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NATIONAL HIGH MAGNETIC FIELD LABORATORY

NHMFL REPORTS

Superconducting Magnet Produces Magnetic Fields of 25 Tesla

(page 27)

Research Experiences for Undergraduates and Research Experiences for Teachers programs concluded successfully

(page 22)

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CELEBRATING 10 YEARS OF PUBLICATION

NHMFL REPORTS

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FROM THE DIRECTOR'S DESK

Jack E. Crow

I cannot recall a time when the laboratory was surrounded by so much genuine interest, support, and leadership, except perhaps for the period leading up to the laboratory's dedication in 1994. Let me explain:

Florida State University welcomed a new president in January 2003. Thomas Kent "T.K." Wetherell succeeded Sandy D'Alemberte, who retired after nine years in the post. Sandy was a frequent visitor and a friend to us all, and we thank him sincerely for his staunch support. Dr. Wetherell earned three degrees from FSU, served in the Florida Legislature for 12 years, and was president of Tallahassee Community College from 1995 to 2001. His legislative experience is particularly noteworthy from the laboratory's perspective because he was the influential Speaker of the House in the early 1990s and helped to secure the initial NHMFL construction funding and recurring support.

The FSU President, as the Chair of the NHMFL Institutional Oversight Committee, appoints the members of the laboratory's External Advisory Committee. This committee plays a vital role in guiding the laboratory and will be especially important as we go through a site visit October 8-10, 2003, and through the renewal process in 2004-2005. At Dr. Wetherell's direction, the EAC has been reconstituted, and a broad group of distinguished science and engineering leaders have agreed to serve. The diversity and experience of this group is remarkable, and we are extremely grateful for their commitment and dedication to the advancement of science, technology, and education through the NHMFL.

NHMFL External Advisory Committee

Magnet & Magnet Materials Technology Members

Alexis Malozemoff	American Superconducting Corp.
Ronald Scanlon	Lawrence Berkeley National Laboratory
Albert Zeller	Michigan State University

Biological & Chemical Sciences Members

Anthony Cheetham	University of California, Santa Barbara
Jean Futrell	Pacific Northwest National Laboratory
Robert Griffin	Massachusetts Institute of Technology
David Hendrickson	University of California, San Diego
Lee Magid	University of Tennessee
Stanley Opella	University of California, San Diego

Condensed Matter Science Members

Meigan Aronson	University of Michigan
Dimitri Basov	University of California, San Diego
Paul Chaikin	Princeton University
George Crabtree	Argonne National Laboratory
Rui Rui Du	University of Utah
Don Gubser	Naval Research Laboratory
William Halperin	Northwestern University
Frank Steglich	Max-Planck Institute, Chemical Physics of Solids
Nai-Chang Yeh	California Institute of Technology

Another group of leaders who volunteer to advise the laboratory serve on the NHMFL Users' Committee. These individuals are nominated and elected by the user community and provide important guidance on the equipment and policies needed for the development and utilization of the laboratory's facilities. Recalling that the laboratory's *first* charge is to serve as the nation's premier user facility for research in high magnetic fields, it is impossible to overstate the significance of this committee's efforts and contributions.

NHMFL Users' Committee

Chuck Agosta	Clark University
Gilbert Clark	University of California, Los Angeles
Nathanael Fortune	Smith College
Roy Goodrich	Louisiana State University
Neil Kelleher	University of Illinois at Urbana-Champaign
Lowell Kispert	University of Alabama
Lia Krusin-Elbaum	IBM – T.J. Watson Research Center
Charles Sanders	Case Western Reserve
Tom Timusk	McMaster University
James Brooks	NHMFL & Florida State University
Nai-Phuan Ong	Princeton University
James Valles	Brown University
Richard Wittebort	University of Louisville

There is one additional person that I would like to introduce to the NHMFL community—the new FSU Vice President for Research who was appointed in late May, Dr. Kirby Kemper. Kirby has been a member of the physics faculty at FSU since 1971 and became the chair of the department in 1997. His interest in the NHMFL is expressed best in his own words: *My main reason for being willing to take this new job was because of the importance of the NHMFL to the intellectual life of our three sister institutions, and my hope that as we move forward to the renewal of the next 5-year grant, I can assist in anyway possible. I have been given the assurance of FSU's President and Provost that the future health of the Mag Lab as a science and education facility is one of their highest priorities and that we are committed to doing whatever it takes within the current fiscal climate to have a successful renewal. I look forward to serving the staff and researchers at all three of our sites in any way possible.* It is noteworthy that within weeks of his appointment, Vice President Kemper visited the facilities and faculty at the University of Florida, at the Pulsed Field Facility at LANL, and at the NHMFL-FSU in Tallahassee.

As I said in the beginning of this column, I cannot recall in the history of this laboratory when there was a greater confluence of talent, credentials, and dedication to success than right now. The laboratory truly appears poised for a successful renewal—and more importantly—to make the most of the science breakthroughs and opportunities at hand to serve the national and international user communities.

A few management changes are also occurring inside the laboratory, but fortunately, no final farewells are necessary. As mentioned in the last newsletter, the director of the Pulsed Field Facility, Greg Boebinger, accepted a new position at Los Alamos National Laboratory. Greg will continue his affiliation with the NHMFL for some time, in his role as a co-principal investigator. An international search for a new director is underway, and Alex Lacerda, who directed the Pulsed Field user programs, is serving as Acting Director. Chuck Mielke, a staff member and experimentalist at NHMFL-LANL, has agreed to be the new Head of User Programs. Chuck is highly competent—and a familiar and friendly face to pulsed field users—so operations continue unabated.

LANL is responsible for the recruitment of a new director, and the full job description appears on their Web site, *http://www.hr.lanl.gov/FindJob/index.stm* (Job #205413). (See also, page 26 for a summary.) The search is being well coordinated, and the committee includes representatives from UF, FSU, and the NHMFL Users' Committee.

The directorship of NHMFL Magnet Science and Technology is also undergoing change. The post has been held since 1997 by Steve Van Sciver, who has juggled a heavy load of teaching, research, and director's duties. His individually-driven research program has expanded substantially over the last few years, which has imposed more pressure on Steve's schedule. Consequently, Steve recently announced his intention to step down so that he could devote greater time to teaching at the College of Engineering and to the exceptional cryogenics research program he runs at the laboratory. Steve has been a strong advocate for magnet and magnet materials technology and has provided fine leadership of MS&T—we are grateful for his contributions and service. Steve will stay on as Director during the transition and will be assisted by Tom Painter, as Interim Operations Manager (see page 24 for more information). Steve will also remain a key contributor to the research and educational programs within the laboratory. With the renewal pending and several major projects near completion, MS&T is at a critical stage and the NHMFL will aggressively pursue the search for a new Director of MS&T so that the new director is in place to provide guidance and leadership in the preparation of the renewal proposal.

A search committee for the MS&T directorship position has been established and includes representatives from UF, LANL, and the NHMFL Users' Committee. It is being chaired by NHMFL Deputy Director for Management and Administration Brian Fairhurst. In another demonstration of institutional support for the NHMFL, FSU has committed new resources so that a search for an external candidate can be conducted. See page 26 for information.

A thread running through my comments this issue has been leadership—and the gratitude of the laboratory for the service of so many established and highly regarded members of our science and research communities. In closing, I would also like to recognize the next generation of science leaders—our undergraduate REU students—and the people who work hard in K-12 classrooms educating future science leaders—our teachers from the RET program. This summer, the laboratory hosted the 11th class of student interns and the 5th group of educators, and we are very pleased to feature them on the covers of this issue. Education is an integral part of all activities at the laboratory, and we are extremely proud of the program participants and our collective efforts on behalf of science and technology education.

Best regards,

Jack Crow

FROM THE CHIEF SCIENTIST'S DESK

J. Robert Schrieffer

In this issue, L.W. Engel and coworkers have reported on a series of elegant experiments concerning the integer quantum Hall effect. By studying the response of the system to a microwave field as a function of two-dimensional disorder, they have observed resonance peaks in the absorption, which they interpret as vibration of the electronic crystal as a whole relative to the background disorder potential. These experiments give first hand evidence of an electronic solid, or Wigner crystal, whose translational motion is pinned by the disorder potential. Theory shows that the strength of the absorption should be proportional to the density of electrons or holes relative to the number required to make a filled Landau level. This is precisely what is observed. The unique high field facilities at the NHMFL have made these studies possible. The group should be congratulated on this excellent experiment, which has led to this important discovery.

Microwave Resonance as Evidence for Wigner Crystal in the Integer Quantum Hall Effect

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D.C. Tsui, Princeton University, Electrical Engineering
L.N. Pfeiffer, Lucent Technologies
K.W. West, Lucent Technologies

The integer quantum Hall effect (IQHE)[1] is a striking high magnetic field phenomenon that has been traditionally explained without considering the electron-electron interaction. Microwave spectroscopy[2] of an extremely low disorder two-dimensional electron system (2DES) reveals a striking resonance concomitant with some IQHE states. This resonance provides compelling evidence that a Wigner crystal—an electron lattice *stabilized by the electron-electron interaction*—can play a crucial role in producing the IQHE. In the standard picture, the IQHE is taken to be a consequence of localization of the relevant carriers. In the context of an integer quantum Hall Wigner crystal (IQHWC) of these carriers, this localization comes from pinning of the many-particle ground state, rather than from trapping of individual carriers. The resonance is interpreted as a pinning mode, characteristic of crystalline domains oscillating in the potential of impurities.

In a magnetic field, B, the electrons of a clean 2DES have discrete energies, or Landau levels. The number of Landau levels that the electrons in the 2DES can fill is given by the Landau filling factor $\nu = ne/Bh$ where n is the areal density of the 2DES, h is Planck's constant and e is the electronic charge. For $\nu<1$, only the lowest Landau level is occupied, and Wigner crystallization is predicted theoretically[3] to occur for ν below ~1/7. In essence, this is a dilute limit, in which the size of the electron wave function (the magnetic length $l_B = (\hbar/eB)^{1/2}$) is much less than the interelectron spacing. A microwave resonance in this regime has long been known to exist, and studies of it continue at the NHMFL.[4] We interpret the resonance as a pinning mode of the Wigner crystal in the lowest Landau level, and has been found to be dependent on the degree of disorder present in the 2DES, with a larger resonance peak frequency, f_{pk}, for larger disorder as expected for a pinning mode.

The microwave studies of 2DES are conducted using planar transmission lines fabricated in metal film on the surface of samples, as shown in Figure 1. The transmission lines are of a standard type known as coplanar waveguide, with a driven center strip conductor, and two broad, grounded side planes. They couple capacitively to the 2DES, which is buried 2000 Å or so below the surface. The absorptive, real part of the diagonal conductivity, Re(σ_{xx}), is calculated from the measured microwave power absorption due to the 2DES. The measurement is sensitive mainly to the conductivity just under the slots, of width typically 20 μm, between the center conductor and side planes. The sample is cooled to 50 mK in an NHMFL dilution refrigerator, and connected by high quality coaxial cables to a room temperature transmitter and receiver.

The IQHE appears in DC transport at low temperature as a flat plateau of Hall conductivity σ_{xy} vs. magnetic field B, accompanied by a vanishing diagonal conductivity σ_{xx}. Figure 2a shows the minimum in $\mathrm{Re}(\sigma_{xx})$ vs. B that is produced by the IQHE around ν=1, for several finite frequencies, f. Typical of the IQHE in the low frequency (DC) limit, the 300 MHz trace shows a wide region of vanishing $\mathrm{Re}(\sigma_{xx})$. This region is coincident with the IQHE plateau in the DC Hall conductivity. The 1.2 GHz and 2 GHz traces show distinct peaks in $\mathrm{Re}(\sigma_{xx})$, located within this plateau region of B. At 11.3 T, as marked by the left hand dotted line, the conductivity rises on going from 300 MHz to 1.2 GHz then decreases in the 2 GHz trace.

Spectra, $\mathrm{Re}(\sigma_{xx})$ vs. f, for many filling factors (magnetic fields) near ν=1 are shown in Figure 2b. A striking resonance appears for ν on either side of 1. As ν=1 is approached, this resonance shifts to higher frequency and gradually vanishes. The peak also disappears as the filling gets too far from ν=1, and so it is clearly associated with the ν=1 IQHE. Similar resonances are seen in this same sample in the IQHEs around ν=2, 3, and 4.

The absence of the resonance just at integer filling strongly implies that the resonance is associated with the electrons (or holes) in the topmost occupied Landau level. Just at integer filling ν=j, neglecting temperature effects, there are exactly j completely filled Landau levels below the Fermi energy, and there are completely empty Landau levels above it. Completely filled or empty Landau levels are to

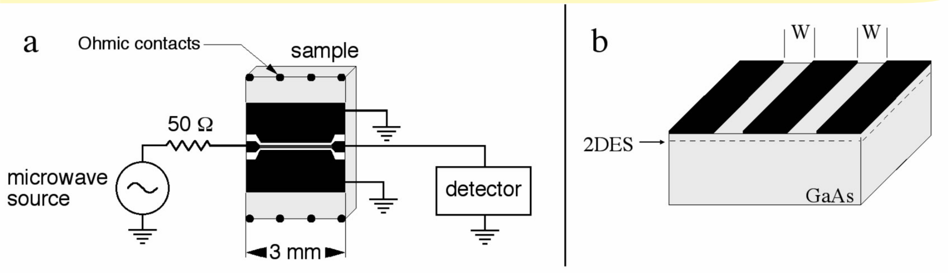

Figure 1. (a) Schematic of the microwave measuring setup. We measure the loss of a microwave transmission line patterned onto the surface of a quantum Hall sample. The transmission line metal is shown as black (not to scale). (b) magnified cross section of sample near transmission line (black) (not to scale). The slots between center and side conductors have width W of typically 20 μm.

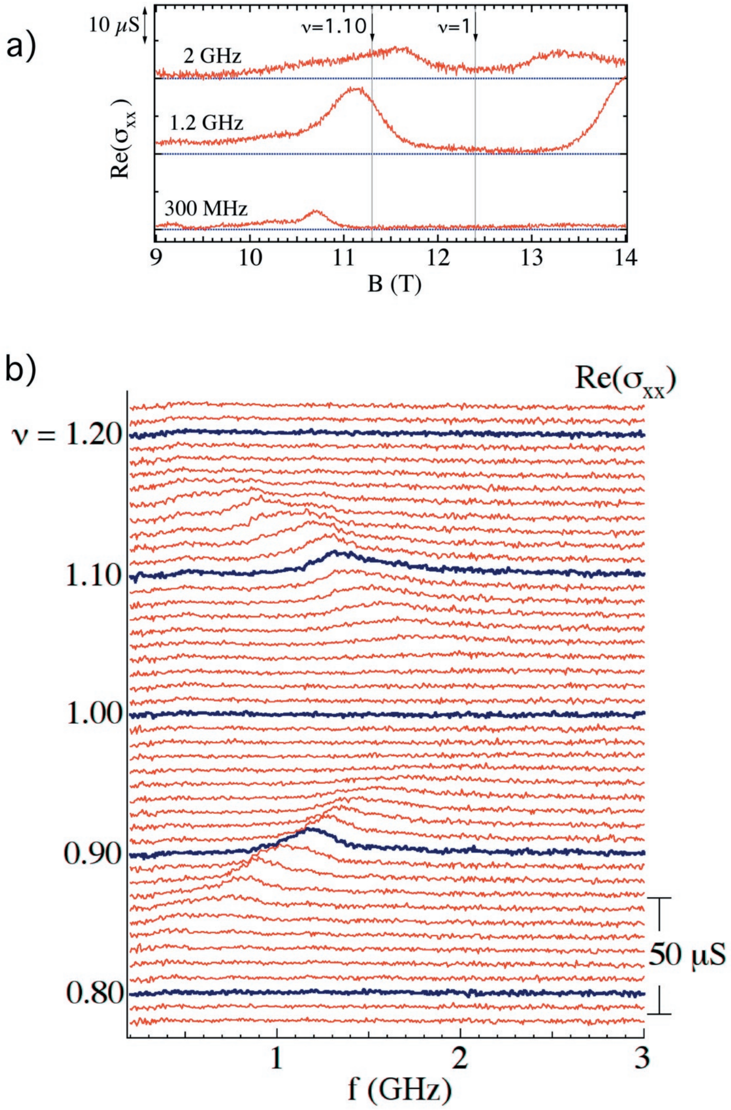

Figure 2. (a) $\mathrm{Re}(\sigma_{xx})$ vs. B, at three different frequencies, temperature about 50 mK. Horizontal grid lines mark zero $\mathrm{Re}(\sigma_{xx})$. In the 300 MHz trace, the flat minimum around Landau filling ν=1 indicates the width of the DC-limit integer quantum Hall effect plateau. At the higher frequencies, features are seen in this region. (b) Spectra, $\mathrm{Re}(\sigma_{xx})$ vs. frequency, f, for many Landau fillings ν, from 0.78 to 1.22. The bar on the right gives the $\mathrm{Re}(\sigma_{xx})$ scale; spectra for successive fillings are offset proportional to ν. Resonances appear on either side of n=1, but vanish just on that filling.

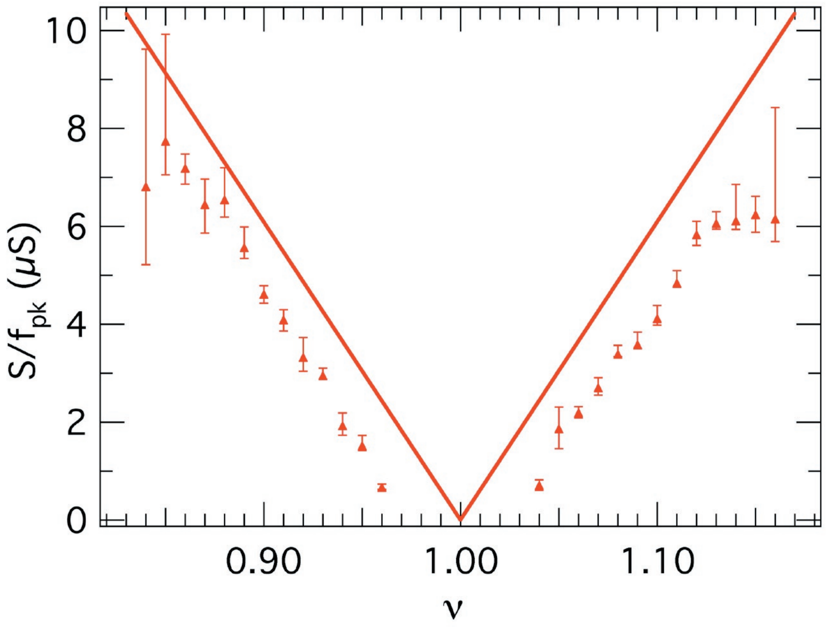

Figure 3. *S/f_{pk}* vs. Landau level filling ν, where *S* is Re(σ_{xx}) integrated over frequency and f_{pk} is the resonance peak frequency. The straight lines are calculated from the expected density of top Landau level electrons (ν>1) or holes (ν<1).

a good approximation inert for the frequencies and temperatures of this experiment. As ν is increased above *j*, electrons begin occupying the next Landau level, and if ν is decreased just below *j*, holes appear in the *j*th level. These "top Landau level" electrons or holes repel each other, and are effectively dilute, and so can Wigner crystallize.[5] This integer quantum Hall Wigner crystal (IQHWC) insulates, as it must to produce the IQHE, due to pinning of the lattice by disorder in the sample, and the resonance is taken to be a pinning mode. As ν approaches *j*, the disappearance of the resonance is due to the absence of top Landau level carriers; as ν goes too far away from *j* the IQHWC must undergo a transition, for example into quantum liquid states related to the fractional quantum Hall effects.

The strength of the resonance should be related to the number of electrons or holes that produces it. For ν near the integer *j*, the areal density of the carriers in the top Landau level is $n^*=n(\nu-j)/\nu$, positive for electrons and negative for holes. A simple model[6] of the pinning mode resonance of 2DES in high magnetic field gives $S/f_{pk}=|n^*|e\pi/2B\approx n|\ \nu-j|e\pi/2jB$, where S is the frequency-integrated Re(σ_{xx}) of the resonance. Figure 3 shows a plot of S/f_{pk} vs. ν, in surprisingly good agreement with the simple formula, and strongly supporting the interpretation of the resonance as due to top Landau level carriers.

Both in sharpness and in frequency range, the IQHWC resonances resemble the above mentioned, disorder-dependent resonance found at far smaller fillings, where only the lowest Landau level is occupied. (S/f_{pk} in that lowest Landau level resonance indicates that most of the electrons in the sample participate.) Both types of resonance gradually disappear on raising the temperature, typically to about 200 mK. A strong argument that the resonances are due to collectively localized domains that move rigidly stems from a comparison of the resonance frequencies, f_{pk}, with the temperature, *T*. We readily observe resonances with $k_BT>>hf_{pk}$, where k_B is Boltzmann's constant. This would not be possible if the electrons were bound to individual impurities, since such impurities would have binding energies of order hf_{pk}, and would thermally ionize at such high temperatures.

Finally, it is now reasonably clear that microwave resonances are a *generic* feature of isotropic electronic crystals in high quality 2DES in high magnetic field. Though a full description is beyond the scope of this article, we have found[7] yet a third class of resonances, besides the IQHWC and lowest Landau level resonances already mentioned. This last type of resonance is associated with "bubble" crystals, whose lattice sites are occupied by clusters (bubbles) containing two or more electron guiding centers. The bubble resonance is found in regions around ν=*j*+0.25 and *j*+0.75, for *j*=4, 5, 6 or more. Pinning modes of the 2DES, and the IQHWC resonance in particular, will be valuable tools for understanding the many phases exhibited by the 2DES, and their interplay with disorder.

This work was supported by the NHMFL In-House Research Program and by AFOSR.

[1] Reviewed in R.E. Prange and S.M. Girvin (Springer-Verlag, New York, 1990).

[2] Yong Chen, R.M. Lewis, L.W. Engel, D.C. Tsui, P.D. Ye, L.N. Pfeiffer, and K.W. West, *Phys. Rev. Lett*., **91**, 016801 (2003).

[3] See, for example, Kun Yang, F.D.M. Haldane, and E.H. Rezayi, *Phys. Rev. B*, **64**, 081301 (2001).

[4] See, for example, P.D. Ye, L.W. Engel, D.C. Tsui, R.M. Lewis, L.N. Pfeiffer, and K.W. West., *Phys. Rev. Lett.,* **89**, 176802 (2002).

[5] A.H. MacDonald and S.M. Girvin, *Phys. Rev. B*, **33**, 4009 (1986).

[6] H. Fukuyama and P.A. Lee, *Phys. Rev. B*, **18**, 6245 (1978).

[7] R.M. Lewis, P.D. Ye, L.W. Engel, D.C. Tsui, L.N. Pfeiffer, and K.W. West., *Phys. Rev. Lett.*, **89**, 136804 (2002).

ATTENTION USERS: Bruce Brandt, Director

I would like to call the attention of all users to Roy Goodrich's invitation on the right side of this page to send him your comments on the existing facilities and services provided by ALL the user facilities of the NHMFL, and suggestions for the future. The Users' Committee is your voice at the NHMFL and Roy's invitation is an excellent opportunity for you to be involved in crafting the proposal for funding the NHMFL from January, 2006 through December, 2010.

Alexei Souslov has recently joined the Instrumentation and Operations Group of the NHMFL's DC High Field Facility in Tallahassee. He will be assisting users in several areas of research, developing user instrumentation for ultrasound measurements, and carrying out his own research.

Dr. Souslov studies the properties of solids by ultrasonic techniques at low temperatures and in magnetic fields. Recently, he developed an ultrasonic spectrometer for measurements of the ultrasound velocity and attenuation in high pulsed magnetic fields. This equipment allowed him to carry out investigations of the metamagnetic transitions on heavy fermion compounds UPt_3 and URu_2Si_2 in magnetic fields up to 50 T at the pulsed field facility of the NHMFL in Los Alamos.

Dr. Souslov created several ultrasound experiments for work in the DC magnets in Tallahassee when he was working at the University of Milwaukee, and has begun to develop a variety of ultrasonic techniques that will be available to users at the NHMFL/Tallahassee. These techniques are:

- pulse-echo;
- resonant ultrasound spectroscopy (RUS);
- surface acoustic wave (SAW).

The pulse-echo technique is useful for investigations of phase transitions, for example. It can even be used to study magnetic and/or electron subsystems in solids when interaction of these subsystems with the crystal lattice is important.

Resonant ultrasound spectroscopy allows one to measure all the components of the elastic tensor on relatively small samples. This is often important for investigations of newly-discovered materials and phenomena because it takes a while for sample growers to discover how to make samples large enough for pulse–echo experiments.

The surface acoustic wave technique is applied to studies of thin films or low dimensional electron systems. The studied sample is deposited on the surface of a piezoelectric substrate, or just placed on this surface. Investigations of the quantum Hall effect and superconductive films are typical examples of SAW applications.

These experimental methods will be available for the NHMFL community. Everyone who is interested in application of ultrasonic techniques to his/her scientific research is welcome to communicate with Alexei by phone (850) 644-6788, e-mail *souslov@magnet.fsu.edu,* or in person in his office A121C. For more on Alexei Souslov, see page 24.

Users' Committee Request for Information

As part of the ongoing process to have more user input to the operation and future of the National High Magnetic Field Laboratory, I will be developing a confidential web-based survey for all people who have been users, or plan to be in the near future, to give input on how you believe the laboratory facilities and operation might be improved. The laboratory is beginning the process of putting together the next 5-year NSF proposal for operation, and all users are requested to share their thoughts on matters important to them. I, as the Chair of the Users' Committee, would like to have your thoughts on the following matters. I will e-mail the user community in the near future with more information on how to address the appropriate site. I plan to make this as painless as possible, and I hope all will respond. Some of the information I will be asking about is:

- Current operation and user support services provided, including the changes you would like to see made, by
  1. the resistive and superconducting magnet facilities in Tallahassee,
  2. the pulsed and superconducting magnet facilities in Los Alamos,
  3. the High B/T facility in Gainesville,
  4. the NMR facilities in Tallahassee and/or Gainesville,
  5. the ICR facilities in Tallahassee, and/or
  6. the EMR facilities in Tallahassee.
- Facilities and measurement techniques that need to be improved at each of the sites.
- New facilities and measurement techniques you would like to see available at any, or all of the sites.
- Which science initiatives will be important for the laboratory to address over the next 5 to 6 years?
- Any other comments, positive or negative, you want to make.

You can be assured that anything you enter will be kept in the strictest of confidence and only will be used as part of the overall input the Users' Committee gives to the management of the NHMFL. Please watch for the e-mail message and respond to the request. This is a great opportunity to provide input to the NHMFL as they develop the vision for the next 5 to 10 years of the laboratory.

Roy Goodrich
Chair Users' Committee

PULSED FIELD USERS PROGRAM

ATTENTION USERS: Chuck Mielke, Head

The measurement techniques that the NHMFL has developed over the years have contributed to making our facilities not only a great asset to the user community but to scientific endeavors globally. A summary of the work by F. Balikirev, *et al.* is a crystal clear example of how excellence in science and instrumentation has had a major impact on our community. The pulsed field Hall resistivity measurements took years to develop and perfect; Balikirev and co-workers are recognized for their significant contributions to this exceptionally challenging series of experiments. To read more about this impressive experimental accomplishment, see the 21 August, 2003 issue of *Nature* (Volume 424, page 912).

Signature of Optimal Doping in Hall-Effect Measurements on a High Temperature Superconductor

F. F. Balakirev, NHMFL/LANL
J.B. Betts, NHMFL/LANL
A. Migliori, NHMFL/LANL
S. Ono, Central Research Institute of Electric Power Industry, Tokyo
Y. Ando, Central Research Institute of Electric Power Industry, Tokyo
G.S. Boebinger, NHMFL/LANL

After over a decade of research since the discovery of high temperature superconductivity, the mechanism of this phenomenon is yet to be established. There is a strong belief in the scientific community, however, that the elusive cause of superconductivity can be found through studying high temperature superconductors in their "normal" state (the state when superconductivity is "lifted" by a magnetic field or temperature). Among the various abnormal normal state properties, the Hall effect has been notoriously difficult to understand.

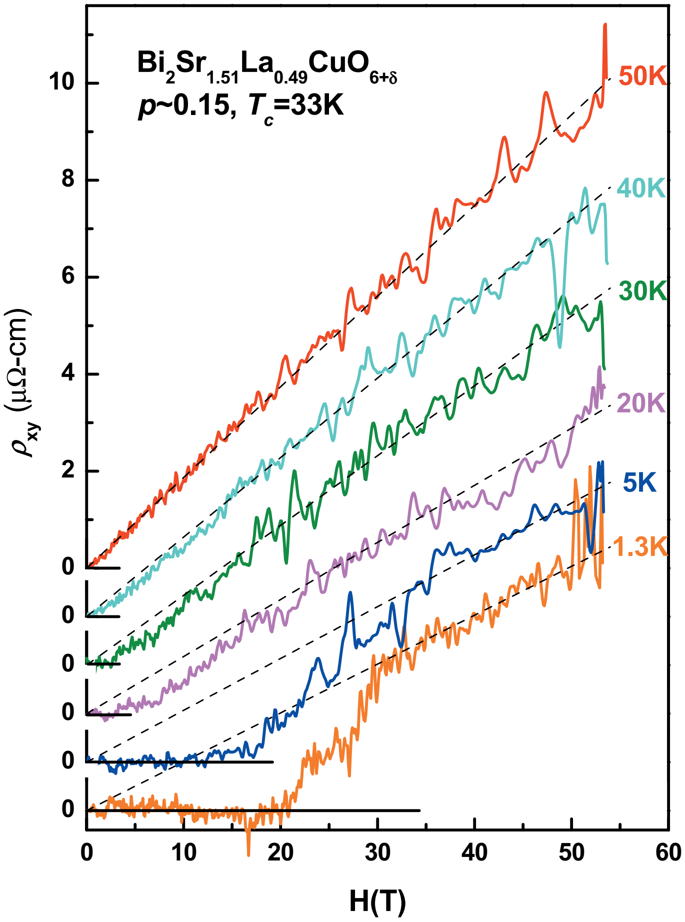

Figure 1. Hall signal as a function of magnetic field in a $Bi_2Sr_{0.51}La_{0.49}CuO_{6+\delta}$ superconducting sample (T_c=33 K, hole doping p~0.15) obtained using a high resolution, low noise, synchronous lock-in technique developed at the NHMFL. Hall coefficient, R_H, is determined with best linear fit, $\rho_{xy}(H)= R_H H$, at high fields (dashed lines), where superconductivity is suppressed by high magnetic field.

NHMFL Pulsed Field Facility scientists, in collaboration with Y. Ando group (CRIEPI, Japan), uncovered a startling evolution of the low-temperature Hall coefficient in the normal state of the high temperature superconductor $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$ (BSLCO) as a function of temperature and hole doping, p, by suppressing high temperature superconductivity with an intense magnetic field. The Hall number per unit cell, $n_{Hall} \equiv V_{cell}/eR_H$, is found to increase rapidly from nearly zero value at the onset of the high temperature superconducting state (p=0.10) to approximately one

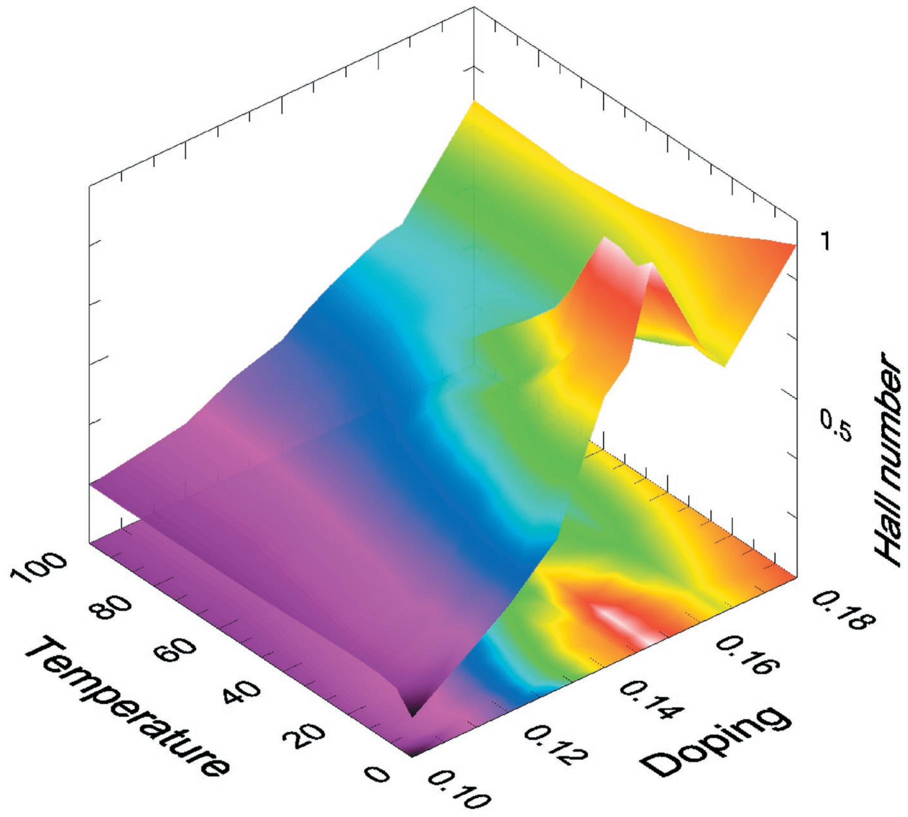

Figure 2. 3D color map plot of the Hall number, $n_{Hall} \equiv V_{cell}/eR_H$, as a function of temperature and doping. n_{Hall} normalized to give the number of holes per Cu atom. Also shown is the 2D color map projection of the data onto temperature and doping plane. While the high temperature data shows a monotonic evolution of $n_{Hall}(p)$ with increasing doping, upon cooling to ~50 K, the anomalous cusp at $p=0.15$ becomes apparent. This must be associated with an abrupt change in the Fermi surface suggesting a quantum phase transition (QPT) between two different metallic phases in the normal state. This observation also highlights the necessity of the high magnetic fields to reveal the intrinsic normal state behavior at low temperatures.

hole per unit cell near optimal doping (p=0.16) corresponding to roughly 7 carriers per each hole introduced with doping. At about the same hole doping level where superconductivity is most robust, n_{Hall} variation with doping exhibits a sharp change suggesting that two competing ground states underlie the high temperature superconducting phase.

A typical field dependence of the Hall signal in a superconducting BSLCO sample with a zero field $T_c=33$ K is shown in Figure 1. As the magnetic field suppresses superconductivity, the low temperature ($T < T_c$) Hall signal rapidly increases and then recovers its conventional linear-in-magnetic-field behavior. The value of R_H is then determined from a linear fit to the Hall resistivity data in this high field regime, $\rho_{xy}(H)=R_H H$ (dashed lines in Figure 1). In marked contrast to behavior seen in high temperature superconductors at high temperatures, upon cooling R_H becomes relatively temperature independent, signaling the recovery of Hall behavior typical of common metals, thus allowing us to investigate the evolution of the density of states in the low temperature limit. Figure 2 shows the surprising temperature and doping dependencies of n_{Hall}. We note that the rapid increase of n_{Hall} with doping in the low temperature limit shows a remarkably linear correlation with doping dependence of T_c in the underdoped regime ($p \leq 0.15$) indicating that the superfluid density in the superconducting state corresponds to the carrier density in the underlying normal state throughout the underdoped regime. The observed maximum value of n_{Hall} implies a big Fermi surface that fills close to half a Brillouin zone.

The pronounced cusp in the zero-temperature-limiting value of the Hall number at optimal doping must be associated with an abrupt change in the Fermi surface, and thus suggests a quantum phase transition between two different metallic phases in the normal state of the high temperature superconductors. From this behavior one can argue that the occurrence of high temperature superconductivity is fundamentally related to quantum fluctuations associated with a zero-temperature phase transition. Recently, a number of models that involve quantum phase transition (QPT) between two different metallic phases in the normal state of the high temperature superconductors have been the subject of active debate among physicists. It takes an extremely high magnetic field to suppress the superconductivity and reveal a clear signature of a QPT in the normal state in the zero temperature limit.

Large Sample ^{15}N Solid State NMR Facility for Oriented Membrane Proteins

P.L. Gor'kov, NHMFL
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J. Hu, NHMFL and FSU, Chemistry and Biochemistry
C. Li, NHMFL and FSU, Chemistry and Biochemistry
Y. Mo, NHMFL and FSU, Chemistry and Biochemistry
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Figure 1. 600 MHz large sample ^{1}H-^{15}N static VT probe, picture taken without VT chamber for better clarity. Developed for ^{15}N PISEMA experiments on large aligned membrane protein samples.

Introduction

Orientational restraints are derived from observations of a wide range of anisotropic nuclear spin interactions (e.g. chemical shifts and nuclear spin dipolar interactions) from aligned samples having a unique orientation with respect to applied magnetic fields, such as membrane proteins in lipid bilayers. It has been demonstrated that three-dimensional structures can be assembled from the orientational restraints.[1] Recently, polarization inversion spin exchange at the magic angle (PISEMA)[2] has been widely used to obtain orientational restraints from membrane proteins in a lipid environment.[3-5] In these experiments, thin glass plates are used to align peptide samples in lipids. For example, the transmembrane peptide of M2 protein (M2-TMP) from influenza A virus and DMPC or DOPC are co-dissolved in trifluoroethonal (TFE) with a peptide to lipid molar ratio of 1:50. The sample mixture is then thinly spread onto approximately 40 thin glass plates (75 µm x 5.7 mm x 12 mm used in our lab). The combination of low protein concentrations and low filling factor due to the introduction of glass plates mandates use of large sample volumes to produce S/N sufficient for detection of ^{15}N signal. After vacuum drying to remove TFE, the glass plates are stacked into a Pyrex glass tube with dimensions 6 mm (height) x 8 mm (width) x 15 mm (length) x 0.9 mm (wall) and the samples are hydrated with HPLC-grade water, sealed, and incubated at ~42°C for a few days.

Increasing use of such experiments for NMR structure determination of membrane proteins has focused attention on the need for better high-field and large sample (> 500 mm^{3}) solid-state probes that overcome typical problems resulting from sample size increase. They must tune to high ^{1}H frequencies, while maintaining sufficient strength and preserving homogeneity of radio-frequency field B_1, they must handle large input power, and they must also efficiently remove RF heat generated inside the sample by long decoupling pulses. **To counter these challenges, a new set of PISEMA-related instruments was developed by the RF Program and released to NMR users in the last quarter. The main piece of hardware, a 600 MHz large sample ^{1}H-^{15}N static NMR probe with variable temperature capability, will greatly enhance membrane protein structure determination facilities at the NHMFL. It is followed by an auxiliary lower field 300 MHz static ^{1}H-^{31}P variable temperature probe, which is used mainly to check on membrane alignment prior to PISEMA type experiments.**

Large Sample ^{1}H-^{15}N Probe for 600 MHz, 89 mm magnet

Due to the rectangular nature of oriented sample preparation, a large 600 mm^3 rectangular solenoid (8 mm x 6 mm x 12 mm, 4 turns) was used in the 600 MHz ^{1}H-^{15}N probe to achieve better filling factor when detecting weak ^{15}N signals from the aligned membrane protein samples. The free-standing coil is constructed from thin, wide foil, to better control RF inhomogeneity that results from proximity to the wall of the solenoid. To better understand how large this coil is, consider that the volume of the RF coil for a standard 4 mm Bruker MAS probe for the same frequency is only 130 mm^3.

Such large coils, when combined with high magnetic fields, present several problems. Increase in coil size means the probe must be able to handle higher RF input power in order to achieve the same B_1 fields. This leads to use of physically larger capacitors and therefore, to larger parasitic energy losses. In addition, as the coil's electrical length approaches ¼ of the proton wavelength, its self-capacitance can become significant at this frequency and lead to severe RF inhomogeneity in proton channel. In this case, the peak current density is at the ground terminal of the coil. This electrical effect is exacerbated by the dielectric constant of the hydrated sample, which reduces the effective speed of light. The 4-turn coil implemented in our probe corresponds to exactly ¼ λ at 600 MHz in air.

We cannot decrease the number of turns in the coil, since that would reduce the sensitivity of the lower 61 MHz nitrogen channel. Instead, we level out the proton inhomogeneity by balancing the high-frequency part of the RF circuit. Figure 3 shows the RF circuit employed for our 600 MHz probe, with coil ends having equal impedance with respect to ground at the proton frequency. With a balanced RF circuit, a virtual ground is introduced in the middle of the coil. The effect is comparable to reducing the number of turns by a factor of two. The peak current is now at the center of the coil, while the peak voltage at its ends is reduced by half, thus also acting in favor of adjacent electronic components where voltages can otherwise easily exceed 4 to 5 kV. Balancing the circuit also solves the tuning issue by increasing tuning capacitance by a factor of 2 to more comfortable values (tuning capacitors C_2 and C_3 are effectively in series).

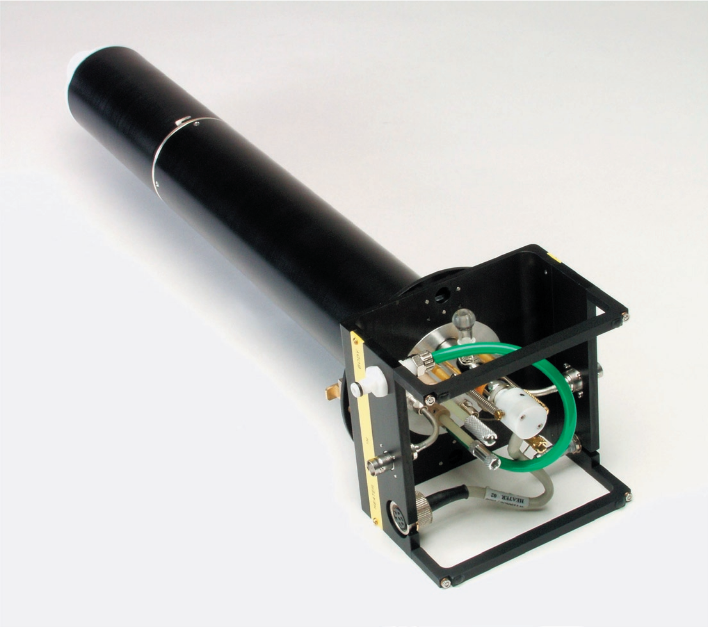

Figure 2. In-house built 300 MHz accessory ^{1}H-^{31}P large sample VT probe. Used for checking on sample alignment prior to PISEMA experiments.

RF isolation between channels is –35 dB at both frequencies. Special attention was given to traps separating the two channels since they are the main reason for efficiency loss in double-resonance circuits. The ¼ λ shorted coaxial trap that provides high impedance for proton and ground for the nitrogen signal has been custom fabricated for minimum loss at the detection frequency, while keeping proton losses at acceptable levels. The parallel proton trap L_1-C_6 was made to withstand high voltage yet remained compact. The fixed high-voltage capacitors (by American Technical Ceramics) used in proton trap

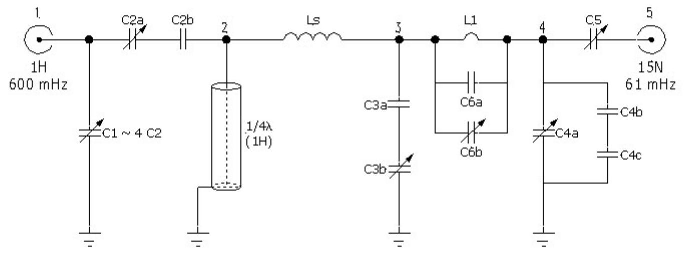

Figure 3. Radio-frequency schematics of the 600 MHz large sample ^{1}H-^{15}N membrane protein probe. C_1, C_{2a}, and C_{3b} provide matching, tuning, and balancing for the proton channel, respectively. C_{4a} and C_5 tune and match the lower frequency nitrogen channel.

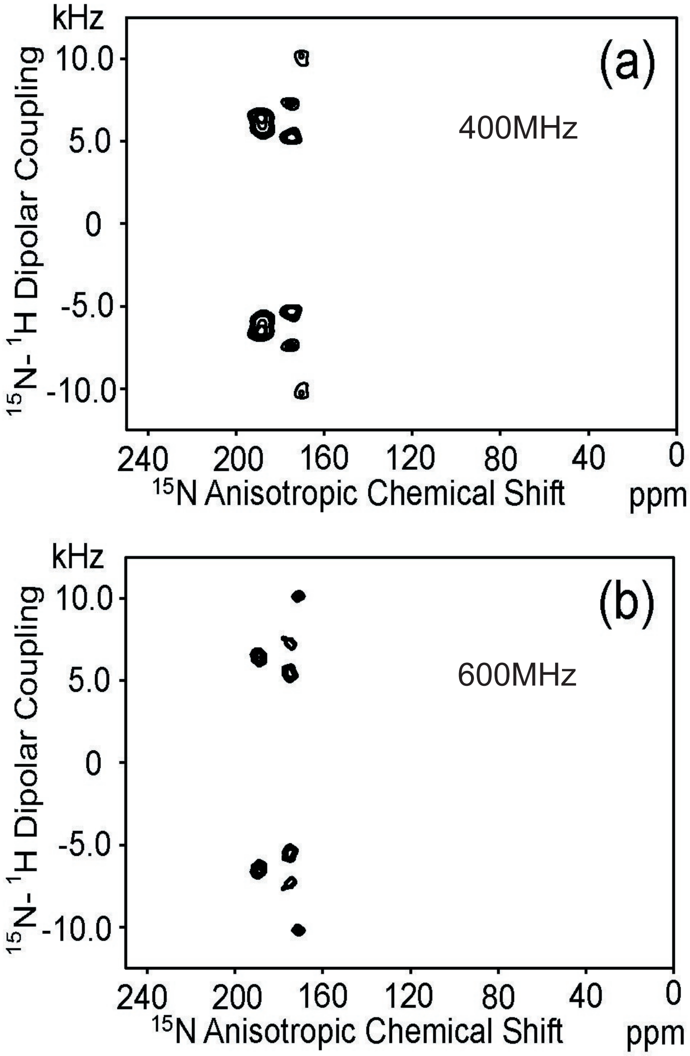

Figure 4. 2D PISEMA spectra of ^{15}N-Leu$_{26,36,38,40,43}$-M2-TMP oriented in DMPC in the presence of 10 mM Amantadine recorded on (a) 400 MHz and (b) 600 MHz. On the 400 system, about 15 mg of the M2-TMP peptide was used for the oriented sample and 32 t_1 increments were used. For each increment, 1024 scans were used to accumulate ^{15}N signals. While on the 600, about 8 mg of the M2-TMP peptide was used for the oriented sample and 64 t_1 increments were used. For each increment, 128 scans were used to accumulate ^{15}N signals. A recycle delay of 6 was employed in both experiments.

and elsewhere throughout the circuit were chosen and arranged carefully in order to cancel acoustic ringing at the 61 MHz nitrogen frequency. Custom fabricated capacitance was used when such arrangements were not possible. The probe's acoustic ringing time at 61 MHz is less than 15 µs. Probe sensitivity was calibrated in terms of 90° pulse-length using a N-Acetyl-^{15}N-valine (NAV) single crystal: p90 = 4.2 µs for nitrogen @ 670 Watts input power; p90 = 2.8 µs for proton at 300 Watts.

Variable temperature control and removal of heat generated inside the sample during the decoupling pulse is accomplished by large airflow directed at the coil from a VT upper stack, an additional in-house built auxiliary device inserted into the probe from the top of the magnet and capable of delivering large volumes of air within and beyond the biological temperature range. The importance of RF heating factor is most evident from measurements of the probe's Q value, both with and without sample. In some of the lossiest samples these numbers differ by a factor of 2, indicating that as much as 50%(!) of the decoupling power may go toward sample heating due to the presence of an electric field.

Results

Figure 4 shows the PISEMA spectra of ^{15}N-Leu$_{26,36,38,40,43}$-M2-TMP oriented in DMPC bilayers in the presence of 10 mM Amantadine, obtained with the previously available 400 MHz probe and with the new 600 MHz. In the oriented sample for 600 MHz, about 50% less M2-TMP peptide sample was used compared to that for 400 MHz, due to difference in the sample coil dimensions. Nevertheless, the PISEMA spectrum obtained at 600 MHz shows better sensitivity than that obtained on the 400. Furthermore, the measurement time at 600 MHz was reduced by a factor of 4 compared to the total acquisition time on the 400 spectrometer, and the number of the t_1 increments was doubled, thus leading to higher resolution in the dipolar domain. Therefore, the sensitivity enhancement by going to a higher field is approximately a factor of four and will open up new venues in NMR studies of membrane proteins at the NHMFL.

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[2] Wu, C.H.; Ramamoorthy, A.; and Opella, S.J., *J. Magn. Reson.*, **A 109**, 270 (1994).
[3] Song, Z., *et al., Biophys. J.*, **79**, 767 (2000).
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Resistive Magnet Upgrades:
BETTER TECHNOLOGY =
HIGHER FIELDS,GREATER DURABILITY

M.D. Bird, NHMFL/Magnet Science & Technology

Design work to upgrade various resistive magnet facilities at the NHMFL is now underway. There are three major upgrade design projects that will eventually impact the magnets in cells 5, 7, 8, 9, and 12. All of these projects involve using the technology developed for the 33 T resistive magnet and the Hybrid insert and applying it to the existing (obsolete) facility magnets. In so doing, field increases up to 7 T should be attained. In addition, reliability and user friendliness of some facilities should increase.

When designing and comparing magnet systems, one needs to consider what is meant by "efficiency." For resistive magnets, the field, B, is proportional to the current, I, and the power, P, is roughly proportional to the square of the field ($I \sim B,\ P \sim I^2R,\ \Rightarrow P \sim B^2$). In addition, for magnets consuming the same amount of power, those with larger bores provide lower fields. One can show then that a simple measure of the "efficiency," E of a resistive magnet is given by:

$$E = B(a_1/P)^{1/2}\ [1],$$

where, a_1 = inner radius.

50 mm Bore (Cell 5)

Upgrading the 25 T, 50 mm bore high field magnet in cell 5 to 32 T is being undertaken first due to the need to provide spare coils for this aging magnet. This 7 T increase is attained by a global re-optimization that includes three main features: (1) changing from a 3-coil design to a 4-coil design, (2) introducing axial current density grading, (3) re-sizing the coils based upon the previous two features. Figure 1 presents a vertical section through the existing 25 T magnet and the newly designed 32 T magnet.

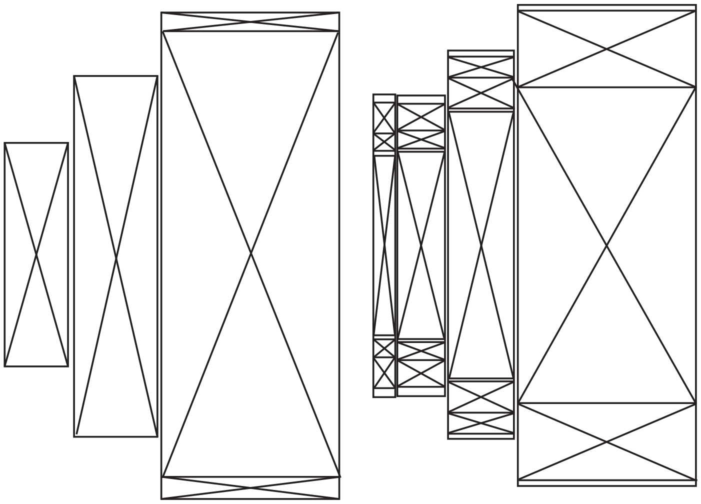

Figure 1. Vertical section of old (left) and new (right) 50 mm bore high field magnets.

One sees that the old system used three coils labeled A, B, and C from the inside out. Coils A and B have uniform current density along their lengths. Coil C has one turn at each end with reduced current density. In the new design, we utilize four coils labeled A_1, A_2, B, and C from the inside out, similar to the existing 33 T magnets in cells 9 and 12. By introducing an additional coil, one has more degrees of freedom for the optimization process which means we can obtain a practical solution closer to the "theoretical" limit of efficiency.

In addition, the new coils include substantial current density grading with coils A_1, A_2, and B utilizing three symmetric zones of grading and C using much larger reduced current density zones at the ends than presently. In the existing magnet, the end turns of the B coil consume the same amount of power as do the mid-plane turns. The end turns, however, are further from field center and do not contribute as much to the field on-sample as do the mid-plane turns. Thus, the end turns are not as efficient as the mid-plane ones as defined above. By introducing axial current density grading, the end turns run at lower current density and consume less power than the mid-plane turns, thereby bringing their efficiencies more in line with the mid-plane.

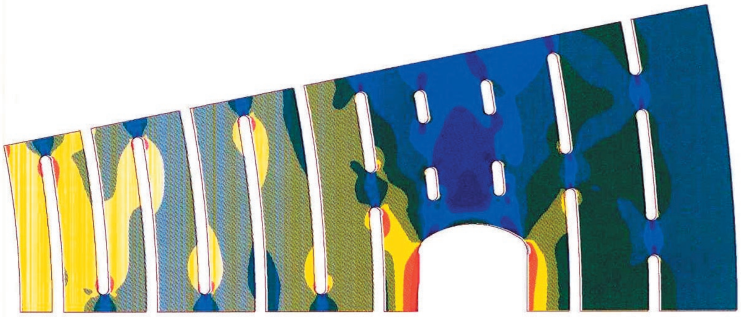

Figure 2. Mid-plane temperature of the new A2 coil.

Figure 3. Mid-plane stress of the new A2 coil.

Finally, given four coils and the possibility of axial current density grading, we re-optimize the whole system resulting in the design shown in the right side of Figure 1. Table I compares parameters and efficiencies of the old and new designs. We see that the outer diameter of the new A coil is larger than that of the old one. What has happened is that power has been shifted from the ends of the B and C coils to the mid-plane of the outer part of the A coil. It is important to recall that a system is more than simply a collection of parts bolted together. If one studies Table I, one might conclude that the A_1 and A_2 coils are less efficient than the old A coil and that the new B coil is less efficient than the old B coil. However, if one computes the efficiency of the new A_1 and A_2 coils together and compares that to the old A coil, one sees an improvement of 5.91 vs. 5.31 T/MW$^{1/2}$. In addition, the new B coil has a larger inner radius than the old one. If we correct their efficiencies by the square root of the inner radii, we see they are similar. Ultimately, the critical parameter is the total system efficiency. Figures 2 and 3 present temperature and stress distributions, respectively in the new A_2 coils as computed by Iain Dixon using ANSYS.

Coil design of this new system is complete and a design review was held June 11, 2003. Detailed mechanical design is underway and purchasing of materials is starting to occur.

TABLE I: Comparison of old and new 50 mm bore magnets.

Coil	a_1 (mm)	B (T)	P (MW)	$B/P^{1/2}$ (T/MW$^{1/2}$)
EXISTING DESIGN				
A	28	10.0	3.54	5.31
B	77	10.1	6.21	4.05
C	152	7.6	6.14	3.07
TOTAL		**27.7**	**15.9**	**6.95**
NEW DESIGN				
A_1	28	7.07	2.63	4.36
A_2	49	9.66	5.36	4.17
B	93	8.00	5.31	3.47
C	152	7.55	5.64	3.18
TOTAL		**32.3**	**18.9**	**7.42**

32 mm Bore (Cells 8, 9, 12)

The second upgrade project is to re-design the 32 mm bore high field magnets and increase the field available to users from 33 T to 35 T. This will be accomplished by using the same *B* and *C* coils as in the new 50 mm bore magnet and installing new A_1 and A_2 coils for the 32 mm bore system as shown in Figure 4. Eventually these new magnets will be installed in cells 8, 9, and 12 as the existing coils wear out.

Again, we can compare efficiency of the new design to the old as shown in Table II. We see that the overall system efficiency of the new magnet is only slightly better than that of the old magnet. The new magnet, however, is designed to provide 2 T more field at the same stress level as the older, lower field magnet. Thus, while the new design principles do not impact the overall "efficiency", they do allow for higher field with the same (or better) lifetime and reliability.

The 32 mm bore upgrade is presently still in the coil design phase which should be completed in September 2003. The numbers presented in Table II are preliminary. The detailed mechanical design phase will then initiate based upon availability of personnel.

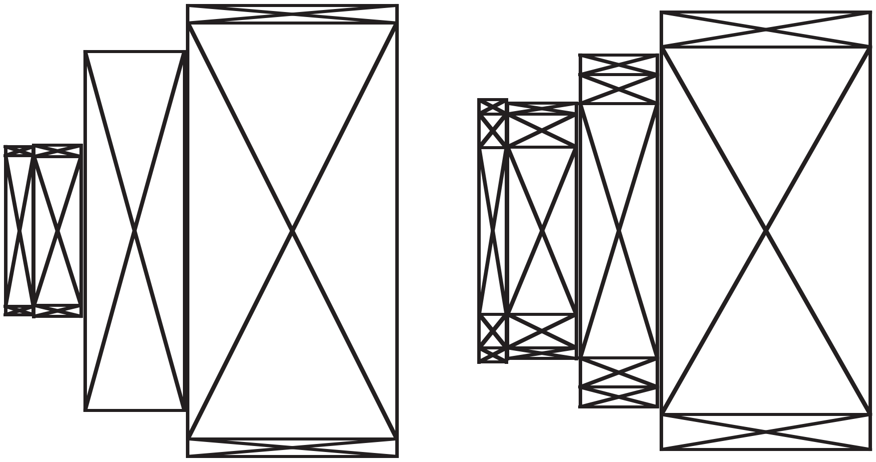

Figure 4. Vertical sections of old (left) and new (right) 32 mm bore high field magnets.

TABLE II Comparison of old and new 32 mm bore magnets.

Coil	a_1 (mm)	*B* (T)	*P* (MW)	$B/P^{1/2}$ (T/MW$^{1/2}$)
EXISTING DESIGN				
A_1	19	7.57	1.88	5.52
A_2	40	8.90	4.12	4.38
B	77	9.17	5.25	4.00
C	152	7.41	5.70	3.10
TOTAL		**33.1**	**17.0**	**8.03**
NEW DESIGN				
A_1	19	7.91	2.47	5.03
A_2	40	11.63	5.42	5.00
B	93	8.15	5.58	3.45
C	152	7.68	5.85	3.18
TOTAL		**35.4**	**19.3**	**8.06**

50 ppm (Cell 7)

Presently, cell 7 provides 24.5 T in a 32 mm bore with inhomogeneity of roughly 50 ppm over a 10 mm DSV for periods up to one hour. For extended periods of time the field is restricted to 23.2 T due to power supply limitations. We intend to upgrade cell 7 to a new coil design based heavily upon one of the designs presented above. There is some advantage to having both cell 5 and 7 configured with 50 mm bore high field magnets. One could then install inserts into either of them to provide high homogeneity, modulation, gradient, etc. However, the current densities in the insert necessary to achieve high homogeneity in the overall system would be quite high which would require developing new coil technology. In addition, the resulting system would be very sensitive to imperfections. Slight coil mis-alignments and manufacturing tolerances could result in unacceptably large in-homogeneities.[2] Hence it appears, at this point, that the new magnet for cell 7 will be a modification of the new 32 mm bore magnet as shown in Figure 5. The field available should be above 29 T for 8 hour shifts.

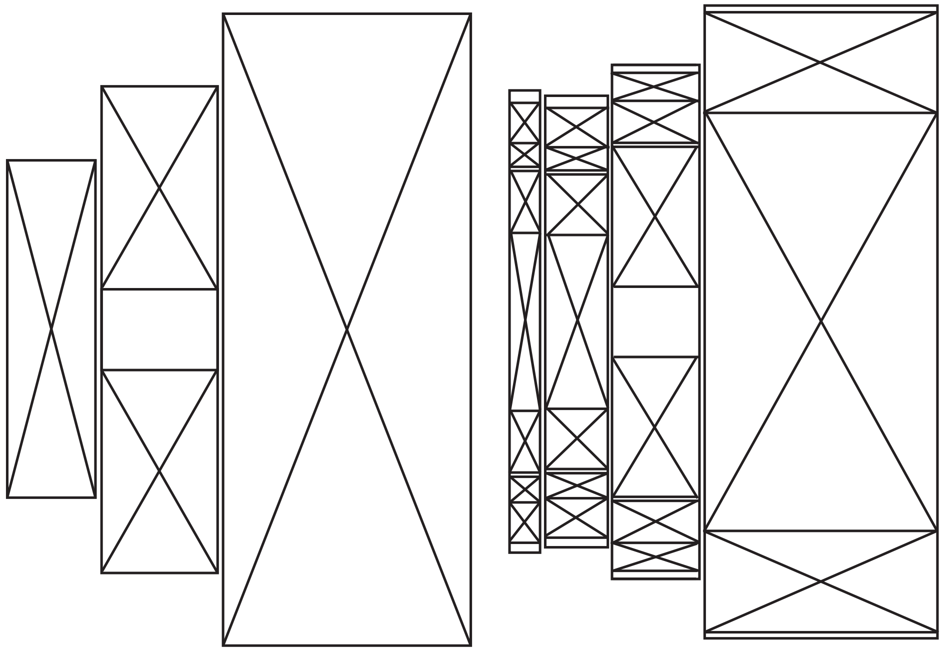

Figure 5. Vertical sections of old (left) and new (right) 50 ppm magnets.

TABLE III Preliminary inhomogeneity of new 50 ppm magnet [B(z)-B0/B0*1e6].

z (mm)	A_1 (ppm)	A_2 (ppm)	B	C	Total
0	0.0	0.0	0.0	0.0	0.0
2	-0.5	-0.7	10.4	-9.4	-0.2
4	-1.4	-2.3	42.1	-37.2	1.3
6	-2.6	-5.9	94.4	-83.4	2.5
8	-3.8	-13.3	166.7	-148.1	1.5
10	-4.3	-26.8	258.2	-231.4	-4.2

In the existing 50 ppm magnet, the *A* and *C* coils are standard high field coils where the field drops off as one moves away from the mid-plane along the axis of symmetry. We call this negative field curvature. The *B* coil has a gap at the mid-plane which gives it positive curvature. The sum of the fields of the three coils is roughly zero field curvature over a 10 mm DSV.

For the new magnet, a different approach is taken. Again the *C* coil is the same high field coil with negative field curvature as the two designs above. The *B* coil again has the split to provide positive curvature. The A_1 and A_2 coils, however, employ slightly lower current density at the mid-plane zone than at the next outboard zone. Thus, their fields are essentially flat. Field inhomogeneities of these preliminary coil designs are presented in Table III assuming no imperfections or mis-alignments. If one used the high field A_1 and A_2 coils of the 32 m bore magnet, one could not introduce enough positive curvature into the *B* coil to compensate the overall system. Hence, the "flat" design of the A_1 and A_2 coils.

Design of this magnet is in a preliminary stage. When then 32 mm bore coil design is complete, we will proceed with design of this new system. It is important to note that the final magnet will have substantially higher in-homogeneity due to manufacturing tolerances than indicated in Table II. The final in-homogeneity is expected to be comparable with that presently in cell 7 or what was attained in Keck prior to ferroshimming, i.e., about 50 ppm over a 10 mm DSV.

Future Systems

The user community has repeatedly requested a transverse field magnet and high gradient insert coils. Design of these systems should begin in coming months as personnel become available.

[1] D.B. Montgomery & R.J. Weggel, *Solenoid Magnet Design: The Magnetic & Mechanical Aspects of Resistive and Superconducting Systems*, John Wiley & Sons, 1969.

[2] M.D. Bird and Z. Gan, "Low Resolution NMR Magnets in the 23 to 35 T Range at the NHMFL," *IEEE Trans. On Appl. Supercond.,* vol. 12, no. 1, March 2002, pp 447-451.

SSNMR: Structural Studies of Condensed Peptides in Heterogeneous Environments

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M.A. Mehta, Oberlin College, Chemistry

Understanding protein structure-function relationships is critical in many areas of biology and medicine. The explosion of atomic-resolution protein structures as the fields of X-ray crystallography and high resolution NMR spectroscopy mature, as well as the insights into protein dynamics, have led to new strategies for drug design, focused the development of proteomic analyses, and guided the fine-tuning of protein structure prediction algorithms. Unfortunately, the inherent limitations of these techniques have constrained structural studies to water-soluble proteins and membrane proteins solubilized in detergent. In contrast, examination of the human genome has led to estimates that up to 40% of proteins are membrane associated. Functional assays have demonstrated that in the absence of a lipid bilayer environment, and even in membrane bilayers lacking specific lipid components, many membrane proteins are inactive. Also, proteins and peptides found at biological interfaces such as mineralized tissues and lipid bilayers play key roles in regulating processes ranging from bone formation and remodeling to cell signaling to expansion and compression in the lungs, but the exact molecular mechanisms behind the regulation are only beginning to be investigated. Solid state nuclear magnetic resonance (SSNMR) has the capability to elucidate both molecular structure and dynamics at atomic resolution in complex systems. The ability to study heterogeneous systems under *in situ* conditions makes SSNMR uniquely suitable for studying these biological interactions.

The last 50 years have seen the emergence of nuclear magnetic resonance (NMR) from a physical phenomenon to a major field encompassing magnetic resonance imaging, *in vivo* NMR, liquid (high resolution) NMR, and solid state NMR (SSNMR). While the original NMR experiments were performed on solid samples, the application of SSNMR to biological problems has lagged behind other magnetic resonance techniques due to the large anisotropic interactions in molecules which are not tumbling isotropically on the NMR timescale. Traditionally, problems arising from the chemical shift anisotropies (CSAs) and dipolar couplings inherent in solid samples have been circumvented by examining single crystals or aligned samples. With the advent of multiple pulse sequences and magic angle spinning (MAS), methods for suppressing these interactions through the use of rf pulses and mechanical sample spinning have overcome the need for sample manipulation and broadened the application of SSNMR techniques to heterogeneous, unoriented systems. While high resolution MAS chemical shift spectra have provided insights into the molecular level details of complex samples, the development of experiments in which rf pulses and mechanical sample spinning are applied in a synchronized fashion have revolutionized the use of SSNMR to provide high resolution structural data. Through coherent application of radiofrequency pulses during MAS, the selective suppression and/or reintroduction of hetero- and homonuclear dipolar couplings as well as chemical shift anisotropies may be accomplished. Using a suite of experiments, these interactions can be selectively measured with high accuracy.

One focus of our research is to extend the development of double quantum homonuclear dipolar recoupling techniques to quantitative measurements at high field so that the gains in sensitivity due to the improved Boltzmann distribution are not offset by losses in double quantum efficiencies due to rf inhomogeneity and insufficient CSA suppression. Concurrently, we are applying these methods to the study of peptide structure and dynamics in condensed phases, including membrane-associated peptides and peptides adsorbed on mineral and polymer surfaces, and to the examination of solvation of peptides in crystalline and amorphous states. Following are some examples of these measurements and the challenges present at high field.

Homonuclear dipolar recoupling techniques, such as DRAWS and R22, are able to measure distances between spin 1/2 nuclei (^{13}C, ^{15}N, ^{31}P, etc.).[1] Through ^{13}C isotopic enrichment, interactions between specific atomic positions in a peptide may be introduced and measured to high accuracy. We have developed an approach to examining protein structures via amino acids which are isotopically-enriched at backbone carbonyl carbons since they are commercially available and relatively easy to introduce at adjacent amino acids in the peptide backbone either synthetically or via *E. coli* overexpression systems.[2-5] Assuming canonical bond lengths and bond angles, the distance between adjacent carbonyl carbons in the peptide backbone is solely dependent on the torsion angle φ. In the absence of motion, this distance has a sinusoidal dependence on φ and varies from 2.7 to 3.7 Å, or a dipolar coupling of 150 to 400 Hz. This coupling can be used to generate a double quantum (DQ) coherence, simplifying spectral analyses (Figure 1).

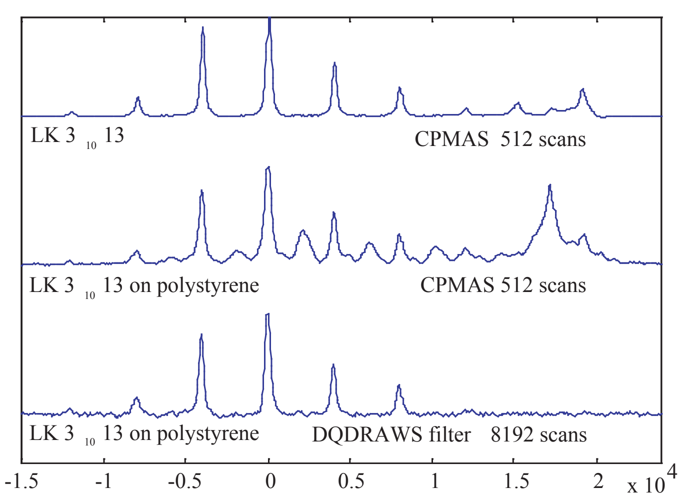
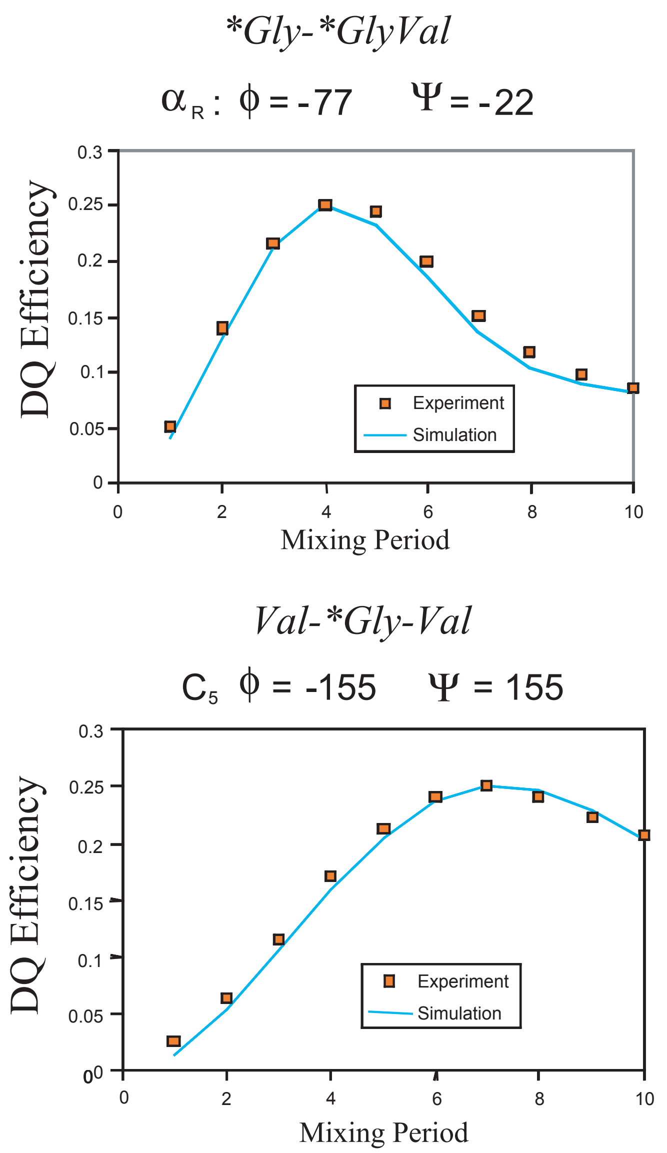


Figure 1. Chemical shift spectra of a doubly-labeled peptide, Ac-LLKLLKLLKLLKL-NH2, lyophilized from solution and adsorbed on a polymer surface, demonstrating the natural abundance contribution to the spectra. The third spectrum is the DQ filtered spectrum showing only the pair of isotopic labels introduced into the peptide.

The buildup of DQ coherence is directly dependent on the dipolar coupling (Figure 2). If the DQ coherence is generated between the two spins and then allowed to evolve, its time dependence will be governed by the dipolar coupling between the carbonyl carbons and the vector sum of the tensors describing the individual carbonyl carbon CSAs (Figure 3). Work on model, crystalline peptides has established the orientation of the CSAs relative to the plane of the amide bond, and when the torsion angle ω is close to 180°, as is typical for peptides, the sum CSA tensor is solely dependent on the principal values and the torsion angles φ and ψ.[5]


*Gly-*GlyVal

α_R : ϕ = -77 Ψ = -22

*Val-*Gly-Val*

C_5 ϕ = -155 Ψ = 155

Figure 2. DQ buildup between carbonyl carbons in adjacent amino acids of microcrystalline tripeptides. Simulations are based on published X-ray crystal structures and data were acquired using a 600 MHz spectrometer.

In Figure 2, it is noteworthy that the simulations match the experiments throughout the 10 msec mixing period since the pulse sequence is comprised of a windowless sequence of π/2 and 2 π pulses at a field of 35 kHz and the only variable in the simulation is the dipolar coupling constant. All other constants, such as the rf field strength and CSA principal values are independently determined. Additionally, the dipolar couplings entered into the simulations were calculated using the published torsion angles and canonical peptide bond lengths and angles. A least-squares minimization would have fit to couplings corresponding to torsion angles within 2° of the published values. The individual CSAs at the labeled positions are typically 150 ppm, or 22.5 kHz in a 600 MHz field where this data was acquired. Figure 3 shows the projection of the DQ dimension for a 2D experiment in which a mixing period is introduced after generation of the double quantum state to allow for evolution. Simulations incorporating canonical bond lengths and angles and the torsion angles from the published X-ray crystal data are shown for comparison.

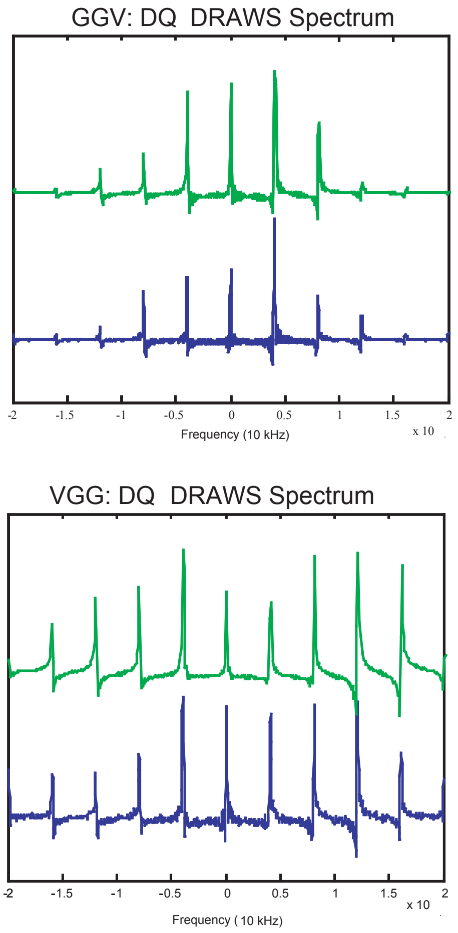


Figure 3. Projections of 2D DQ-DRAWS data acquired for *G*GV and *V*GG (blue) and simulations (green) using the published φ, ψ torsion angles of -77, -22 and -155, 155.

In samples where the structure is unknown, a DQ buildup curve is acquired and simulated by varying the torsion angle φ. To first order the DQ buildup is not dependent on the orientations of the CSAs for the two spins, but at high fields incorrect orientations can lead to a 0.05 to 0.1 Å error in this calculation. A 2D DQ-DRAWS spectrum of the sample is collected and simulated by using the torsion angle φ from the DQ buildup experiment and varying the torsion angle ψ. The φ, ψ torsion angles are then put back into the DQ buildup simulation and the fit is refined, followed by further simulation of the 2D spectrum to improve the fit for ψ.

While the development of SSNMR technologies at higher magnetic fields leads to sensitivity enhancements, the application of dipolar recoupling techniques becomes more challenging. At 17.6 T (750 MHz), the typical carbonyl carbon chemical shift anisotropy reaches 30 kHz while the dipole couplings of interest for structural studies remain at less than 300 Hz. The approaches to developing recoupling sequences have taken one of two strategies: (1) γ-encoded sequences focus on developing pulse sequences that start with longitudinal magnetization and rely on spin locking in concert with the spinning of the rotor to recouple the spins in order to have less of a dependence on the angular orientations of individual molecules and thus a higher theoretical double quantum efficiency[6] or (2) use an initial state with transverse magnetization and apply rotor synchronous pulses to refocus the dipole couplings while suppressing the CSA interactions.[1] Previous studies have shown that at an intermediate field strength of 9.4 T (400 MHz), the efficiency of double quantum coherence generation via various dipolar recoupling sequences deviates substantially from predictions based on first order theory, and that this discrepancy is due to error terms introduced by the chemical shift anisotropies.[7] Full density matrix calculations using experimentally determined CSAs are able to account for any measured losses in double quantum efficiency due to insufficient attenuation of CSA interactions and/or relaxation to the proton bath. As dipolar couplings get smaller, longer mixing times

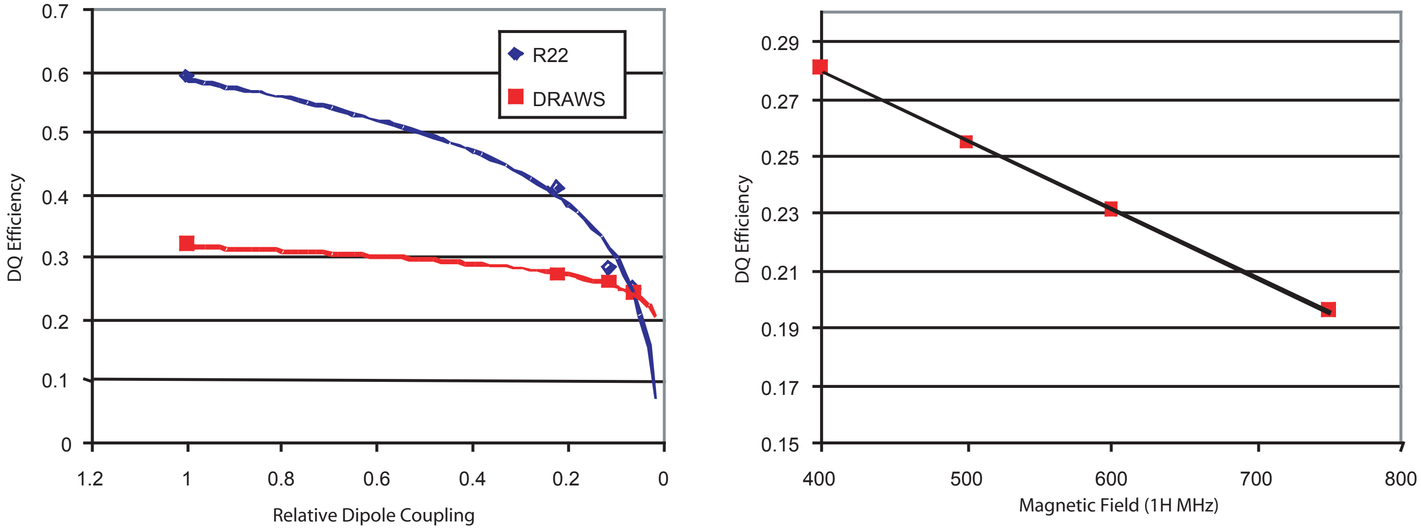


Figure 4. Left: Ability of the DRAWS and R22 pulse sequences to generate DQ coherences in carbonyl-labeled samples as a function of relative dipolar coupling at 400 MHz. Right: Field dependence of the DQ efficiency generation between adjacent carbonyl carbons in an α-helical peptide using a DRAWS pulse sequence.

are required and the error terms have a larger effect on the overall performance of a particular sequence. This is demonstrated in Figure 4 with a graph of DQ efficiencies between carbonyl carbons as a function of relative dipolar coupling for distances from 1.5 to 3.9 Å (1 to 3 bond couplings) using data acquired with a 400 MHz spectrometer.[7] For peptides, the performance of the best recoupling sequences, R22 and DRAWS, developed to date using the two strategies show roughly the same performance at 400 MHz. As the magnetic field strength is increased, however, the DRAWS sequence is better able to compensate for the increase in CSAs. The second graph in Figure 4 shows numerical calculations predicting the maximum attainable DQ efficiency for adjacent carbonyl carbons in an α-helical secondary structure as a function of magnetic field strength using currently available probe technologies for a reasonable coil size and the DRAWS recoupling sequence. Experimental measurements at 400, 500, and 600 MHz have borne out these predictions. As is evident from Figure 4, while using higher magnetic field strengths will increase sensitivity for structural measurements, the full benefit of having increased Zeeman polarization will not be realized using current dipolar recoupling sequences due to insufficient suppression of CSA error terms. Further improvements in CSA suppression through the development of better phase cycling schemes, use of composite pulses, more efficient rf generation, or perhaps new approaches could potentially increase DQ efficiencies 2-fold at high magnetic field strengths, and we are pursuing several of these strategies.

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[3] W.J. Shaw, J.R. Long, J.L. Dindot, A.A. Campbell, P.S. Stayton, G.P. Drobny, "Determination of a Statherin N-Terminal Peptide Conformation on Hydroxyapatite Crystals", *J. Am. Chem. Soc.,* **122**, 1709 (2000).

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[5] P.V. Bower, N. Oyler, M.A. Mehta, J.R. Long, P.S. Stayton, G.P. Drobny, "Determination of Torsion Angles in Proteins and Peptides using Solid State NMR"*, J. Am. Chem. Soc.,* **121**, 8373 (1999).

[6] M. Carravetta, M. Eden, O.G. Johannessen, H. Luthman, P.J.E. Verdegem, J. Lugtenburg, A. Sebald, M.H. Levitt, "Estimation of carbon-carbon bond lengths and medium-range internuclear distances by solid-state nuclear magnetic resonance," *J. Am. Chem. Soc.,* **123**, 10628 (2001).

[7] T. Karlsson, J.M. Popham, J.R. Long, N. Oyler, G.P. Drobny, "A Study of Homonuclear Dipolar Recoupling Pulse Sequences in Solid State NMR," *J. Am. Chem. Soc.* **125**: 7394-7407. (2003).

EDUCATION at the NHMFL

Adapting to a Changing Educational Climate

After a spring retreat and outside evaluation, the Center for Integrating Research and Learning (CIRL) has taken a long hard look at its programs, outreach offerings, and plans for the future. The following mission statement resulted:

> *To expand scientific literacy and to encourage the pursuit of scientific studies among educators and students of all ages through connections between the NHMFL and the National Science Foundation, the community of Tallahassee, the State of Florida, and the nation.*

In addition, Center staff identified the following areas of focus that will drive future programs: (1) K12 initiatives in science education; (2) undergraduate and graduate experiences in science and science education; (3) professional development in science teaching; (4) general public science awareness; (5) science curriculum development and training; (6) partnerships; and (7) continuous feedback and improvement.

Research Experiences for Undergraduates and Research Experiences for Teachers programs concluded successfully (see *NHMFL Reports*, Volume 10 (3), 2003) with all student and teacher presentations available on our Web sites: http*://reu.magnet.fsu.edu* and *http://ret.magnet.fsu.edu*. In addition, 42 teachers were provided with quality professional development this summer through two 4-day summer institutes. Teachers who participate become ambassadors for the NHMFL and for inquiry-based hands-on classroom science. Teachers working with Center educators, in consultation with Leon County Schools, created a content-rich series of activities for middle and high school teachers and students. Materials can be checked out from the Center and teachers can earn continuing education recertification credits. The new program will be pilot-tested this academic year with an eye to marketing the materials to other counties in Florida.

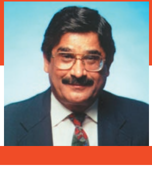
The Center continues university partnerships by providing experiences for Florida State's First Year Experience; Bryan Hall Learning Community; Women in Math, Science, and Engineering; and the Office of Science Teaching Activities. In partnership with Florida Agricultural and Mechanical University's Center for Equity, Center educators maintain a pilot "Girls in Science" program. The Center continues its longstanding community outreach, having recently initiated a "Science for Kids" night at Borders Bookstore. In addition, through a new partnership with The Boys and Girls Clubs of America, the NHMFL provides science instruction, hands-on activities, and tours of the facility to K12 students from surrounding counties that are designated as underserved and with student populations that are typically underrepresented in the sciences.

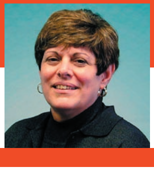
Redesign has begun on the education Web site (http*://education.magnet.fsu.edu*) to better reflect the Center's mission. The updated and expanded Web site will include features such as *Book of the Month* for parents and students, *Teacher and Student Resources, Student Support for Science Fair Projects,* and newly created activities for students to do at home with their parents. In the face of school district and state budget cuts, the Center and its committed group of educators are dedicated to bringing more and better science experiences to teachers, students, parents, and the general public. Through the Center's programs, thousands of students each year experience the excitement of real world science, teachers become more involved in science instruction and creation of challenging activities for their students, and the NHMFL is seen as a vital, dynamic resource for quality educational programs.

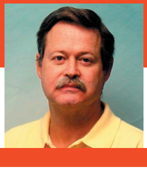
For further information about the NHMFL Center for Integrating Research and Learning, contact the program director, Dr. Pat Dixon, pdixon@magnet.fsu.edu*, 850-644-4707.*

PEOPLE IN THE NEWS


O.Castillo


N.Dalal


P.Dixon


P.Froelich


N.Hoffman


P.Littlewood

Oscar Castillo, has been named one of the FSU 2003-04 Delores Auzenne Fellowship for Minorities winners. As an undergraduate, Castillo worked in Justin Schwartz's lab from June 2001 through graduation in April 2002. He is now a mechanical engineering graduate student working on MgB_2 superconducting wires as part of CAPS.

Castillo grew up in Tallahassee after immigrating from Peru as a toddler. He was recently naturalized as a U.S. citizen. Schwartz states that "Oscar was a very promising undergraduate who became a stronger student after getting involved in research—both because of seeing something 'real' that related to classes, and because his success in research motivated him. His advancement to graduate school demonstrates once again the importance of integrating research and classroom experiences."

Naresh S. Dalal, professor of chemistry and chairman of the FSU Department of Chemistry and Biochemistry, has been named an FSU Distinguished Professor. Dalal conducts EPR research and has been previously designated as Paul Dirac Professor of Chemistry and Biochemistry. He earned his Ph.D. in Physical Chemistry from the University of British Columbia in Vancouver, Canada. Dalal is a 2000 APS Fellow—the fourth FSU chemist to gain this distinction in physics, succeeding Michael Kasha, Alan Marshall, and Geoffrey Bodenhausen.

Pat Dixon, Director of the Center for Research and Learning (CIRL), received a "Being There Award" from the FSU Division of Student Affairs for her work on the University Judicial Panel. There were four other recipients who have contributed significantly to the mission of the DSA. Dixon joined the NHMFL in 1996 to work on a grant to create curriculum materials for the State Department of Education. Soon, thereafter, she assumed expanded duties as Assistant Director with primary responsibility for the laboratory's teacher education and curriculum development activities.

Dixon received her B.S. from Syracuse University and her Ph.D. in Educational Foundations and Policy Studies from FSU. Her educational research interests include teacher practice and how professional development opportunities affect classroom practice. She has taught classes at the FSU College of Education and is presently teaching at Flagler College. CIRL has expanded its outreach to area classrooms, statewide teacher workshop opportunities, and continues to provide teachers, students, and the general public with meaningful experiences related to a science research facility.

Philip Froelich, FSU professor of Oceanography, is FSU's newest Francis Eppes Professor. After nearly two decades away, he returned to FSU on August 1 and is establishing his laboratory and office at the NHMFL as a member of the Geochemistry Program. He was an assistant, and then associate, professor at FSU from 1979 to 1985; was Doherty Scholar and Associate Director at Lamont-Doherty Earth Observatory of Columbia University until 1994; and Director and Professor in the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology.

Froelich is a leading expert on the cycling of silica in the ocean and the relationship between the silica cycle and climate change. In addition, he has strong interests in the behavior of elements like arsenic, selenium, and antimony and their impact on the environment. At Georgia Tech, he taught a very popular freshman course entitled: "How to Build a Habitable Planet." He intends to continue to offer this course at FSU.

The Francis Eppes professorships are named for President Thomas Jefferson's grandson, one of the founders of FSU's predecessor: Seminary West of Suwannee. Froelich and Zachary Fisk, of the NHMFL Condensed Matter Science Program, are the two FSU Eppes professors in the sciences.

Norris Hoffman, Professor of Chemistry at the University of South Alabama, will be spending his sabbatical leave in the ICR Program in 2004. Dr. Hoffman is an inorganic chemist who will be investigating the mechanisms for transition metal ion catalysis. He received his B.S. degree from UF and Ph.D. from Stanford University. His postdoctoral research was done at Max-Planck-Institut für Kohlenforschung. His general interests include synthetic and mechanistic studies of organotransition-metal compounds, kinetics spectroscopic studies, and computational chemistry.

In August, the NHMFL-LANL Pulsed Field Facility welcomed Professor **Peter Littlewood** to the laboratory for an eight-month sabbatical tenure partially funded by the NHMFL Visitors Program. Professor Littlewood is an internationally recognized condensed matter theoretician who is the Head of the Condensed Matter Theory Group at the University of Cambridge as well as a professor of Physics.

Littlewood will spend his sabbatical working with the NHMFL staff on numerous projects having to do with condensed

PEOPLE IN THE NEWS cont.


T.Painter


D.Reitze


A.Souslov


K.Yang

matter theory. His research will focus in part on highly excited semiconductors including fundamental phases of the interacting electron hole system. Littlewood is also interested in novel electronic materials including transition metal oxides, high temperature superconductors, doped ferromagnetic semiconductors and disorder narrow gap semiconductors.

The staff at NHMFL-LANL is excited to have the opportunity to collaborate with Professor Littlewood over the coming months, and plans are already being made for Littlewood to visit the NHMFL in Tallahassee and Gainesville to give talks.

Tom Painter, an engineer for the Magnet Science & Technology Group, has been appointed Interim Operations Manager for MS&T. He will monitor project scheduling and staff allocations; as well as have a major role in development of new project proposals for MS&T. Painter earned his B.A. from Pennsylvania State University and his M.A. degree from the Massachusetts Institute of Technology. He measured the AC loss time constants of multifilamentary Nb$_3$Al superconducting wires at the Japan Atomic Energy Research Institute (JAERI).

Painter's research interests include superconducting magnets and cryogenic systems. He has worked on the engineering design, fabrication, installation, and test of the United States Demonstration Poloidal Coil (US-DPC). The coil used Nb$_3$Sn superconducting wire and Incoloy 908 cable-in-conduit conductor (CICC) technology. The US-DPC was a prototype ohmic heating coil for a tokamak fusion reactor funded by the Department of Energy. At the NHMFL, he has worked on the 45 Tesla Hybrid magnet outsert coils that also used CICC technology this time with modified 316N conduit material, as well as the 900 MHz NMR magnet system recently installed.

David Reitze, professor of physics at UF, is one of six professors among the University of Florida Research Foundation's (UFRF) annual class of UF Research Foundation Professors. The three-year professorships recognize faculty who have established a distinguished record of research and scholarship. Reitze specializes in laser-matter interactions and high-resolution imaging of biological systems. He teaches electromagnetism, introductory physics, an advanced physics lab, and a graduate course in optical properties of materials; and, he is also the project manager for the design, assembly, and installation of the Laser Interferometer Gravitational Wave Observatory (LIGO).

Alexei Souslov, has joined the Instrumentation & Operations group, Users' Support section as a visiting assistant scholar/scientist. Souslov graduated from Leningrad State University (St.-Petersburg, Russia) in 1987, and received his Ph.D. at the A.F. Ioffe Physico-Technical Institute of the Russian Academy of Sciences (St. Petersburg, Russia) in 1995. He has worked at the Delft University of Technology (Delft, the Netherlands), at the Very Low Temperatures Research Centre of the French National Centre for Scientific Research (CRTBT-CNRS, Grenoble, France), and at the University of Wisconsin (Milwaukee, WI USA). For more information about his work with the NHMFL's Instrumentation & Operations Group, see article on page 8.

Kun Yang, FSU assistant professor of physics and member of the Condensed Matter/Theory Group, has won the 2002-2003 Outstanding Young Researcher Award (OYRA) of the Overseas Chinese Physics Association (OCPA). The OYRA is given each year to young ethnic Chinese physicists working outside of Asia in recognition of their outstanding achievements in physics. Yang received his B.S. in physics from Fudan University, China and his Ph.D. in physics from Indiana University. He was a postdoctoral associate at Princeton University in 1994-1997 and a Sherman Fairchild Senior Research Fellow at Caltech in 1997-1999. Yang was the recipient of an Alfred P. Sloan Research Fellowship in 1999 and the Research Innovation Award from Research Corporation in 2000.

A young condensed matter theorist, Yang has made significant contributions in many areas of condensed matter and statistical mechanics, particularly in the field of strongly correlated electrons. His theoretical work on the bilayer Quantum Hall states with spontaneous interlayer phase coherence has had broad impact in the field. This work is recognized as one of the pillars for supporting the understanding of new superfluidity phenomena.

CONFERENCES & WORKSHOPS

Events for 2003

33rd Southeast Magnetic Resonance Conference (SEMRC)

http://semrc2003.magnet.fsu.edu
October 17-19, 2003
Early Registration Deadline: September 27, 2004
Ramada Inn & Conference Center
Tallahassee, Florida

The NHMFL is pleased to bring SEMRC back to Florida and to host the conference again, as it did in 1995 and 1999 (in Tallahassee) and in 1997 and 2001 (at University of Florida in Gainesville). The focus of this biennial meeting is the exchange of ideas and recent magnetic resonance research highlights, including new applications and technique developments. Particular emphasis is placed on activities in the region.

Contact: Co-chairs: Hans van Tol and Bill Brey
(*semrc2003@magnet.fsu.edu*)

Events for 2004

5th Biennial Structural Biology Symposium Membranes: A Challenge for Protein Magnetic Resonance

http://fajerpc.magnet.fsu.edu/IMBconf/home.htm
January 23-24, 2004
Registration Deadline: December 1, 2003
Tallahassee, Florida
Contacts: Co-Chairs
Tim Cross (*cross@magnet.fsu.edu*, 850-644-0917) and
Peter Fajer (*fajer@magnet.fsu.edu*, 850-644-2600)

44th Sanibel Symposium

http://www.qtp.ufl.edu/%7Esanibel
February 28-March 6, 2004
Early Registration Deadline: October 31, 2004
St. Augustine, Florida
Contact: *sanibel@qtp.ufl.edu*

16th International Conference on High Magnetic Fields in Semiconductor Physics (SemiMag16)

http://SemiMag16.magnet.fsu.edu
August 2-6, 2004
Abstract Deadline: April 2, 2004
Early Registration Deadline: June 25, 2004
Tallahassee Holiday Inn Select
Tallahassee, Florida
Contact: Chair Yong-Jie Wang
(*SemiMag16@magnet.fsu.edu*, 850-644-1496)

Applied Superconductivity Conference (ASC04)

http://www.ascinc.org (under development)
October 4-8, 2004
Adam's Mark Hotel
Jacksonville, Florida
Contact: Chair Justin Schwartz
(*ASC04ConfChair@magnet.fsu.edu*, 850-644-0874)

15th Conference of the International Society of Magnetic Resonance (ISMAR 2004)

http://www.ismar.org/
October 24-29, 2004
Sawgrass Marriott Resort Hotel
Ponte Vedra Beach, Florida (near Jacksonville)
Contact: Chair Timothy A. Cross
(*mail@ismar.org*, 850-644-0917)

Events for 2005

Physical Phenomena at High Magnetic Fields – V (PPHMF-V)

August 5-9, 2005
Tallahassee, Florida
Contact: Coordinator Alice Hobbs
(*aclark@magnet.fsu.edu*, 850-644-3203)

24th Low Temperature Physics Conference (LT-24)

August 10-17, 2005
Orlando Hyatt Conference Center
Orlando, Florida
Contact: Chair Gary Ihas
(*ihas@phys.ufl.edu*, 352-392-9244)

Other Meetings of Interest

5th International Conference on the Scientific and Clinical Applications of Magnetic Carriers

http://www.magneticmicrosphere.com
May 20-22, 2004
Registration & Abstract Deadline: March 12, 2004

Job Opportunities

Los Alamos
NATIONAL LABORATORY

Center Leader at NHMFL-LANL

Summary: This individual will serve as Director of the Los Alamos campus of the National High Magnetic Field Laboratory, site of the laboratory's Pulsed Field Facility. In this capacity, he/she will (1) serve as a member of the NHMFL Executive Committee; (2) be responsible for the Los Alamos NHMFL users program; (3) lead the joint NSF/DOE project to develop a non-destructive 100 T magnet and 100 T science program; (4) foster and coordinate a strong in-house science program that extends capabilities of the pulsed field facility; (5) conduct state-of-the-art research in high magnetic field research and/or technology; and (6) manage the financial, human resource, safety, security, and administrative functions of the Center.

Required Skills: Record of technical achievement in condensed matter physics or other scientific discipline where high magnetic fields are a major tool. Success in building programs with DOE, DOD, or NSF (or equivalent) customers. Experience establishing and maintaining research collaborations and in strategic and tactical planning. Ability to balance competing interests with available resources and establish clear priorities. Effective communication skills. Ability to obtain a Q clearance, which normally requires U.S. citizenship.

Education and Experience: Ph.D. in physics, chemistry, materials science, or equivalent combination of education and experience.

To Apply: Please submit a resume, list of publications, and references to Dr. Gregory S. Boebinger, Los Alamos National Laboratory, P.O. Box 1663, MS G754, Los Alamos, NM 87545. To review a complete job description: *visit http://www.lanl.gov/jobs* and search for Job# 205413. This recruitment is being conducted by LANL, which is operated by the University of California for the National Nuclear Security Administration of the Department of Energy.

Director of Magnet Science & Technology Program

Summary: The Director of MS&T will be responsible for executing the charge from the NSF, including (1) routine maintenance and continued growth of multi-million dollar, high performance resistive, pulsed, low temperature and high-temperature superconducting magnet technology development programs; (2) development and coordination of in-house research, enabling technology and education programs that create a basis for future magnet systems; and (3) identification of growth opportunities and development of proposals for supplementary funding from government and industrial sources.

The Director will administer an annual budget of $5-6M, organize and supervise a department of 50 to 70 persons working on multiple magnet technology development programs in parallel, and coordinate these activities for all 3 operating sites. In addition, and similar to other Directorates within the NHMFL, the Director of MS&T will coordinate activities with his/her peers, manage the budgetary, human resource and administrative functions of MS&T, and will represent MS&T within the NHMFL and the university, as well as outside the university with other laboratories, collaborators, and suppliers.

Required Skills: The successful candidate will have a proven record of successful project / program management and new product development in either (1) high field magnet design and construction (superconducting, resistive or pulsed) and will be familiar with the sub-systems associated with these products OR (2) precision engineering development projects in comparable fields such as aerospace, electric power, etc.

Other required attributes include (1) well-developed skills in strategic and tactical planning and the subsequent application of mature leadership and management skills in the execution of precision engineering projects and technology programs; (2) ability to balance competing interests with available resources and establish clear priorities and focus; (3) proven record of commitment to responsible and high-quality operations; (4) experienced and successful business development efforts with external agencies and equivalent customers; (5) relevant experience in managing personnel, budgets, and programs; (6) effective interpersonal skills, including uncompromising honesty and integrity; and ability to earn the respect of subordinates, supervisors, peers, and collaborators. Record of effective two-way written and oral communications skills, as evidenced by internal and external interactions, including briefings, presentations, and meetings.

Education and Experience: Strong technical and analytical skills, preferably developed via a combination of an advanced degree and a minimum of 10-15 years experience in a relevant field. For example, a Ph.D. in a science/engineering discipline combined with the successful management (performance, schedule, cost) of complex technical projects would be desirable.

To Apply: Complete Standard FSU Application (available at *http://personnel.fsu.edu/forms/printonly/3B-3c.pdf*) and mail this application, cover letter, resume/CV and contact information for three references to Ms. Barbara Butler (REF: MST), NHMFL, Florida State University, 1800 East Paul Dirac Drive, Tallahassee, FL 32310.

Researchers Set New World Records for High Temperature Superconducting Magnet

Engineers and scientists at the National High Magnetic Field Laboratory (NHMFL) successfully tested an innovative 5 tesla high temperature superconductor (HTS) insert coil in a 20 tesla powered magnet at the laboratory on August 23, 2003. This test represents the first time that a superconducting magnet has ever generated magnetic fields of 25 tesla. The HTS insert coil broke at least seven world records, including the highest field generated in a superconducting magnet and highest increment of field in an HTS insert of useful size. These records were previously held by Japanese industrial scientists.

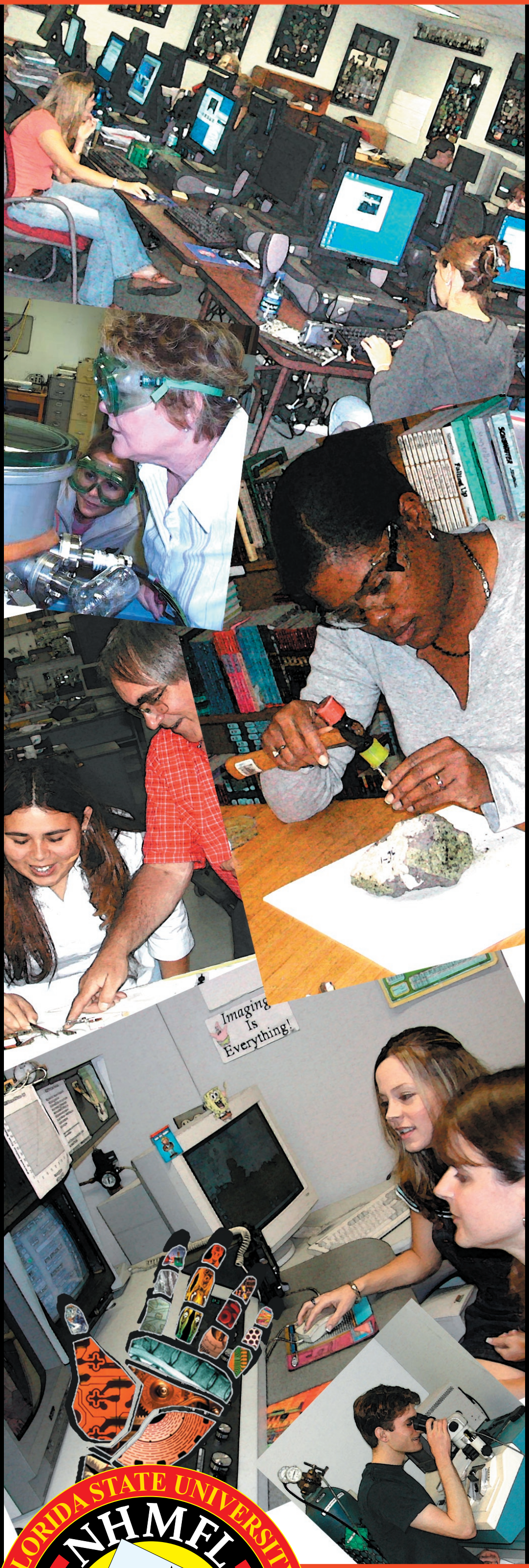
"This is a critical and essential technological breakthrough for high temperature superconducting materials for state-of-the-art magnets," stated project leader, Dr. Justin Schwartz. Dr. Schwartz and his team, in collaboration with Oxford Superconducting Technology of Carteret, New Jersey, have been working together for about a decade to demonstrate that HTS materials can be used to reach higher magnetic fields for research in chemistry, physics, biology, and medicine. This successful test is the culmination of a concentrated three-year effort within this university/industry partnership. Dr. Ken Marken, the Project Leader at Oxford noted, "The drive for ever higher fields in commercial NMR spectroscopy magnets was a compelling motivation for Oxford's investment in this achievement, and we look forward to using the technological advances demonstrated in our high field business."

"Every advance in high field superconducting magnet technology drives new and exciting scientific opportunities. For example, one of the most rapidly growing applications of superconducting magnet technology is the use of the MRI for improved diagnostic medicine. In biology and chemistry, these high field magnets play an important role in charting the human genome, understanding protein structure, and determining nucleic acid structure. The mysteries of complex biomolecules are being unlocked at higher fields, as well as studying real time changes in biological tissues," commented Dr. Schwartz.

"This successful demonstration is an important step in meeting the need for high fields in superconducting magnets that has remained elusive for nearly two decades," commented Dr. Jack Crow, director of the NHMFL. Superconducting magnet technology for almost twenty years has been limited to 20 tesla. The discovery of new HTS materials in the mid-1980's opened up great potential for applying these materials in new technologies, however, researchers have found it an extremely challenging task. One of the original charges to the NHMFL by the National Science Foundation is to produce superconducting magnets at 25 tesla and beyond.

Oxford Superconducting Technology supplied long-lengths of Bi-2212 superconducting wire for the successful experimental program. The NHMFL and Oxford research teams spent much time on conductor development and characterization, coil winding studies, and the testing of coils in order to reach this world-record achievement.

The NHMFL is supported by the National Science Foundation and the State of Florida and operated by Florida State University, the University of Florida, and Los Alamos National Laboratory. It operates state-of-the-art user facilities at all three sites and offers researchers from a wide range of disciplines – including biology, chemistry, engineering, geochemistry, materials science, medicine, and physics-expanded opportunities to investigate new materials, complex chemical mixtures, and molecular structures.



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NHMFL
FLORIDA STATE UNIVERSITY ★ UNIVERSITY of FLORIDA ★ LOS ALAMOS

42 teachers were provided with quality professional development this summer through two 4-day summer institutes. Teachers who participate become ambassadors for the NHMFL and for inquiry-based hands-on classroom science.