded wires for electrical resistivity and magnetization measurements at high pressure. Physical properties at high H and low T have been studied at the National High Magnetic Field Laboratory facilities in Los Alamos and Tallahassee. Many of these collaborators have been working with us for a number of years and have made major contributions to our joint research.

2.5 Invited Talks and Conference Presentations

- M. B. Maple, “Superconductivity in layered transition metal pnictides,” California Condensed Matter Theory Meeting, University of California - Riverside, November 1st – 2nd, 2008.

- M. B. Maple, “Unconventional superconductivity in novel d- and f-electron materials,” Conference on Concepts in Electron Correlation, Hvar, Croatia, September 24th – 30th, 2008.

- D. A. Zocco, N. P. Butch, J. R. Jeffries, J. J. Hamlin, and M. B. Maple, “Superconductivity and magnetism in Fe-based pnictides under pressure,” Poster session: Conference on Concepts in Electron Correlation, Hvar, Croatia, September 24th – 30th, 2008.

- J. J. Hamlin, D. A. Zocco, T. A. Sayles, M. B. Maple, J.-H. Chu, and I. R. Fisher, “Superconductivity, magnetism and charge density waves in rare-earth tritellurides under pressure,” Poster session: Conference on Concepts in Electron Correlation, Hvar, Croatia, September 24th – 30th, 2008.

- M. B. Maple, “Strongly correlated electron phenomena in filled skutterudites,” ARW Workshop on Correlated Thermoelectrics: Properties and Applications of Thermoelectric Materials, Hvar, Croatia, September 20th – 26th, 2008.

- D. A. Zocco, J. J. Hamlin, R. E. Baumbach, T. A. Sayles, N. P. Butch, M. B. Maple, J.-H. Chu, I. R. Fisher, M. A. McGuire, A. S. Sefat, B. C. Sales, R. Jin, D. Mandrus, J. R. Jeffries, S. T. Weir, and Y. K. Vohra, “Pressure dependence of electronic ground states in f-electron materials,” Poster session: ARW Workshop on Correlated Thermoelectrics: Properties and Applications of Thermoelectric Materials, Hvar, Croatia, September 20th – 26th, 2008.

- M. B. Maple, “Correlated electron phenomena in filled skutterudite compounds,” Sonderforschungsbereich SFB 463 Symposium on Rare-Earth Transition-Metal Compounds: Structure, Magnetism, and Transport, Bad Schandau, Germany, September 2nd, 2008.

- M. B. Maple, “New correlated electron physics from new materials,” International Conference on Strongly Correlated Electron Systems, Buzios, Brazil, August 17th – 22nd, 2008.

- M. B. Maple, “Unconventional superconductivity, magnetism, and quadrupolar order in the heavy fermion compound $PrOs_4Sb_{12}$ and its derivatives,” International Seminar and Workshop on Competing Orders, Pairing Fluctuations, and Spin Orbit Effects in Novel Unconventional Superconductors, COFUS ’08, Dresden, Germany, July 2nd, 2008.

- M. B. Maple, Closing Remarks, 2nd Workshop on Novel Electronic Materials, Lexington, KY, May 17th, 2008.

- M. B. Maple, “Correlated electron phenomena in Ce- and Pr- based filled skutterudite arsenides and antimonides,” 2nd Workshop on Novel Electronic Materials, Lexington, KY, May 15th, 2008.

- M. B. Maple, “Evolution of superconducting and hidden order phases in URu_2Si_2 under applied pressure,” Materials Research Society Spring Meeting, San Francisco, CA, March 28th, 2008.

- B. Taylor, R. E. Baumbach, and M. B. Maple, “Progression of the vortex-solid to vortex-liquid phase boundary with oxygen doping in $Y_{0.8}Ca_{0.2}Ba_2Cu_3O_x$ films,” American Physical Society March Meeting, New Orleans, LA, March 10th – 14th, 2008.

- N. P. Butch, B. T. Yukich, and M. B. Maple, “Unconventional magnetic scaling exponents near a T = 0 transition in $URu_{2-x}Re_xSi_2$,” American Physical Society March Meeting, New Orleans, LA, March 10th – 14th, 2008.

- M. B. Maple, “Strongly correlated electron phenomena in filled skutterudite compounds,” The 137th Annual Minerals Metals and Materials Society Meeting, New Orleans, LA, March 10th, 2008.

- M. B. Maple, “New routes to heavy fermion behavior, non-Fermi liquid behavior, and unconventional superconductivity in f-electron materials,” ICAM Sponsored Workshop “The Heavy Fermion Frontier” in Celebration of Joe Thompson’s 60th Birthday, Santa Fe, NM, November 12th, 2007.

- M. B. Maple, “Superconductivity, magnetism, and heavy fermion behavior in lanthanide-based filled skutterudite compounds,” International Conference on “New Quantum Phenomena in Skutterudite and Related Systems” (Skutterudite 2007), Kobe, Japan, September 27th, 2007.

- M. B. Maple, “Investigation of strongly correlated electron ground states in single crystals of Pr-based filled skutterudite compounds,” International Conference on Crystal Growth, Salt Lake City, Utah, August 13th, 2007.

- M. B. Maple, “Superconductivity in Novel Materials,” REU Seminar, University of California, San Diego, California, July 23rd, 2007.

- T. Yanagisawa, “Ultrasonic study of the filled skutterudite compound $NdOs_4Sb_{12}$,” International Conference on Strongly Correlated Electron Systems, Huston, May 13th – 18th, 2007.

- R. E. Baumbach, W. M. Yuhasz, K. T. Chan, and M. B. Maple, “Pulsed laser deposition of filled skutterudite $YbFe_4Sb_{12}$ thin films,” Poster session: International Conference on Strongly Correlated Electron Systems, Huston, May 13th – 18th, 2007.

- P.-C. Ho, T. Yanagisawa, N. P. Butch, W. M. Yuhasz, C. C. Robinson, A. A. Dooraghi, and M. B. Maple, “A comparison of the normal and superconducting state properties of $Pr(Os_{1-x}Ru_x)_4Sb_{12}$ and $Pr_{1-x}Nd_xOs_4Sb_{12}$,” Poster session: International Conference on Strongly Correlated Electron Systems, Huston, May 13th – 18th, 2007.

- T. A. Sayles, W. M. Yuhasz, J. Paglione, T. Yanagisawa, J. R. Jeffries, M. B. Maple, Z. Henkie , A. Pietraszko, Y. Nemoto, and T. Goto, “Magnetic Ordering in $PrFe_4As_{12}$,” Poster session: International Conference on Strongly Correlated Electron Systems, Huston, May 13th – 18th, 2007.

- J. Paglione, "Violation of the Wiedemann-Franz law at a Quantum Critical Point," California Institute of Technology, CA, May 2007.

- J. Paglione, "Are electrons free at a quantum phase transition?" Temple University, April 2007.

- M. B. Maple, “20th anniversary of high Tc superconductivity 'Woodstock' session,” introduction and overview of the 1987 'Woodstock' session, Denver, Colorado, March 5th, 2007.

- N. P. Butch, J. R. Jeffries, B. T. Yukich, T. A. Sayles, J. Paglione, P. -C. Ho, and M. B. Maple, “The search for quantum criticality in the $URu_{2-x}Re_xSi_2$ phase diagram,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- J. R. Jeffries, N. P. Butch, B. T. Yukich, and M. B. Maple, “The evolution of the hidden order phase in $URu_{2-x}Re_xSi_2$ under pressure,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- P.-C. Ho, J. Singleton, W. Yuhasz, T. Yanagisawa, M. B. Maple, P. Goddard, A. Pietraszko, Z. Henkie, and H. Harima, “Fermi-surface topology and field-dependent effective masses in the skutterudite $PrOs_4As_{12}$,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- P. -C. Ho, T. Yanagisawa, N. P. Butch, W. M. Yuhasz, N. A. Frederick, and M. B. Maple, “A comparison of the normal and superconducting state properties of $Pr(Os_{1-x}Ru_x)_4Sb_{12}$ and $Pr_{1-x}Nd_xOs_4Sb_{12}$,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- J. Paglione, T. A. Sayles, P. -C. Ho, and M. B. Maple, “Incoherent Non-Fermi Liquid Scattering in a Kondo Lattice,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- D. J. Scanderbeg, B. J. Taylor, R. E. Baumbach, K. T. Chan, and M. B. Maple, “Superconducting Phase Diagram and Vortex-Glass Scaling of the Electron-Doped Superconductor $Sm_{2-x}Ce_xCuO_{4-y}$,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- B. J. Taylor and M. B. Maple, “Evolution of the vortex-solid to vortex-liquid melting line in $Y_{1-x}Pr_xBa_2Cu_3O_{6.96}$ and $YBa_2Cu_3O_{6.5}$ to 45 Tesla,” American Physical Society March Meeting, Denver, CO, March 5th – 9th, 2007.

- J. Paglione, “Electrons are not always ‘free’," Department of Physics CM Seminar at the University of California, Davis, CA, March 2007.

- N. P. Butch, “Probing the unusual properties of URu_2Si_2 via applied pressure and Re substitution,” National High Magnetic Field Laboratory, Los Alamos, NM, March 2007.

- J. R. Jeffries, “Competing Ordered States in URu_2Si_2: pressure and substitution,” presented at Lawrence Livermore National Laboratory, Livermore, California, March 2007.

- M. B. Maple, “Experimental investigation of magnetic, superconducting, and other phase transitions in novel f-electron materials at ultrahigh pressures,” SSAA Program Symposium for the NNSA, Washington, DC, February 7th, 2007.

- J. Paglione, “Heavy-electron physics: new ways to break old rules," University of Ontario Institute of Technology, Faculty of Science, Ontario, Canada, February 2007.

- J. Paglione, “Heavy-electron physics: new ways to break old rules," Louisiana State University, Department of Physics CM/AMO Seminar, Baton Rouge, LA, February 2007.

- M. B. Maple, “Novel strongly correlated electron phenomena in filled skutterudite compounds,” Douglass MacLaughlin Retirement Symposium, University of California, Riverside, Riverside, California, January 26th, 2007.

- J. Paglione, “A Quasi-Breakdown of the Quasi-Particle Paradigm," University of Maryland, Department of Physics CM/AMO Seminar, Maryland, January 2007.

- B. J. Taylor, “The vortex solid to vortex liquid transition of type-II superconductors and the origin of universal scaling of the critical temperature,” Technical University of Munich, Garching, Germany, 2007.

- M. B. Maple, “Novel strongly correlated electron phenomena in filled skutterudite compounds,” Invited Seminar, University of Illinois, Urbana-Champagne, IL, December 8th, 2006.

- M. B. Maple, “Tuning of hidden order and superconductivity in URu_2Si_2 by applied pressure and Re doping,” Fall MRS ’06 Actinides III Symposium, Boston, Massachusetts, November 27th, 2006.

- M. B. Maple, “Experimental research on strongly correlated electron phenomena in novel materials,” Physics 191 Seminar, University of California, San Diego, La Jolla, California, November 6th, 2006.

- M. B. Maple, “Investigation of the double superconducting transition and low-temperature specific heat of $Pr(Os_{1-x}Ru_x)_4Sb_{12}$,” Hilbert von Löhneysen Mini-Birthday Symposium, Karlsruhe, Germany, October 27th, 2006.

- M. B. Maple, “Novel types of superconductivity in f-electron materials,” Conferment of the Honorary Professorship of the W. Trzebiatowski Institute for Low Temperature and Structure Research, Polish Academy of Sciences, Wroclaw, Poland, September 6th, 2006.

- M. B. Maple, “Strongly correlated electron phenomena in filled skutterudite lanthanide osmium antimonides,” 6th International Conference of f-elements, Wroclaw, Poland, September 8th, 2006.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudites,” International Conference on Magnetism (ICM), Kyoto, Japan, August 17th – 22nd, 2006.

- M. B. Maple, “xxx,” International Conference on Strongly Correlated Electron Systems, Vienna, Austria, July 26th – 30th, 2005.

- M. B. Maple, “Unconventional superconductivity, heavy fermion behavior, and crystal field effects in the filled skutterudite compound $PrOs_4Sb_{12}$ and its alloys,” 8th International Conference on Materials and Mechanisms of Superconductivity and High Temperature Superconductors (M2S-HTSC-VIII), Dresden, Germany, July 6th – 15th, 2006.

- M. B. Maple, “Novel strongly correlated electron phenomena in filled skutterudite compounds,” Bill Buyers Symposium, Deep River, Ontario, Canada, June 4th, 2006.

- J. R. Jeffries, N. P. Butch, J. Paglione, and M. B. Maple, “Ordered states of URu_2Si_2 under hydrostatic pressure,” American Physical Society March Meeting, Baltimore, MD, March 13th – 17th, 2006

- P. -C. Ho, W. M. Yuhasz, T. Yanagisawa, N. A. Frederick, N. P. Butch, T. A. Sayles, J. R. Jeffries, M. B. Maple, Y. Nemoto, and T. Goto, “Normal and superconducting state properties of the $Pr_{1-x}Nd_xOs_4Sb_{12}$ system,” American Physical Society March Meeting, Baltimore, MD, March 13th – 17th, 2006

- W. M. Yuhasz, P. -C. Ho, T. A. Sayles, T. Yanagisawa, N. A. Frederick, and M. B. Maple, “Superconductivity in $PrRu_4As_{12}$ single crystals,” American Physical Society March Meeting, Baltimore, MD, March 13th – 17th, 2006

- R. E. Baumbach, “Pulsed laser deposition of $PrFe_4Sb_{12}$ and $YbFe_4Sb_{12}$ thin films,” Poster at the Fourth Annual UC Symposium on Surface Science and its Applications, Lawrence Berkeley National Laboratory, CA, February 9th – 10th, 2006.

- B. J. Taylor and M. B. Maple, “Universal critical dynamic form of the vortex-lattice melting line,” Poster at the Gordon Research Conference – Superconductivity, Santa Ynez Valley Marriott, Buellton, CA, January 22nd – 27th, 2006.

- J. Paglione and M. B. Maple, “Rare Earth Substitution Effects in $Ce_{1-x}R_xCoIn_5$,” Poster at the Gordon Research Conference – Superconductivity, Santa Ynez Valley Marriott, Buellton, CA, January 22nd – 27th, 2006.

- M. B. Maple, “Heavy fermion behavior and unconventional superconductivity in the filled skutterudite compound $PrOs_4Sb_{12}$,” Symposium on “Frontiers in Low Temperature Physics,” Chalmers University of Technology, Göteborg, Sweden, December 2nd – 3rd, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudite compounds," Joint Workshop on “NQP-skutterudites and NPM in multi-approach,” Tokyo Metropolitan University, Tokyo, Japan, November 21st, 2005.

- M. B. Maple, “Superconductivity, magnetic order, and heavy fermion behavior in filled skutterudite compounds,” 3rd Hiroshima Workshop on “Novel Functional Materials with Multinary Freedoms,” Hiroshima University, Hiroshima, Japan, November 16th – 19th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudite compounds,” Technical University of Munich Colloquium, Munich, Germany, October 10th, 2005.

- B. J. Taylor, D. J. Scanderbeg, and M. B. Maple, “Evolution of vortex-matter melting in the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ and $YBa_2Cu_3O_{6.5}$ systems,” 12th US-Japan Workshop on High Performance Superconductors, Lake Delavan, WI, October 10th – 12th, 2005.

- N. P. Butch, J. R. Jeffries, P.-C. Ho, M. B. Maple, S. D. Wilson, Pengcheng Dai, D. T. Adroja, S.-H. Lee, J.-H. Chung, and J. W. Lynn, “Quantum criticality and non-Fermi liquid behavior in $Sc_{1-x}U_xPd_3$,” Poster session: Conference on Concepts in Electron Correlation, Hvar, Croatia, September 30th – October 5th, 2005.

- J. R. Jeffries, D. D. Jackson, C. Aracne, S. T. Weir, Y. K. Vohra, and M. B. Maple, “Enhanced magnetic exchange under pressure in Au_4V and $Au_{1-x}V_x$ dilute alloys,” Poster session: Conference on Concepts in Electron Correlation, Hvar, Croatia, September 30th – October 5th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudite compounds,” Workshop on Correlated Thermoelectronic Materials, Hvar, Croatia, September 25th – 30th, 2005.

- M. B. Maple, “Investigation of superconductivity, magnetization, and quantum critical phenomena at low temperature, high pressures, and high magnetic fields,” NNSA Annual Meeting, Las Vegas, Nevada, August 23rd – 25th, 2005.

- R. E. Baumbach, “Non Fermi liquid behavior in annealed UCu_4Pd,” The second Canadian-American-Mexican (CAM) Physics Graduate Student Conference, San Diego, CA, August 19th – 21st, 2005.

- W. M. Yuhasz, “Characterization of the filled skutterudite compound $PrOs_4As_{12}$,” The second Canadian-American-Mexican (CAM) Physics Graduate Student Conference, San Diego, CA, August 19th – 21st, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in novel f-electron systems: opportunities for neutron scattering,” Workshop on “Next Generation Neutron Source: Opportunities in Bio- and Materials Sciences,” San Diego, California, June 8th – 9th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in novel f-electron materials,” meeting of CIAR Quantum Materials Program, Vancouver, Canada, May 18th – 21st, 2005.

- M. B. Maple, “Pr-doped YBCO: a model system for studies of high temperature superconductivity and vortex physics,” UC/Los Alamos Workshop, University of California, Santa Barbara, May 13th – 14th, 2005.

- B. J. Taylor, D. J. Scanderbeg, M. B. Maple, C. Kwon, and Q. Jia, “High B/T vortex-matter states in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films,” Poster at the UC/LANL Workshop on Complex Functional Oxides, Santa Barbara, CA, May 13th – 14th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in f-electron systems,” Workshop on “Probing Matter at High Magnetic Fields with X-Rays and Neutrons,” Tallahassee, Florida, May 10th – 12th, 2005.

- M. B. Maple, Conference Summary, Workshop on “Novel Electronic Materials,” Lexington, Kentucky, April 24th – 27th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudite compounds,” Workshop on “Novel Electronic Materials,” Lexington, Kentucky, April 24th – 27th, 2005.

- M. B. Maple, “Strongly correlated electron phenomena in Pr-based filled skutterudite compounds,” 2nd US-Japan Workshop on “Synchrotron Radiation and Nanoscience,” San Diego, California, April 4th – 6th, 2005.

- R. E. Baumbach, N. P. Butch, M. B. Maple, and D. MacLaughlin, "Non-Fermi-liquid behavior in annealed UCu_4Pd," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- N. P. Butch, W. M. Yuhasz, P. -C. Ho, J. R. Jeffries, N. A. Frederick, T. A. Sayles, X. G. Zheng, M. B. Maple, J. B. Betts, A. H. Lacerda, F. M. Woodward, J. W. Lynn, P. Rogl, and G. Giester, "Ordered Magnetic State in $PrFe_4Sb_{12}$ Single Crystals," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- N. A. Frederick, S. K. Kim, T. A. Sayles, P. -C. Ho, N. P. Butch, and M. B. Maple, "Low temperature normal and superconducting state properties of lightly doped $PrOs_4Sb_{12}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- J. R. Jeffries, N. A. Frederick, E. D. Bauer, H. Kimura, V. S. Zapf, K. -D. Hof, T. A. Sayles, and M. B. Maple, "Superconductivity and non-Fermi liquid behavior near antiferromagnetic quantum critical points in $CeRh_{1-x}Co_xIn_5$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- P. -C. Ho, N. P. Butch, T. Yanagisawa, W. M. Yuhasz, N. A. Frederick, T. A. Sayles, D. P. Arovas, M. B. Maple, J. B. Betts, and A. H. Lacerda, "The effect of Nd substitution on superconductivity of $PrOs_4Sb_{12}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- T. A. Sayles, W. M. Yuhasz, N. A. Frederick, N. P. Butch, P. -C. Ho, M. B. Maple, and Z. Henkie, "Magnetic susceptibility, electrical resistivity, and specific heat measurements of the filled skutterudite $PrOs_4As_{12}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- D. J. Scanderbeg, B. J. Taylor, Y. Kim, and M. B. Maple, "Thin film growth via pulsed laser deposition and characterization of the electron-doped superconductor $Sm_{2-x}Ce_xCuO_{4-y}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- B. J. Taylor, D. J. Scanderbeg, M. B. Maple, and C. Kwon, "Investigation of vortex-matter states in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- T. Yanagisawa, W. M. Yuhasz, M. B. Maple, Y. Nemoto, and T. Goto, "Ultrasonic dispersion due to the rattling motion in the filled skutterudite $La(Os_{0.5}Ru_{0.5})_4Sb_{12}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- W. M. Yuhasz, N. A. Frederick, P. -C. Ho, N. P. Butch, B. J. Taylor, T. A. Sayles, M. B. Maple, J. B. Betts, A. H. Lacerda, P. Rogl, and G. Giester, "Heavy fermion behavior, crystalline electric field effects, and weak ferromagnetism in $SmOs_4Sb_{12}$," American Physical Society March Meeting, Los Angeles, CA, March 21st – 25th, 2005.

- M. B. Maple, “Non-Fermi liquid behavior near magnetic quantum critical points in U-based systems,” Workshop on “Quantum Critical Behavior in Correlated Electron Systems,” KITP, University of California, Santa Barbara, February 1st, 2005.

2.6 Website Reflecting Project Results

Maple Group, Physics of Correlated Electron Materials: http://mbmlab.ucsd.edu/

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[Suslov 03] A. Suslov, J. B. Ketterson, D. G. Hinks, D. F. Agterberg, and B. K. Sarma, “H-T phase diagram of URu_2Si_2 in high magnetic fields,” Phys. Rev. B 68, 020406-1 (2003).