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A look at 2011: big user numbers, big infrastructure gains, and big changes

Here we go again! This issue of *MagLab Reports* contains 39 highlights selected out of 2011’s 444 submitted research reports contained in our (way longer, online-only) Annual Report. The highlights, picked by myself after the Science Council narrows it down to 50 or so “finalists,” represent the most provocative research of the past year across each of the lab’s (many) disciplines. I look for work that’s made an impact in its research community and that demonstrates techniques that we, as a user facility, want the larger community to know are available.

Why the great number of research reports? Magnetic fields are a tool at the heart of several rapidly expanding research areas:

- **Graphene**, model magnetic systems (low-dimensional, frustrated, Bose-Einstein condensed, quantum entangled…the list gets too long for this column), and the ever-since-1987—but-still-a-mystery-yet-now-also-becoming-technologically-important high-temperature superconductors.
- **Energy**, from petroleum analysis to pollution analysis (Deepwater Horizon and the North Pacific), to a molecular level probing of energy storage technologies.
- **Applications** of novel resonance techniques that utilize MagLab magnets and probe technologies for not only biochemistry and biomedicine (protein structures, the structure and function of HIV, and the pioneering of sodium MRI and f-MRI), but increasingly in materials (NASA foams and battery materials).

In June, we celebrated the commissioning of the 25 T Split Magnet. The launch of the Split represented a huge triumph for both the team who built it and the staff and users who, almost immediately, began utilizing its suite of capabilities.

With four large ports open at the

**Science Council**

Composed of distinguished research scientists representing all three sites of the Magnet Lab, the Science Council is responsible for, among other things, recommending each year’s research highlights. Members are:

- **Albert Migliori**, LANL Fellow and Pulsed Magnet User Program
- **Art Edison**, Professor of Biochemistry and AMRIS User Program
- **Gail Fanucci**, Assistant Professor, AMRIS User Program
- **Zhehong Gan**, Scholar-Scientist, NMR User Program
- **Lev Gor’kov**, Program Director, Professor, Condensed Matter Science/Theory
- **Stephen Hill**, Director, EMR Program User Program
- **Jurek Krzystek**, Scholar-Scientist, EMR User Program
- **David Larbalestier**, Director, Applied Superconductivity Center
- **Dragana Popovic**, Scholar-Scientist, Condensed Matter Science/Experimental
- **Ryan Rodgers**, Associate Scholar-Scientist, ICR User Program
- **Theo Siegrist**, Professor, Condensed Matter Science/Experimental
- **Glenn Walter**, Associate Professor, AMRIS User Program
- **Huub Weijers**, Engineer, Magnet Science & Technology

*Above: From administrators to students to facilities personnel, all hands were on deck for the installation of long sections of underground pipe as part of the lab’s ongoing effort to improve helium recovery & economy. The project has already resulted in dramatically reduced helium usage.*

*(Photo by Dave Barfield)*
mid-plane of the magnet where stress and temperatures are highest, the Split required a complete rethinking of resistive magnet technology’s limits. The Split is notable for both what it doesn’t have — namely, 50% of its mid-plane — and for what it does have: direct 180-degree optical access at 25 tesla, and user access to a type of experiment that simply didn’t exist before. With 18,726 individual parts and a half-decade of planning, the Split is the most challenging, complicated resistive magnet project ever developed.

Two months after the commissioning of the Split, and just a month after a major wildfire temporarily shut down Los Alamos, the Pulsed Field Facility reclaimed the world record for a non-destructive pulse with a 97.4 T shot, opening up user research to 95 T and paving the way for 2012’s 100 T milestone. The record was great, but the expanded capability for our users was the goal; in fact, even the record-setting shot contained user experiments. Work conducted in the newly boosted field resulted in user work that has already been published in Proceedings of the National Academy of Sciences, Physical Review Letters and Physical Review B.

Research Reports reflect sustained user community growth

In 2011, 444 research reports were received in 18 categories, representing the life sciences, chemistry, magnet science and technology, and condensed matter physics.

• 20% of the research activities (87 reports) were already published in 2011, many in prominent journals.
• 22 reports were accepted for publication; 42 were submitted for publication; and 173 have manuscripts in preparation.
• In 2011, 81 first-time principal investigators requested magnet time.
• The majority of research projects were funded by the U.S. National Science Foundation, the U.S. Department of Energy, and the U.S. National Institutes of Health. Other funding organizations included: NASA, U.S. Department of Defense, U.S. Air Force Office of Scientific Research, U.S. Army, U.S. Navy, and numerous universities. Research was also supported by science federations, ministries, and universities in countries around the world including: Brazil, Canada, China, Denmark, Germany, Japan, Russia, Slovenia, South Korea, and the United Kingdom.
• The Magnet Lab User Collaboration Grants Program encourages collaborations between internal and external investigators, promotes bold but risky efforts and provides initial seed money for new faculty and enhancements of experimental techniques. This program supported 32 of the 444 research activities and was the primary support for seven projects.

**EP2DS-MSS15**

In July, the Magnet Lab hosted the 19th International Conference on Electronic Properties of Two-Dimensional Electron Systems and the 15th Conference on Modulated Semiconductor Structures. With two dozen invited speakers and 385 registered attendees, the event offered the chance for attendees from all over the world to share their work and get acquainted with the MagLab.

**Honors, awards and promotions**

User Committee Chair [Jan Musfeldt](#) of UT Knoxville conducted the lab’s first-ever career impact survey in 2011. Jan has been an active and extremely effective chair, advocating for users and involving users directly in the MagLab’s strategic planning and renewal proposal development.

[Kun Yang](#), a Florida State University professor and member of the Condensed Matter/ Theory group, was elected a Fellow of the American Physical Society for “significant theoretical contributions to our understanding of novel phenomena in Quantum Hall Systems”.

[Chris Hendrickson](#) of ICR was...

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**ABOVE**: Pictured in the Ion Cyclotron Resonance bay are Alecia Shorts of Gardner-Webb University and Terrie Kweifio of Virginia Tech, both Research Experiences for Undergraduates (REU) students during summer 2011. Shorts studied outcomes of the Deepwater Horizon oil spill, while Kweifio worked in technique development. (*Photo by Dave Barfield*)

**ABOVE**: Some of the publication covers highlighting research conducted by Magnet Lab users and staff in 2011.

**ABOVE**: Kun Yang and Jan Musfeldt.
named a Florida State University Distinguished University scholar, one of only ten named by the university. The award recognizes outstanding performance by non-tenured or non-tenure-seeking Florida State employees who have longstanding track records of research and/or creative activity at the university and occupy more senior levels in their respective positions.

**Lab outreach reaches students, community, educators**

With 20 different programs, the Center for Integrating Research and Learning (CIRL) continued its broad, highly successful outreach efforts. CIRL hosted 15 Research Experiences for Undergraduates and 19 Research Experiences for Teachers participants this year, providing the hands-on research opportunities essential for students interested in STEM fields, and for the teachers charged with engaging a new generation of kids in science. Events like SciGirls, MagLab Summer Camps, Science Café, Doing Science Together, and the MagLab annual Open House offered opportunities for community members of all ages to connect with the lab. The MagLab substantially grew its Twitter and Facebook communities and enjoyed a surge in the popularity of its YouTube channel.

**Diversity effort makes inroads**

While continuing its already varied diversity initiatives, the MagLab sought to advance its diversity initiatives in new ways during 2011. In collaboration with “The Alliance for the Advancement of Florida’s Academic Women in Chemistry and Engineering” (AAFAWCE), an NSF ADVANCE-PAID grant, it organized a workshop on “Faculty Recruitment for Excellence and Diversity” (FRED) to present methods for recruiting to promote excellence and diversity in the workplace. From 2012 onward, FRED will be required for any scientist to serving on a scientific search committee. Dragana Popović, Director of the Magnet Lab’s Diversity Program, became the co-PI on the FSU portion of the AAFAWCE grant, a collaboration of five Florida universities to increase the role of women in STEM fields. She is also co-PI on a recently submitted ADVANCE-IT proposal “Collaborative Research: Advance-IT, Florida!” a collaboration of the same five Florida institutions (FSU, UF, FAMU, USF, FIU) that seeks to institutionalize the initial successes of the original ADVANCE-PAID program.

That’s about it. Here’s hoping 2012 brings the same productivity and research growth we saw in 2011.

Gregory S. Boebinger
MagLab Director

To see the Annual Report in its entirety, visit magnet.fsu.edu and search for “Annual Report.”
Graphene

The fabrication of monolayer graphene on boron-nitride substrates has resulted in an increase of the charge carrier mobility, allowing the authors to observe quantum Hall effects at all integer filling factors. The picture that emerges is one of exchange driven quantum Hall ferromagnetism within the combined spin-valley isospin space. By tuning the Zeeman energy over a wide range, the dependence of the isospin ferromagnetic order on Landau level index \( N \) is demonstrated for fixed relative filling. In particular, for \( N=0 \) at half filling, the experiment finds evidence for Skyrmionic excitations.

- Accepted for publication in Nature Phys. (http://www.nature.com/nphys/journal/vaop/ncurrent/pdf/nphys2307.pdf)

Evidence for Skyrmionic Excitations in Graphene

A.F. Young, H. Ren, P. Cadden-Zimansky, P. Kim (Columbia University, Physics); C.R. Dean (Columbia Univ., Electrical Engineering); L. Wang (Columbia Univ., Mechanical Engineering); K. Watanabe, T. Taniguchi (National Institute for Materials Science, Japan)

Introduction

The fabrication of graphene on boron-nitride (BN) has produced an increase in the upper-bound of the carrier mobility possible in unsuspended graphene. This increased mobility enables the SU(4) symmetric Landau levels (LLs) to have their degeneracy lifted at lower fields, and subsequently the spin-activation of these emergent LLs to be characterized using high-field measurements at tilted angles.

Experimental

Our samples are prepared by first mechanically exfoliating graphene and BN onto separate substrates. The exfoliated flakes are separately characterized by optical and AFM measurements and the graphene flakes are then transferred onto BN and re-characterized. Multiple gold probes are subsequently deposited on the graphene using conventional electron beam lithography techniques. Samples that show the most well developed quantum Hall states are measured at the Magnet Lab, where transport measurements at low temperatures and fields as high as 35 T are performed.

Results and Discussion

We have observed quantum Hall effects at all integer filling factors in graphene (Figure 1), consistent with exchange-driven quantum Hall ferromagnetism within the combined spin-valley isospin space. Tilted field measurements of the activation gaps associated with the broken symmetry quantum Hall states has allowed us to extract quantitative information about the spin textures of the ground state and its elementary excitations. For the half-filled Landau levels, such as the \( \nu = 4 \) state, the effective g-factor of the charge carriers can exceed its bare value of 2 (Figure 2). Measurements of multiple samples show a correlation between effective g-factor, measured energy gaps, and sample quality. This correlation suggests that the multiple-spin Skyrmionic excitations that serve as charge carriers in these states are disorder limited, with larger Skyrmions forming as sample quality improves.

REFERENCES

The most common structure of the natural graphite crystal is the Bernal (staggered) stacking. This report describes high-field magnetotransport evidence for Bernal stacking in a graphene bilayer grown on SiC. These findings render this system particularly attractive for electronic and optoelectronic device applications.


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**Graphene**

**Introduction**

Graphene bilayers in Bernal stacking exhibit a transverse electric field tunable band gap, a property that renders this material attractive for device applications. Here, we investigate magnetotransport properties of quasi-free-standing epitaxial graphene bilayer on SiC.

**Experimental**

We prepared quasi-free-standing epitaxial graphene bilayer on SiC by atmospheric pressure graphitization in Ar, followed by H2 intercalation. To probe the transport properties of these graphene bilayers, we fabricate top-gated Hall bars. The Hall bar location on the substrate is first chosen using optical and atomic force microscopy (AFM) in order to identify an appropriately wide terrace. Electron beam (e-beam) lithography and O2 plasma etching are used to pattern the Hall bar active area; the graphene is etched outside the Hall bar. Metal contacts are realized using a second e-beam lithography step, followed by a 40 nm Ni deposition and lift-off. For the gate dielectric, 15nm thick Al2O3 film was deposited using atomic layer deposition (ALD). E-beam lithography and then Ni deposition are used to define the top gate. Magnetotransport properties were measured using the DC field facility at the National High Magnetic Field Laboratory.

**Results and Discussion**

At the charge neutrality point, the longitudinal resistance ($\rho_{xx}$) shows an insulating behavior (Figure 1a), which follows a temperature ($T$) dependence consistent with variable range hopping in a gapped state. In a perpendicular magnetic field ($B$), we observe quantum Hall states (QHSs) both at filling factors ($v$) multiples of four ($v = 4, 8, 12$), as well as broken valley symmetry QHSs at $v = 0$ and $v = 6$ (Fig. 1, b and c). These results unambiguously show that the quasi-free-standing graphene bilayer grown on the Si-face of SiC exhibits Bernal stacking, rendering this material interesting for electron physics and potential platform for device applications.

**Conclusions**

We investigated the magnetotransport in quasi-free-standing graphene bilayers on SiC. We observed QHSs at fillings $v = 0, 4, 6, 8, 12$, consistent with a Bernal stacked graphene bilayer in the presence of a transverse field.

**Acknowledgements**

We thank NSF (DMR-0819860) and NRI for support.
Kondo/Heavy Fermion Systems

The β-pyrochlore osmates $\text{AO}_2\text{Os}_6$ ($A=$Cs, Rb, K) are remarkable for their crystalline structure where small size ions, $A$, are placed inside large cages formed by the $\text{OsO}_6$ octahedra. The elastic potential for the $A$-ions moving in the cage is then highly anharmonic. Indeed, normally, the phonon frequencies of lighter ions should be higher; it is different in $\text{AO}_2\text{Os}_6$ where, for instance, for $A=K$ the dispersionless Einstein mode is as low as $\sim 20$ K. Importantly, these low energy modes dubbed the “rattling modes” seem to be responsible for the s-wave phonon driven superconductivity (SC). The highest $T_c=9.6$ K is observed for KOs$_2$O$_6$, with the lightest $A=K$. Thermodynamic and transport data have provided numerous evidences in favor of the strong electron-lattice interactions in these materials. In particular, superconducting characteristics definitely differ from the ones for the weak coupling BCS SC.

The major fact obtained in this report is that the electron-phonon coupling is uncommonly strong in KOs$_2$O$_6$. In the de Haas-van Alphen experiments numerous fundamental frequencies were observed, as it seems, in the reasonable agreement with the shapes of the Fermi surfaces found from the band structure calculations. Comparison of the “band” mass and the observed mass extracted by way of the Lifshitz-Kosevich analysis provides the direct measure of the e-ph coupling, $\lambda$. For most orbits it was found $\lambda \sim 6$, the value never seen anywhere. (For one orbit, for the frequency $\rho$ the observed mass was 26 times heavier than the free electron mass!)

These results indicate the new type of SC in the β-pyrochlore osmates, $\text{AO}_2\text{Os}_6$. Theoretically, there is no clue to how to approach such strong coupling phonon SC. In the famous case of SC in lead, Pb one has $\lambda \sim 1$.

* Accepted for publication as a Rapid Communication in Phys. Rev. B (http://arxiv.org/abs/1201.5425)

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de Haas-van Alphen Measurements on the Rattling-Induced Superconductor KOs$_2$O$_6$ Using PDF in 35 T


**Introduction**

The alkali-metal osmium oxides $\text{AO}_2\text{Os}_6$ ($A=$ K, Rb, and Cs) crystallize in the cubic β-pyrochlore structure. The $A$ ion is enclosed in an oversized cage formed by $\text{OsO}_6$ octahedra and vibrates in an anharmonic potential with a flat bottom, giving rise to nearly-localized low-energy anharmonic phonon modes, i.e. rattling modes. With reducing the ionic size from Cs to K, the anharmonicity grows and the rattling intensifies. $\text{AO}_2\text{Os}_6$ exhibit superconductivity below the transition temperatures of $T_c = 9.6$, 6.3, and 3.3 K for $A=$ K, Rb, and Cs, respectively. Hiroi and coworkers$^{1,2}$ have found from a detailed comparative study of the three compounds strong evidence that the superconductivity is mediated by the rattling mode. To shed light on the nature of the electron-rattling interaction, we have studied the many-body mass enhancement in KOs$_2$O$_6$ via de Haas-van Alphen (dHvA) torque measurements$^3$.

**Experimental**

KOs$_2$O$_6$ single crystals were grown at the ISSP. We used a 35 T resistive magnet (cell 8) and the portable dilution refrigerator (PDF) at the NHMFL-Tallahassee. The PDF was essential because of heavy effective masses of electrons. dHvA torque oscillations were detected using piezoresistive microcantilevers.

**Results, Discussion, and Conclusions**

Figure 1(a) shows an example of magnetic torque in KOs$_2$O$_6$. The measurement temperature is 0.05 K. The field-up and field-down sweeps separate at a field between 31 and 32 T, which we identify with $B_{c2}$. dHvA oscillations are clearly observed and the Fourier transforms

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**FIGURE 1.** a. Magnetic torque in KOs$_2$O$_6$. b. Corresponding Fourier transforms (in $1/B$). Inset: $T$ dependence of the oscillation amplitude of the frequency $\rho$. 

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indicate several fundamental frequencies with their harmonics and combinations (Figure 1b). The inset shows the temperature dependence of the amplitude of the frequency $\rho$. With increasing temperature, the amplitude rapidly decreases. A Lifshitz-Kosevich fit (solid curve) indicates an associated effective mass of $26 m_e$, $m_e$ being the free electron mass.

We determined effective masses for a total of 17 frequencies at three different field orientations and compared them with band masses. Mass enhancement parameters $\lambda = (m^*/m_{\text{band}} - 1)$ are in a range between 5 and 8, consistent with the specific-heat mass enhancement parameter of 6.3. These values are unusually large for electron-lattice coupling. We examined dependence of the estimated $\lambda$'s on band (or Fermi surface sheet), orbit, and orientation, in comparison with MgB$_2$ and LuNi$_2$B$_2$C, and concluded that the many-body mass enhancement in KOs$_2$O$_6$ is relatively homogeneous, most likely reflecting the local nature of the electron-rattling interaction.

**Acknowledgements**

This work was supported by a Grant-in-Aid for Scientific Research on Innovative Areas “Heavy Electrons” (No. 23102725) of The Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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Kondo/ Heavy Fermion Systems

In this work, published in Physical Review Letters, a method has been developed that enables continuous tuning of the density of high-mobility two-dimensional (2D) electrons formed just underneath the surface of SrTiO₃, an insulator well known for its ferroelectricity. The 2D layer of electrons produced by this clean, powerful method exhibits evidence for the Kondo effect involving Ti³⁺ spins.


Electrolyte Gate-Controlled Kondo Effect in SrTiO₃ Using 30 T

D. Goldhaber-Gordon, M. Y. Lee, J. R. Williams (Stanford Univ., Physics);
Sipei Zhang, C. Dan Frisbie (Univ. of Minnesota, Chemical Engineering and Material Science)

Introduction

A classic correlated material, in which much of the electronic properties are understood, is SrTiO₃ (STO) and its related compounds like interfaces between LaAlO₃ (LAO) and STO. Recently investigation into transport in high-quality STO and LAO/STO interfaces have shown departures from conventional metallic behavior, including superconductivity and ferromagnetism. Understanding how these phases evolve as a function of density is key to the origin of correlated phenomena in these systems.

Experimental

To investigate the evolution of phases at low density, where STO is an insulator, to high density where the phase is poorly understood, we fabricated Hall bars on STO to investigate the longitudinal and Hall resistance as a function of density (between 0 and 2x10¹⁴ cm⁻²), achieved using ionic gating. The experiments were performed in a flow cryostat, with a variable temperature range between 1.4 K and 300K in Cell 9, which provides a DC magnetic field up to 31 T.

Results, Discussion, and Conclusions

Using the NHMFL, we were able to expand on the body of evidence for Ti³⁺ magnetism in STO that conducts in two dimensions. We demonstrate a gate-controlled Kondo effect in the 2D electron system in undoped STO formed beneath the bare surface by the electric field from an ionic gel electrolyte, and interpret this system as an admixture of magnetic Ti³⁺ ions (unpaired and localized electrons) and delocalized electrons partially filling the Ti 3d conduction band, as predicted theoretically. The Kondo effect is an archetype for the emergent magnetic interactions amongst localized and delocalized electrons in conducting alloys, and the ability to produce and tune the effect by purely electrostatic means in any conducting system is of interest in its own right. The observed appearance of the Kondo effect in STO as a function of applied electric field points to the emergence of magnetic interactions between electrons in STO due to electron-electron correlations rather than the presence of dopants. This work has been published in Physical Review Letters¹ and was selected as a Physics Viewpoint² and as an Editor’s Choice.

Acknowledgements

The development of ionic gating technique was supported as part of the Center on Nanostructuring for Efficient Energy Conversion, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science Office of Basic Energy Sciences under Award Number DE-SC0001060. The measurement and study of STO were supported by the MURI program of the Army Research Office Grant No. W911-NF-09-1-0398. The Minnesota contribution was supported by the National Science Foundation through the MRSEC program at the University of Minnesota, Award DMR-0819885.

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Magnetism and Magnetic Materials

Investigating the spin dimer system SrCu$_2$(BO$_3$)$_2$ in high magnetic fields brings up a unique opportunity to study the interactions between low energy magnetic excitations $S_z=1$ (triplons) in the presence of strong magnetic frustration in a 2D lattice. The external magnetic field is used to close the spin gap at a field-induced quantum critical point, as well as to control the triplon population density once the gap is closed. Triplon repulsion and frustration-induced localization lead to the emergence of magnetic stripes forming texture that manifests as steps in the magnetization at integer ratios of the saturation magnetization. A significant spin lattice coupling was observed with the first magnetostriction measurements in pulsed fields to 97.4 T. In addition to confirming the known low-field textures, by their effect in the lattice parameter, two new features at magnetic fields of 74 T and 82 T were observed, demonstrating unambiguously that the interplay of magnetic and lattice degrees of freedom can be probed over a large magnetic field range.

Microstrain-Sensitivity Magnetostriction of SrCu$_2$(BO$_3$)$_2$ to 97 T

R. Daou (HLD, Dresden); S. Crooker, A. Uchida, M. Jaime (LANL, NHMFL); F. Weickert (LANL, CMMS); H.A. Dabkowska, B.D. Gaulin (McMaster, Physics)

**FIGURE 1.** a. magnetostriction vs field measured in a 50 T mid-pulse (250 ms) magnet at NHMFL-LANL, showing evidence of strong spin-lattice correlations. b. Magnetization vs field showing plateaus at 1/9, 1/4 and 1/3 of magnetization saturation. c. The temperature of the sample, measured simultaneously with the magnetostriction, shows changes when the spin gap is closed at ~20 T, and also at ~40 T when stripe-like structures that break the tetragonal lattice symmetry form in the sample (2). d. Our magnetostriction measurements were extended to 97.4 T in the NHMFL 100 T repetitive pulse magnet, and revealed two features at 74 T and 82 T never before observed. Left panel inset: magnetostriction vs field showing magnetic texture between 28 T and 36 T (3). Right panel inset: magnetic field profile.

**Introduction**

The orthogonal-dimer geometry of the Shastry-Sutherland lattice$^1$ and the ratio of next-nearest to nearest neighbor exchange interactions between the spin 1/2 Cu$^{2+}$ ions, $J_{II}/J_0 \sim 0.62$ ($J_0 = 74$ K), make SrCu$_2$(BO$_3$)$_2$ a paradigm of frustrated quantum magnetism$^2$, where an external magnetic field can be used to induce magnetic texture$^3$. The strength of required magnetic fields has until now prevented, however, the unambiguous observation of magnetization fractions beyond 1/3 of saturation.

Here we report microstrain-sensitivity magnetostriction (MS) data obtained for a single crystal sample of SrCu$_2$(BO$_3$)$_2$ in pulsed magnetic fields to 97.4 T using a recently developed fiber Bragg gratings FBG technique$^4$. The magnetostriction was measured with the magnetic field $H//c$-crystallographic axis (Figure 1) and with $H\perp c$-axis (not shown) at different temperatures down to $T = 0.5$ K$^5$. We found a remarkable correspondence between magnetostriction and magnetization vs field data, that confirms previously discussed magnetic texture following the series $1/n$ with $n = 3, 4, \ldots 9$ in SrCu$_2$(BO$_3$)$_2$$^{[3]}$. We also found two new features at $\mu_0H = 74$ T and 82 T that we attribute to superstructure corresponding to 2/5 and 1/2 ($n=2$) of magnetization saturation respectively.

**Acknowledgements**

AF acknowledges NSF funding under grant DMRG-0955707. Experiments at the High Magnetic Field Laboratory Dresden (HLD) (not shown) were sponsored by Euro-MagNET II under the EU contract 228043. Work at the NHMFL was supported by the National Science Foundation, the U.S. Department of Energy, and the State of Florida.

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5. M. Jaime et al., submitted.
LaCoO$_3$ is a material with a spin state cross-over occurring at laboratory accessible fields. Additionally, a new form of cooperative orbital-magnetic order, combining the $S=0$ and $S=1$ states, was discovered. This field induced spin-state crystallization is a novel phenomenon, and may also occur in ferric perovskite making up part of the Earth’s crust, affecting the dynamics of seismic waves.

**Spin-State Crystallization in LaCoO$_3$ in Magnetic Fields Using 97 T**


During recent tests of the 95 tesla plus multishot magnet in Los Alamos, a new world record for non-destructive magnetic fields of 97.4 T was achieved. During the testing, several experiments were run in parallel involving recent users at the pulsed field facility. One of these concerned magnetization measurements of LaCoO$_3$ — performed in-situ utilizing the same susceptometer as used to calibrate the magnetic field using the de Haas-van Alphen effect in copper wire.

LaCoO$_3$ is of interest because it is a rare example of a crystalline material subject to a spin state crossover tuned by laboratory accessible magnetic fields$^1$. Whereas one simple spin-state crossover had been expected involving solely single ion effects, pulsed magnetic fields to ~65 T (inset to Figure 1a) revealed a curvature of the phase boundary at higher temperatures that had been missed in a recent study by competing group in Japan$^2$. A field-induced phase appeared to be developing. Sure enough, a field-induced phase was subsequently revealed in magnetic fields approaching 100 T by the observation of a second transition.

The discovery of spin-state crystallization could be relevant deep within the Earth’s crust where a spin state crossover is expected to occur in ferric perovskites of the same crystalline structure$^3$. Spin-state crystalline, if it occurs, could potentially alter the dynamics of seismic waves.

**Acknowledgements**

Supported by NSF DMR-0654118 and BES program “Science at 100 tesla.” John Singleton, Chuck Swenson, Ross McDon-ald, Yates Coulter and Mike Gordon are acknowledged for technical help during the experiment.

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Magnetism and Magnetic Materials

Magnetization measurements were performed on a new family of Cu coordination polymers in fields of up to 92 T at the pulsed-field facility in Los Alamos. Magnetic fields in excess of 60 T were essential for determining the magnetic exchange energies and dimensionalities of these model antiferromagnetic compounds.

· Published in Inorganic Chemistry 51, 2121-2129 (2012).

High-Field Magnetization of the 1D CuBr₂(pyzO) (H₂O)₂ and 2D CuBr₂(pyz) Using 92 T

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Introduction

The magnetic properties of the newly crystallized CuBr₂(pyzO)(H₂O)₂ (pyzO = pyrazine-N,N'-dioxide) coordination polymer have been studied at fields up to 85 T and compared with those obtained for the related CuBr₂(pyz) (pyz = pyrazine) complex. The crystal structure of CuBr₂(pyzO)(H₂O)₂ is characterized by one-dimensional chains of Cu²⁺ ions linked through bidentate pyzO ligands. These chains are joined together through OH···O hydrogen bonds between the water ligands and pyzO oxygen atoms and through Cu-Br···Br-Cu contacts. Bulk magnetic susceptibility measurements at ambient pressure show a broad maximum at 28 K that is indicative of short-range magnetic correlations. The dominant spin exchange is through the Cu-Br···Br-Cu pathway.

The magnetic data were fitted to a Heisenberg 1D uniform antiferromagnetic chain model with \( J_{1D}/k_B = -45.9(1) \) K. Muon-spin relaxation measurements were unable to definitively establish the presence of long range magnetic order in CuBr₂(pyzO) (H₂O)₂ down to 0.26 K. The results for the CuBr₂(pyzO)(H₂O)₂ complex has been compared to the related CuBr₂(pyrazine) material, the structure of which is characterized by bibrided Cu-Br₂-Cu chains linked through bridging pyrazine molecules resulting in a 2D rectangular lattice.

Experimental

Measurements made use of a 1.5 mm bore, 1.5 mm long, 1500-turn compensated-coil susceptometer, constructed from 50 gauge high-purity copper wire and specially adapted for the 100 T multi-shot magnet. When a sample is within the coil, the signal is \( V \propto (dM/dt) \), where \( t \) is the time. The sample is mounted within a 1.3 mm diameter ampoule that can be moved in and out of the coil. Accurate values of \( M \) are obtained by subtracting empty coil data from that measured under identical conditions with the sample present. Fields were provided by the 60 T short-pulse and 100 T multi-shot magnets at NHMFL-Los Alamos. The susceptometer was placed within a ³He cryostat for which temperatures as low as 0.4 K could be achieved.

Results and Discussion

Isothermal magnetization was measured as a function of pulsed magnetic field (figure). In the case of CuBr₂(pyzO)(H₂O)₂, the magnetization saturates at a field of 66.7(5) T, with strong upward curvature at lower fields indicative of one-dimensional magnetism. In a Heisenberg chain, the magnetization is expected to saturate at a field \( B_{sat} = -2 g\mu_B J_{1D}/k_B \), where the dominant exchange energy \( J_{1D} \) is expressed in Kelvin. Using the measured value of \( B_{sat} = -2 k_B J_{1D}/g\mu_B \), the value of \( J_{1D} \) was obtained as 78.2(5) K, yielding a \( J_{1D} + J \) of 51.8(5) K.

Conclusions

Pulsed-field magnetization data to fields greater than 60 T were essential for validation of this method for obtaining exchange energies and confirmation of the magnetic dimensionality. Close agreement was found between the exchange energies obtained from fits of magnetic susceptibility data and those obtained from pulsed field magnetization.

Acknowledgements

Work at ANL was supported by U.S. DOE under contract DE-AC02-06CH11357 and work at the NHMFL was performed under the auspices of the NSF, the DoE project “Science at 100 T,” and the State of Florida.

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Magnetism and Magnetic Materials

Madalina Furis (U. Vermont) has demonstrated the first successful high-field Magnetic Circular Dichroism (MCD) experiment at 27.5 T in the Florida HELIX split-pair magnet. The measurements were performed on crystalline thin films of a prototypical organic semiconductor, copper phthalocyanine, revealing the onset of carrier-mediated exchange at low temperature.

Magnetic Circular Dichroism (MCD) of Copper Phthalocyanine Crystalline Thin Films Using the 25 T Split Magnet

Z. Pan, N. Rawat, C. Lamarche, M. Furis (UVM, Physics); T. Tokumoto, D. Semenov, S. McGill (NHMFL)

Introduction

Research on metal-phthalocyanines (MPC) as archetype for organic semiconductors and optoelectronics applications has been extensive over the last decade. However, the magnetic studies on MPC, especially in the solid state phase, are sparse. In a crystalline phase MPC, \( \pi \) electrons are highly delocalized through the quasi-1D molecular chain, and interactions between localized unpaired d-shell electron spin of central ions could be mediated by the delocalized \( \pi \) electrons of the PC ring\(^1\). Understanding the exchange mechanism will be extremely critical for magnetic applications. In our study, we are particularly interested in copper phthalocyanine (CuPC) crystalline thin film fabricated by solution processed pen-writing techniques\(^2\), since in this spin \( \frac{1}{2} \) system, direct exchange is negligible\(^3\) and we could study pure indirect exchange through itinerant carriers. In order to identify the electronic states responsible for the magnetism in the CuPC crystalline thin film, we performed magnetic circular dichroism (MCD) spectroscopy measurement in high magnetic fields.

Experimental

MCD measurements was carried out in the split-coil HELIX magnet in cell 5 of NHMFL with B fields up to 27.5 tesla at 100 and 300 K. Light from an Oriel 300 watt Xenon lamp dispersed by a Cornerstone 260 monochromator with bandwidth of 2 nm was modulated into left and right circularly polarization in 50 kHz and focused using free space optics onto samples in Faraday geometry \((k||B)\). Signal was collected by a multimode fiber and focused onto a silicon diode detector.

Results and Experiment

Figure 1 displays 300K MCD spectra from the CuPc film recorded at different magnetic fields. Each of the Gaussian features is associated with a distinct transition between states located at the bandgap of CuPc. All features are significantly broadened and redshifted in comparison to the ones observed in monomers. Since the MCD magnitude is proportional to the time-average of the total change in orbital momentum associated with a particular electronic transition and the electronic g-factor, it is expected that MCD increases linearly with applied magnetic field in the absence of any magnetic interactions. This is precisely what we observe at room temperature where MCD evolving with B field (inset) can be very well fitted with a straight line. This dependence remains linear at 100 K with a slight increase in slope which corresponds to an increase in the g-factor. The results are not surprising since carrier-mediated exchange is only expected to manifest itself at temperatures lower than 10 K.

Conclusions

We demonstrated the first successful high field MCD experiment at 27.5 T. MCD evolved linearly as B field increase at both 100 and 300 K with different slope (g-factor). Lower sample temperatures are needed to reveal the magnetic exchange mechanism in this system.

Acknowledgements

The Furis group was supported through NSF CAREER award DMR #105658.

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Magnetism and Magnetic Materials

Understanding why wave functions localize in the presence of disorder is a fundamental but difficult problem that is important for a wide variety of systems. Experimental and theoretical understanding of Bose glasses and Anderson localization has long been sought in diverse systems including superconductors, cold atoms, metals with impurities and helium. Bose glasses in quantum magnets are one of the most accessible and simplest to describe theoretically. This work makes one of the first contacts between theory and experiment in this field, and thus is a critical step forward.

Magnetic Susceptibility Measurements of the Bose-Glass Phase in $\text{NiCl}_{1.85}\text{Br}_{0.15}-4\text{SC(NH}_2\text{)}_2$ Down to 1 mK

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Introduction

The phenomenon of a magnetic field induced Bose-Einstein Condensation (BEC) of quasiparticles in quantum magnets has been the subject of several investigations over the last decade, and it has been studied in a wide variety of materials, including NiCl$_2$$\cdot$4SC(NH$_2$)$_2$ (DTN) which consists of coupled quasi-1D S=1 chains with strong single-ion anisotropy$^{1,2}$. By adding disorder to a spin-gapped antiferromagnet by doping with non-magnetic impurities, the BEC is hindered with respect to the pure system by Anderson localization of the quasiparticles. At the critical field of the pure system quasiparticles do not condense in a zero-momentum state, but they fragment over an extensive number of localized states, and therefore the ground state of the system lacks global phase coherence.

Experimental

We have measured the AC susceptibility of a bound-diluted quantum magnet NiCl$_{1.85}$Br$_{0.15}$-4SC(NH$_2$)$_2$ down to 1 mK and with a magnetic field ranging from 0 to 15 T. The experimental setup has been described elsewhere$^{2,3}$.

Results and Discussion

Below a crossover temperature $T_{cr} = 100$–200 mK, we find that the critical fields $H_c$ for Bose-Einstein condensation obey the scaling relation $|H_c(T) - H_c(0)| \sim T^\alpha$, with a novel and universal scaling exponent $\alpha \sim 0.9$, which is in agreement with numerical results from a theoretical model$^{4,5}$.

Conclusions

Our findings provide strong evidence of the existence of a Bose glass phase in NiCl$_{1.85}$Br$_{0.15}$-4SC(NH$_2$)$_2$, and they display a quantitative signature of the transition between a Bose glass and a Bose-Einstein condensate.

FIGURE 1. Scaling of the critical temperatures with the distance from $T = 0$ critical fields, exhibiting a crossover between various exponents.

Acknowledgements

This research was carried out at the NHMFL High B/T facility which is supported by NSF Grant DMR 0654118 and by the State of Florida.

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Magnetism and Magnetic Materials

Multi-frequency EPR measurements were performed in fields up to 35 T on a Co(II) complex that was recently found to display slow magnetization relaxation behavior at low temperatures. High-fields were essential for unambiguously determining the spin-Hamiltonian parameters for this compound. The results suggest a new mechanism underpinning this slow relaxation behavior, thus motivating the development of new theoretical models describing the spin-lattice relaxation.

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High-Field EPR Studies of a Mononuclear CoII Molecular Magnet

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Introduction

We report high field EPR studies on a mononuclear cobalt complex [(3G)CoCl](CF3SO3) (1). AC susceptibility measurements on 1 demonstrate slow relaxation of magnetization with a relaxation barrier of 24 cm⁻¹. High-field EPR measurements were performed on 1 to obtain a definitive determination of the sign and magnitude of the magnetic anisotropy of the compound¹.

Experimental

Single-crystal high-field EPR measurements were carried out on 1 in a 35 T resistive magnet. A Millimeter Vector Network Analyzer and several different multipliers were used as a microwave source and detector. Powder EPR data for 1 were collected in a 15/17T superconducting magnet. A phase-locked Virginia Diodes solid-state source was employed, followed by a chain of multipliers.

Results and Experiment

The EPR data are interpreted with the following Hamiltonian:

\[ \hat{H} = D S_z^2 + E (S_x^2 - S_y^2) + \mu_B \mathbf{B} \cdot \mathbf{g} \cdot \mathbf{S} \]

The main panel of Figure 1 shows the positions of the EPR peaks observed via high-field studies of a single crystal oriented in situ such that the field was close to the parallel (z) direction. The most notable feature is that three resonances are observed in the frequency range between 315 and 355 GHz. This can only be explained if 1 possesses easy-plane type anisotropy (D > 0) and the field is applied close to the z-axis; otherwise, only one ground state transition would be observed. The solid blue curve corresponds to the best simulation of the data employing the following parameters: D = +12.7 cm⁻¹, E = 1.2 cm⁻¹, g_z = 2.17 and a field misalignment of 15°. The same parameterization (with g_x = g_y = 2.30) accounts perfectly for the powder data (lower left portion of Figure 1).

Conclusions

High-field EPR data unambiguously demonstrate that 1 possesses easy-plane type anisotropy. To the best of our knowledge, this is the first example of a mononuclear transition metal complex with easy-plane type anisotropy that also exhibits slow magnetic relaxation. We propose that this behavior is due to spin-phonon selection rules that force relaxation to occur through excited states. A theoretical model is under development to explain the slow relaxation behavior.

Acknowledgements

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**Molecular Conductors**

The high magnetic field behavior of resonance peaks and coherence peaks of angular magnetoresistance oscillations (AMRO) in quasi-two-dimensional electron systems was studied. The two-dimensional AMRO, or Kartsovnik-Kajita-Yamaji (KKY) oscillations, are widely observed in many layered materials with weak electron transport along the interlayer direction. Direct observation of spin-splitting of Shubnikov-de Haas oscillations and the observation of the modulation of the KKY oscillations are among the outstanding outputs of which the latter cannot be explained from the current theory of the KKY oscillations.

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**High Field Behavior of Kartsovnik-Kajita-Yamaji Resonance Peaks and the Coherence Peak of Quasi-two-dimensional Electrons**

W. Kang (Ewha Womans Univ., Physics); Y. J. Jo (Kyungpook Univ., Physics)

**Introduction**

We studied high magnetic field behavior of resonance peaks and coherence peaks of angular magnetoresistance oscillations (AMRO) in quasi-two-dimensional electron systems. The two-dimensional AMRO, or Kartsovnik-Kajita-Yamaji (KKY) oscillations, are widely observed in many layered materials with weak electron transport along the interlayer direction. The positions of peaks follow the expression proposed by K. Yamaji. However, the height of peaks, especially that of the coherence peaks, varies drastically from one compound to another, which obscures their origin. There is a debate on the occurrence mechanism for the coherence peak. Recently, we observed giant and almost delta-function like KKY resonances and coherence peaks in a pressurized sample of \( \beta \)-\( \text{(BEDT-TTF)}_2\text{I}_3 \). In view of their quality, this sample is the most suitable to study quantitatively temperature and magnetic field dependence of resonant electronic transport behavior.

**Experimental**

The samples are mounted to a specially designed sample supports which is also fit into the probes in the NHMFL. Most of samples studied at home were conserved and brought to NHMFL. Precise determination was necessary in view of strong azimuthal angle dependence. Fine tune of the azimuthal angle was made in SCM2 (18T, mainly in the persistent mode) and further experiments were performed in one of resistive magnet to resolve the newly emerging structures on the AMRO near 90 degree.

**Results and Discussion**

We obtained two new outstanding results concerning the direct observation of spin-splitting of Shubnikov-de Haas oscillations (Figure 1) and the modulation of the KKY oscillations (Figure 2). The latter cannot be explained from the current theory of the KKY oscillations and is subject to further studies.

**Acknowledgements**

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1. W. Kang, et al., Invited oral presentation at the ISCOM2011 (Gniezno, Poland, Sept. 2011)

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**FIGURE 1.** Magnetic field dependence of the first KKY resonance peak of \( \beta \)-\( \text{(BEDT-TTF)}_2\text{I}_3 \). Direct observation of the spin-splitting becomes apparent above 20 T.

**FIGURE 2.** Modulation behavior of KKY resonances in \( \beta \)-\( \text{(BEDT-TTF)}_2\text{I}_3 \). Being an essentially geometrical effect, the KKY resonances are not expected to show any modulation behavior.
This is a remarkable piece of theoretical artwork from the Master. The paper, in very physical and elegant fashion, sheds a new light on the nature of Charge Density Waves, an issue debated for decades. The author points out the important role of strong interactions between charge carriers and crystal lattice vibrations leading to polaronic effects. The conclusion agrees with recent experimental observations.


Strong Electron-Phonon Interactions and Polaronic Effects in Compounds with Transition-Metals-Atoms

L. P. Gor’kov (FSU, NHMFL)

Introduction

Mechanisms of Charge Density Waves (CDW) in Transition-Metals Di-Chalcogenids (TMDC) continue to be the topic of debates since the CDW discovery in 1974. For a long time the interpretation of the phenomenon was in terms of the popular “nesting” mechanism. Numerical calculations have not confirmed presence of such features for the Fermi-surfaces in these materials. Analysis of the early experimental data for CDW in 2H-TaSe2 have found the short coherence length in the system below transition and large fluctuations, all in strong disagreement with predictions of the nesting scenario1. Recent progress in the ARPES experiments revived the topic. In the report it is shown that both the normal and superconducting properties of TMDC reflect the important role of strong electron-phonon interactions displaying the polaronic effects.

Results and Discussion

We consider interaction of conduction electrons with the displacements of transitional atoms. Strong enough coupling transforms the harmonic potential of an ion into the potential well with two-or-more deep minima. The system becomes the system of the Ising spins. The inter-site interactions are responsible for the CDW transformation. Since the structural vector, \( Q \) at such mechanism has nothing in common with the Fermi surfaces’ parameters, the system remains metallic below the CDW transition. Among the most typical manifestations of such strong \( e-ph \) coupling in the system are large characteristic energy scales significantly exceeding the temperatures for the onset of the CDW phase. Large value of the pseudogap seen in the tunneling experiments is related to the deep minimum of the two-well potential. It is shown that onset of CDW affects the density of state for the electronic band away from the Fermi surface, thus explaining the result of ARPES experiments2. Properties of conduction electrons above and below the transition agree with the results of ARPES experiments. If \( e-ph \) coupling is strong enough for one or more bands, polaronic effects practically decouple these bands from the rest. This suggests the interpretation for a rather unexpected observation of the dHvA oscillations on the small pocket in 2H-NbSe2 in the vortex state well below \( H_{c2} \).

Conclusions

The available experimental data, including the recent ARPES results, support the interpretation of properties of the transition-atoms-dichalcogenides in terms of the local polaronic effects.

Acknowledgements

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Other Condensed Matter

The two-dimensional conduction layer forming at the interface of LaAlO$_3$ (LAO) and SrTiO$_3$ (STO) oxides is a subject of intense experimental and theoretical studies. This report focuses on unusual coexistence of magnetism and superconductivity observed between these nonmagnetic insulators. The nature of this intriguing phenomenon is not clear but for sure stems from an exotic superconducting ground state. On the application side, this novel two-dimensional magnetic material may be used in spintronics where both orbital and spin properties are used to process information.

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Coexistence of Magnetism and Two-Dimensional Superconductivity at Oxide Interface Using SCM and Torque Magnetometry

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Introduction

Transition metal oxide has been a rich field for many intriguing physical phenomena, including high temperature superconductivity and colossal magnetoresistance. Interface devices of semiconductors are the driving force of current modern technology, such as transistors in computer chips, solid state lasers, and solar panels. We cannot help but wonder what novel effects will appear by combining interface fabrication and transition metal oxides. In this work atomic flat interface made between two nonmagnetic band insulators LaAlO$_3$ and SrTiO$_3$ (see the structure sketch in Figure 1a) turns out to be magnetic as well as superconducting$^1$, an coexistence never observed in two dimensional systems.

Experimental

Nb ohmic contacts were fabricated to measure the conductivity of the LAO/STO wafer. The torque magnetometry studies were performed in SCM1 and SCM2 using metal cantilevers. Background magnetic signals are measured of an empty cantilever, a bare SrTiO$_3$, and a 0 u.c. sample that was grown and annealed in the same condition. We also tried to carry out the torque magnetometry and electrical transport property in situ in the same setup.

Results and Discussion

We resolved the magnetic moment by measuring the torque on the interface sample under an external magnetic field. Figure 1b compares the magnetic field dependence of the resistance and magnetization of the sample. The magnetization curve resembles that of soft ferromagnet$^1$. On the other hand, the zero resistance demonstrates that the interface is indeed superconducting.

Conclusions

The unusual coexistence of superconductivity and magnetism would probably lead to an exotic superconducting ground state. On the practical side, our discovery leads to a new way to realize two dimensional magnetic materials, a crucial step for “spintronics”, which uses the “spin” property of the electron to make ultrahigh density hard drive and faster computer chips.

Acknowledgements

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Qubits and Quantum Entanglement

Silicon based quantum dots and qubits are promising building blocks for quantum computer applications due to their long spin coherence times and potential scalability. Single electrons bound to donor atoms in Si:P have low temperature spin-lattice relaxation times of the order of seconds. Triple-Gate finFETs where fabricated and conductance measurements were carried out at 20 mK and magnetic fields of up to 18 T. The observed resonant transport features are consistent with tunneling through single donors, and the convergence is likely due to onset of two-electron tunneling. At high gate voltages, the carrier transport is in the Coulomb blockaded regime of multi-electron quantum dots. Producing entangled states should be possible in such systems.

Engineering CMOS-Compatible Quantum Dot Qubits for Local and Non-Local On-Chip Quantum Communication

C. C. Lo, J. Bokor (Lawrence Berkeley National Lab and Univ. of California, Berkeley); T. Last (UC Berkeley); T. Schenkel (LBNL)

Introduction

Semiconductor-based quantum dot and donor qubits are particularly promising as fundamental building blocks for quantum information processing (QIP) owing to their long coherence times and scalability1,2. For instance, single electron spins bound to shallow donor atoms in silicon (e.g. P, As, and Sb) have spin-lattice relaxation times at low temperatures in the order of seconds. Towards the development of CMOS-compatible silicon-based nanostructures for QIP, we carried out low temperature magnetotransport measurements to characterize few-dopant triple-gate finFETs (TG-finFETs).

Experimental

We developed silicon TG-finFETs owing to their compatibility with single-ion implantation for large-scale donor qubit integration for QIP. These custom-built few donor doped devices were fabricated on 50nm thick silicon-on-insulator wafers. After defining the silicon fins by dry etching, the side-gates were deposited and patterned with a narrow gap in between. The exposed fins then received a low-dose ion implantation, the side-gates were deposited and patterned with a narrow gap in between. The exposed fins then received a low-dose ion implantation, and the smallest fins received five donor atoms on average. The SEM micrograph of a typical device prior to center fin-gate deposition is shown in Figure 1.

Magnetotransport measurements were carried out for two TG-finFETs using the SCM1 dilution refrigerator at the NHMFL with a base temperature of 20mK.

Results and Discussion

Figure 2 shows the conductance plot of a TF-finFET with lithographic length of 100nm and width of 50nm, measured with 0V dc drain bias and ac excitation of 20μV. The measurement was carried out with fixed side-gate voltages while the fin-gate voltage (Vg) is varied. For Vg<100mV, a few of the transport resonance features shift with magnetic field: while some features split, others converge with increasing magnetic field. The splitting of the resonance lines can be understood as a manifestation of the Zeeman shifts for resonance features associated with paramagnetic states3. The convergence of the resonance features, on the other hand, is related to the increased probabilities for two-electron co-tunneling events that occur4. While these transport signatures are compatible with tunneling through single donors, further investigation is required for the definitive identification of the origin of these features. The oscillations at higher gate voltages (Vg>150mV) are periodic and reproducible, indicating carrier transport in the Coulomb blockaded regime of a multi-electron quantum dot.

Acknowledgements

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FIGURE 1. SEM micrograph of a TG-finFET prior to fin-gate deposition.

FIGURE 2. Conductance measurements carried out at T = 20 mK. The side gates are biased at 0.8 V. Scale is from 0-3.7 μS.
Semiconductors

Superfluorescence is a phenomenon where macroscopic coherence spontaneously appears from initially incoherent electron-hole pairs and abruptly decays producing giant pulses of light. It has been observed in atomic gases and rarefied impurities in glasses and crystals. This report describes the first evidence for superfluorescence in a semiconductor. The solid-state realization of superfluorescence using high magnetic fields and low temperatures provides an unprecedented degree of controllability, opening up new opportunities for both fundamental many-body studies and device applications.

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Time-Resolved Evidence for Superfluorescent Radiation from Quantum Wells in 17.5T

J. H. Kim, G. T. Noe, J. Kono (Rice U., ECE/Physics); A. A. Belyanin (TAMU, Physics); S. A. McGill (NHMFL)

**Introduction**

Superfluorescence (SF) is the process of cooperative emission of coherent radiation from an initially incoherent ensemble of excited dipoles. It represents one of the unusual examples of self-organization processes where macroscopic coherence spontaneously develops through many-body interactions among the individual dipoles. SF has been observed in atomic and molecular gases, but not in condensed matter systems where ultrafast scattering phenomena typically destroys such coherence.

Here, we present evidence for SF through time-resolved differential transmission (TRDT) and time-resolved photoluminescence (TRPL) measurements on an undoped In$_{0.2}$Ga$_{0.8}$As/GaAs multiple quantum well sample in magnetic fields up to 17.5 T. A magnetic field quenches the kinetic energy of electrons and holes and restricts the phase space available for phonon scattering, thereby increasing the coherence time. Furthermore, the concentration of density of states via Landau quantization increases the oscillator strengths of interband magneto-optical transitions. Combining the TRDT and TRPL measurements reveals the nature of the relaxation and the subsequent emission from the magneto-excitonic states.

**Experimental**

We performed the experiments in the Fast Optics Facility of the National High Magnetic Field Laboratory in Tallahassee, FL, using the 17.5 T superconducting magnet in Cell 3 (SCM3). The sample was placed in the magnet in the Faraday geometry. We used a high-intensity chirped pulse amplifier (CPA) to optically pump the sample, creating a high density of electron-hole pairs in the magneto-excitonic states. For TRDT measurements we used a tunable optical parametric amplifier (OPA) to probe the population of the states as a function of time delay using an optical delay line. For TRPL measurements, we collected the emission using two 0.6-mm core diameter multimode fibers: one placed directly behind the excitation spot and the other at the edge of the sample after redirecting the in-plane emission with a right-angle micro-prism. We then used a streak camera with a time resolution of 2 ps with a spectrometer to measure the spectrally resolved, time-resolved PL after the optical fiber.

**Results and Discussion**

Our data exhibit superfluorescent bursts under the conditions of high magnetic field, high excitation power, and low temperature (Figure 1). The data shown here is representative. We varied the magnetic field, excitation power, and temperature to show how the population and emission change under the various conditions.

![Figure 1. TRPL map as a function of delay time and photon energy at 17.5 tesla, 2 mW excitation, and 5 K.](image)

**Conclusions**

Our time-resolved measurements mark the first time SF has been convincingly observed in a condensed matter system.

**Acknowledgements**

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Anomalous Robustness of the $\nu = 5/2$ Fractional Quantum Hall Effect Near a Sharp Phase Boundary


Introduction

Fractional quantum Hall effect (FQHE) in a 2D electron system where two subbands are occupied reveals intriguing phenomena1-3. Here we report our studies on electrons confined to a wide GaAs quantum well (QW), when both the symmetric (S) and antisymmetric (A) subbands are occupied. We studied the stability of the even denominator FQHE at $\nu = 5/2$ and $7/2$, when the Landau levels (LLs) belonging to different subbands cross.

Experimental

Each of our samples consists of a GaAs QW bounded on its sides by undoped Al$_{0.24}$Ga$_{0.76}$As spacer layers. The density ($n$) and subband separation are controlled by applying front- and back-gates, and measured through the Fourier analysis of the Shubnikov-de Haas oscillations. The FQHE measurements were carried out in SCM1 and resistive magnets.

Results and Discussion

Our surprising discovery2, illustrated in Figure 1, is the anomalous robustness of the $\nu = 5/2$ FQHE near the crossing of the spin-up $N=1$ LL of the symmetric subband (S1) and the spin-up $N=0$ LL of the antisymmetric subband (A0). This is clearly evident in the plot of the excitation gap ($5/2\Delta$) of the $\nu = 5/2$ FQHE vs magnetic field ($B$) or $n$ in Figure 1d: the $\nu = 5/2$ FQHE becomes stronger with increasing $n$ before it collapses. Another noteworthy observation in Figure 1d is that, at a common density of $n = 3.2 \times 10^{11}$ cm$^{-2}$, $5/2\Delta$ for the 31-nm-wide QW is nearly twice larger than for the 30-nm-wide QW. We conclude that the dramatic rise of $5/2\Delta$ is related to the crossing of the S1 and A0 levels. When the density is further increased and the Fermi energy ($E_F$) moves to the A0 level, $5/2\Delta$ suddenly collapses. The sharpness of the collapse suggests a first-order transition of the FQHE to a metallic state.

Conclusions

Our results1-3 show that: (i) The even-denominator FQHE states are stable when $E_F$ is in an $N = 1$ LL. (ii) The odd-denominator states are most stable when $E_F$ is in an $N = 0$ LL. (iii) The 5/2 FQHE is anomalously stable near the crossing of the S1 and A0 levels.

Acknowledgements

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FIGURE 1. a. Waterfall plot of $R_{xx}$ vs $1/\nu$ for the 31-nm-wide GaAs QW as $n$ is changed from 2.79 to $3.31 \times 10^{11}$ cm$^{-2}$. b. & c. Arrhenius plots of $R_{xx}$ at $\nu = 5/2$ vs inverse temperature for the 31- and 30-nm-wide QWs at the indicated densities. d. Measured energy gap for the $\nu = 5/2$ FQHE in both samples as a function of magnetic field or density. e. Measured energy gaps for the $\nu = 5/2$ and 7/3 FQHEs in the 30-nm-wide QW.
Superconductivity – Basic

A long-lasting question concerning possible coexistence of superconductivity and antiferromagnetism competing locally in the real space seems to be now resolved positively by the NMR experiments of Mounce et al. The problem was first posed in the late 90’s - early 2000s, after the observations (B. Lake et al.) of a static incommensurate antiferromagnetism in the vortex state of LSCO with a sizable average magnetic moment on the Cu$^{2+}$ sites; the moment kept increasing with increase of the magnetic field. Scanning tunneling microscopy (STM) could see such a superstructure only as a checkerboard pattern in DOS on the surfaces of cleaved BSCCO. Unlike neutrons which are a bulk probe or the surface-sensitive STM, NMR is a bulk probe that can explore the local environment. In this report the authors provide results confirming coexistence of the diamagnetic currents at a vortex with SDW close to the normal vortex core and show evolution of the local SDW with increasing field.


Spin Density Wave Near the Vortex Cores of Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$

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Introduction
The coexistence of superconductivity and magnetism in the high temperature superconducting (HTS) cuprates is a dichotomy still not fully understood. To investigate this relationship, experiments of spatially resolved nuclear magnetic resonance (NMR) are performed on the HTS Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (BSCCO) at high magnetic fields and low temperatures. A model for the experimental results indicates a spin density wave originates from the vortex cores and is enhanced with increasing external magnetic field.

Experimental
Samples were prepared by $^{17}$O isotopically exchanging single crystals of BSCCO and annealed to the overdoped regime with $T_c = 82$ K. Spectra and spin-lattice relaxation data were taken with the crystal c-axis parallel to the external magnetic field and at low temperatures down to $T = 4$ K. Experiments were performed at the NHMFL and Northwestern University.

Results and Discussion
Previous spatially resolved NMR experiments on YBa$_2$Cu$_3$O$_{7+\delta}$ (YBCO) have shown a local magnet field dependent relaxation due to the Doppler shift of quasiparticles$^1$. Results from BSCCO show a non-monotonic relationship between local magnetic field and spin-lattice relaxation, while the average $1/T_1$ is consistent with the Volovik effect$^2$ indicating a vortex mechanism through Doppler shift. We use a model of a spin density wave (SDW) decaying away from the vortex core in addition to the local magnetic fields due to supercurrents. This results in a non-monotonic relationship between local magnetic field and Doppler-shifted relaxation. With increasing magnetic field, the SDW increases in magnitude changing the relaxation profile, Figure 1.

Conclusions
The spatially resolved NMR relaxation for BSCCO is explained by an additional SDW contribution to the local magnetic field. The field dependence of the SDW fitting parameters indicate an increasing amplitude with increasing magnetic field. This work has recently been published in Physical Review Letters$^3$.

Acknowledgements
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Superconductivity – Basic

Currently, there is great interest in the origin and properties of the fractional quantum Hall (FQH) state at the even-denominator Landau level filling factor $\nu=5/2$. This interest partly stems from the expectation that the quasi-particle excitations of this state might obey non-Abelian statistics and be useful for topological quantum computing. The stability and robustness of the $5/2$ state are thus of great importance. This report describes the study of the stability of the FQH effect at $\nu=5/2$ when two electric subbands are occupied. The $5/2$ state is found to be surprisingly stable near the crossing of the Landau levels belonging to the different electric subbands.


Quantum Oscillations in the Thermoelectric Properties of YBa$_2$Cu$_3$O$_{6.54}$ to 45 T in the Hybrid Magnet

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**Introduction**

Quantum oscillations and Hall effect measurements have revealed the existence of a small closed electron Fermi surface in underdoped YBCO$^{1,2}$, in sharp contrast with the large hole Fermi surface seen in overdoped Tl2201$^3$. This naturally suggests that a Fermi surface reconstruction occurs as a function of doping, possibly at a quantum phase transition where a form of density-wave order sets in. While a number of scenarios have been proposed, “the cause of the reconstruction, and its implication for the origin of high-temperature superconductivity, is a subject of active debate”$^4$.

In order to identify the cause of the reconstruction, we need to gain a better understanding of the Fermi surface of underdoped cuprates, a question we have recently examined through a series of thermoelectric experiments in high magnetic field.

**Experimental**

We performed a series of thermoelectric experiments up to 45 T using the hybrid magnet in cell 15 at the National High Magnetic Field Laboratory in Tallahassee. Our work focused in highly ordered ortho-II specimens of YBa$_2$Cu$_3$O$_{6.54}$ ($p = 0.11$) grown by the group of Liang, Bonn, and Hardy at the University of British Columbia. In Figure 1 we show the Seebeck coefficient $S$ of YBa$_2$Cu$_3$O$_{6.54}$ as a function of applied magnetic field at a temperature of 2 K. At sufficiently high field, above the vortex lattice melting line, the normal-state thermopower is strongly negative and exhibits large quantum oscillations (QOs)$^3$. The curve shown in Figure 1 are raw, unsmoothed, data. QOs were also observed in the Nernst effect.

**Results and Discussion**

The existence of a small electron pocket was initially inferred from the simultaneous observation of QOs and a negative Hall effect$^{1,2}$. It has been argued, however, that a negative Hall effect may come from vortices or a Fermi surface with changing curvature. The thermopower, however, is free from these effects and the observation of QOs on a strongly negative Seebeck coefficient is unambiguous evidence that the Fermi surface supporting the orbits is indeed electron-like$^5$. We recently examined the range in doping and temperature of this negative Seebeck coefficient in YBCO and Eu-LSCO, a cuprate in which a form of spin and charge order known as “stripe order” has been observed. Our study revealed a detailed and striking similarity between the two materials, showing that the electron pocket and the Fermi surface reconstruction must share a common origin, namely stripe order$^6$. NMR experiments in high magnetic field recently revealed stripe order in YBCO$^7$.

**Conclusions**

We have observed large QOs in the

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**Acknowledgements**

We acknowledge support from CIFAR, NSERC, FQRNT, CFI, and a Canada Research Chair.

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5. N. Doiron-Leyraud et al., to be published.

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**FIGURE 1.** Seebeck coefficient $S$ over temperature $T$ of YBa$_2$Cu$_3$O$_{6.54}$ as a function of magnetic field $B$. From$^5$.

Nernst and Seebeck effects on YBa$_2$Cu$_3$O$_{6.54}$, which confirms the existence of an electron pocket and provides a novel window for the study of the Fermi surface of YBCO.
**Superconductivity – Basic**

A key challenge in understanding quantum oscillations in high Tc superconductors has been an identification of the underlying electronic structure, and a reconciliation with complementary experiments such as photoemission. Using data that extends over an unprecedented field range up to 101 T, Sebastian et al. suggest an elegant way of reconciling quantum oscillation experiments that reveal multiple frequency components, with photoemission results that reveal a nodal density of states with a small bilayer coupling. A comprehensive explanation is suggested in which quantum oscillations arise from bilayer-split nodal Fermi surface pockets accompanied by magnetic breakdown tunnelling.


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**Multiple Quantum Oscillation Frequencies from Nodal Pocket in Underdoped Cuprates to 95 T**

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**Introduction**

Discerning the electronic structure of the underdoped cuprates poses a pressing conundrum. Among key questions to be addressed are the issue of whether the electronic structure comprises multiple pockets, and whether any of these are located at the antinodal region of the Brillouin zone where photoemission experiments reveal a significant gap in density of states at the Fermi Energy.

**Experimental**

We have performed quantum oscillation measurements on YBa$_2$Cu$_3$O$_{6.56}$ (hole doping of ≈ 10%) using the resonant oscillator technique, up to unprecedentedly high magnetic fields of 101 T at NHMFL Los Alamos. The wide field range thus accessed (24 – 100 T) enables a frequency resolution of ≈30T, enabling superior resolution of multiple quantum oscillation frequencies.

**Results and Discussion**

A distinct pattern of quantum oscillation frequencies observed, with a spectrally dominant frequency at 532(2)T, flanked on either side by frequencies 440(10)T and 620(10)T spaced equidistantly from the central frequency (Figure 1). At first sight, these three frequencies appear challenging to reconcile with a single Fermi surface pocket indicated from chemical potential oscillations.

We propose that this pattern of frequencies can be explained by the effect of bilayer splitting accompanied by magnetic breakdown on a nodal pocket. YBa$_2$Cu$_3$O$_{6.56}$ comprises bilayers (i.e. pairs of planes) of CuO$_2$, the effect of bilayer coupling is to split each Fermi surface pocket into two surfaces (as shown in Figure 2). This still leaves us with the problem of how to explain three frequencies from a Fermi surface pocket.

In the case of a nodal pocket, however, we invoke the additional effect of magnetic breakdown due to the small size of bilayer splitting at the nodes compared to the antinodes.

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**FIGURE 1.** Quantum oscillations measured in contactless resistivity using a proximity detection oscillator (PDO) from 24 - 101 T in (a), the Fourier transform in (b) shown by black lines. Red and blue dotted lines are simulations for an elliptical and diamond nodal pocket.
Quasiparticles can therefore tunnel between the two split pockets at the nodes. An example is shown in Figure 2b, where the pink and purple ellipses are the split elliptical nodal pockets. The dotted purple line shows an elliptical orbit arising due to magnetic breakdown between the two split pockets, with frequency equal to the average of the two split frequencies. Another example is shown in figure a, where the nodal pocket has a diamond shape. The resulting frequency spectrum therefore would have the form \( F + \Delta F \), \( F - \Delta F \), and their average \( F \) — which is in fact precisely the same as that experimentally observed.

The dotted lines in Figures 1a and 1b show a simulation of the oscillation spectrum anticipated for a nodal pocket of an ellipsoidal shape, and a diamond shape respectively with a single adjustable variable: the size of magnetic breakdown field, good agreement is seen with the experimentally observed quantum oscillation spectrum.

**Conclusions**

Quantum oscillations measured up to 101 T in the underdoped cuprate \( \text{YBa}_2\text{Cu}_3\text{O}_6.56 \) reveal well separated multiple frequencies with a characteristic \( F + \Delta F, F - \Delta F, F \) pattern. We propose that these can be explained by effects of bilayer splitting accompanied by magnetic breakdown on a nodal pocket.

**REFERENCES**

Superconductivity – Basic

A team of scientists from Oxford University and Bristol University reports dHvA oscillations in LiFeAs and LiFeP. ARPES data disagree with the Fermi surfaces in LiFeAs obtained in the band structure calculations. That prompted the bulk study of electronic spectrum of these materials in the dHvA experiments. The outcome is that the observed Fermi surfaces are in good agreement with those from the band calculations. For LiFeAs the comparison of the calculated “band masses” with the observable orbital masses has shown considerable enhancement due to both electron-electron and electron-phonon interactions. As LiFeAs and LiFeP are predicted to have similar electron-phonon coupling it is very likely that the observed effect is related to enhanced electronic correlations linked to higher $T_c$ in iron-based superconductors.


Quantum Oscillations in the 111 Iron Pnictide Superconductors: LiFeAs and LiFeP Using 45T Hybrid Magnet

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The aim of our experiment was to study the Fermi surface topology of the '111' structure superconductors in the superconducting LiFeAs with $T_c=18.5$ K and LiFeP with $T_c=5$ K which are two of only a few iron-based superconductors which superconduct at ambient pressure in their undoped stoichiometric form. ARPES studies have suggested that LiFeAs has a Fermi surface that disagree with band structure calculations and bulk studies of the Fermi surface are required to clarify whether spin fluctuations are relevant in iron pnictides. Furthermore, these materials can be grown in high crystalline form and have been found to show different gap symmetry, having a fully gapped superconducting order parameter in LiFeAs and there are suggestions that LiFeP has nodes. An additional challenge concerning experimental investigation of these materials, which are supposed to be some of the cleanest iron pnictides, is their significant sensitivity to air.

During our last experiment in the 45T hybrid magnet we have been able to observe dHvA oscillations in these two compounds in order to map out the Fermi surface of these two isoelectronic systems. We have determined almost completely the Fermi surface of LiFeP in broad agreement with band structure calculations and found out that the mass enhancement varies significantly between bands, being quite small for one of the bands. These findings could suggest that the inner hole band could be the place for nodes formation. Our study on LiFeAs has found that the observed orbits belong to the electron bands and are well described by the band structure calculations without any energy shifts; the mass enhancement for the observed electron bands in LiFeAs is significant, a factor up to 5, being linked to the higher $T_c$ of this optimally doped system. However, more work is required to clarify how well nested the Fermi surface of LiFeAs is.

Acknowledgements

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REFERENCES

Engineering Materials

The desire to create next generation materials with better mechanical properties can be achieved using metal matrix composites by incorporating a fine dispersion of strengthening particles. A crucial requirement to achieve the enhanced performance is that the fine particles be homogeneously dispersed throughout the matrix. In addition, preferential directional (textured) performance of the final material can be achieved by leveraging the magnetocrystalline anisotropy of the material. This research indicates that both uniformly dispersed nanoparticles and a textured matrix can be obtained in a single alloy by a combination of thermomagnetic processing and electromagnetic acoustic transducer technologies.


G.M. Ludtka; G. Mackiewicz-Ludtka, O. Rios; J.B. Wilgen; R.A. Kisner, G. Muralidharan (Oak Ridge National Lab); M. Manuel (Univ. of Florida)

Introduction

This research demonstrates that significantly enhanced materials microstructures and improved performance can be achieved by coupling two previously independent materials research concepts, namely, the thermo-magnetic processing (T-MP) and the electromagnetic acoustic transducer (EMAT) technologies. In prior, separate NHMFL research endeavors, ORNL researchers have demonstrated that: 1.) thermo-magnetic processing (T-MP) can significantly enhance Ni solubility in Fe by up to 30%; and 2.) using the electromagnetic acoustic transducer (EMAT) technology can significantly improve cast product homogeneity. Based on these earlier successful results, we proposed simultaneously coupling these two R&D approaches/effects (i.e., T-MP with EMAT), in order to simultaneously achieve: 1.) enhanced elemental solid-solubility in Mg and in at least one Fe-based alloy; and 2.) uniform dispersion of intentional additions of inert nanoparticles in Mg. Developing homogeneous dispersions of inert nanoparticles is and has been pursued as one of the “holy grails” for achieving unprecedented materials performance and highly desired mechanical properties, e.g., in creep and oxidation resistant alloys. Successfully coupling these two technologies would provide the ability to create uniquely controlled nano-scale microstructures that currently are unachievable by any other materials processing technologies.

Experimental

A series of 14 different Mg samples were prepared that either had a pure Mg or Mg-Li alloy matrix and nanoparticles dispersions of either diamond, Er₂O₃, or Dy₂O₃. In addition, several Fe-Co-Ni alloys were cast for enhanced texturing and increased solute solubility. The Mg alloy samples were processed with the T-MP and EMAT processes superimposed (stopped EMAT 20 °C above liquidus) to homogeneously distribute the nanoparticles whereas the Fe-based alloys had the EMAT effect turned off to promote magneto anisotropy-induced texturing to occur during solidification.

Results and Discussion

Subsequent radiography and microscopy analyses of the Mg and Mg-alloy castings showed uniform dispersions of nanoparticles could be achieved but results were directly dependent on the quality/uniformity of the starting materials. The Fe-based experiments, shown in Figure 1, showed that very highly textured, bulk castings could be achieved over a broad range of cooling rates (30 to 300 °C/min) by applying a high magnetic field (19 T) during solidification.

Conclusions

Combined T-MP and EMAT processing facilitates uniform, non-agglomerated dispersions of nano-particles in Mg. In addition, T-MP processing of Fe-based alloys during solidification can achieve highly textured, bulk castings.

Acknowledgements

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Magnet Technology

REBCO coated high temperature superconductor has excellent tensile properties in rolling direction due to the use of high strength alloy as a substrate. In transverse direction, however, the conductor fails early, mechanically as well as electrically due to delamination and destruction of the superconducting layer. The authors achieved a technological breakthrough in magnet technology by devising a method that mechanically uncouples transverse loads from the conductor by using a thin-walled polyester heat shrink tube around the conductor.


Mechanical Decoupling of ReBCO Coated Conductors in High Field Coils Using Thin-Walled Heat-Shrink Tubing Insulation to Prevent Stress-Induced Damage


**Experimental**

We incorporate an unusual conductor insulation, a medical-grade, low-temperature compatible, extremely thin-walled heat-shrink tubing, manufactured by and proprietary to Vention Medical, Inc. This tubing consists of an extruded and expanded polyethylene terephthalate, a polyester, with a melting point of about 508 K, an operating temperature range of 77 K – 408 K, and a 3.8 µm minimum thickness.

Recently confirmed in an epoxy-impregnated world-record superconducting coil (Figure 1), this insulation uniformly insulates tape conductors, including the edges of the conductors, and does not crack at low temperatures, especially while sustaining bending or tensile strain. Because shrinkage and not adhesion is the functional basis of this tubing, thermal and electromagnetic tensile and shear stresses are minimized at the boundary between conductor and encapsulant.

**Introduction**

REBCO coated conductors, such as those based on YBa2Cu3O7-x and other rare-earth variants of this structure are now being developed and commercialized. Particularly, they show great potential for the construction of high field magnets, since they retain their superconducting state in magnetic fields well above 100 T at low temperatures, whereas the materials presently used to construct superconducting magnets, Nb-Ti and Nb3Sn, cannot operate in fields that exceed 25 T or so. Construction of superconducting magnets requires not just a suitable conductor, but also a suitable insulation to resist over-voltages during quenches, and suitable winding encapsulants to prevent tape movement, delamination, and resulting damage during encapsulant curing, thermal cycling, and electrical energization of the magnet.

**Conclusions**

Because all present designs of coated conductors tend to have relatively weak bonding between their metal and oxide components, and because high field magnets necessarily develop significant stresses, this invention addresses an important problem of this technology. A U.S. provisional patent application (61/420,429) has been filed that is being converted into a U.S. utility patent.

**Acknowledgements**

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**REFERENCES**


Magnet Technology

In a household extension cord, the copper wire is coated with plastic, which electrically insulates the wire. At the Magnet Lab, magnets are made from electrically conducting wires that also need to be insulated from one another. One magnet that is being developed, the 32 T all-superconducting magnet, is made with bare flat wires that carry the current. When the coil is wound, these flat tapes are electrically isolated from one another with a flat stainless steel tape that is coated with a layer of insulating material. In this study, two different insulating materials that coat the stainless steel tape, each with its own method for being applied, were developed.

Introduction

Insulation in a high field superconducting magnet plays a critical role. High field magnets require very thin (e.g. < 12.5 μm) insulation with sufficient mechanical and dielectric strength under high stresses at cryogenic temperatures. Within the framework of the construction of the 32 T all-superconducting magnet, two types of reel-to-reel systems, which insulate either the coated conductor or steel co-winding tapes, have been developed.

Experimental

A UV cured epoxy coating system has been built as shown in Figure 1. A suitable UV cured epoxy EPO-TEK® UVO-114 has been identified and used in the process. For insulation of steel co-winding tape, we also chose a ceramic sol gel coating process. The sol gel is made by mixing (in weight) one part of silica sol gel (Silbond H-5), two parts of ethanol and 0.3 part of 0.3 μm sized alpha alumina powder. The reel-to-reel dip coating system in Figure 1 is modified by addition of a tube furnace, so the sol gel coated steel tape is dried at 300 C and calcinated at 700 C.

Results and Discussion

The UV epoxy insulation is nominally 10 μm thick with a typical breakdown voltage of about 400 V. It has about 5 μm thickness variation along the tape width. The corners are not fully covered, although in case of the 32 T pancake coils, the corner coverage is not critical. These problems are related to the rheology of the coating process. Sol gel coating on steel tapes has superior thermal properties. The coating thickness is approximately 2 μm with a typical breakdown voltage of about 200 V. Similar to the epoxy coating, the sol gel coating has issues of corner coverage and the thickness build-up near the edges. An air-flow assisted sol gel drying process is being developed as a promising technique to mitigate these problems. Both methods were used to insulate hundreds of meters of steel co-winding tapes which have been successfully used in the 32 T test coils.

Conclusions

Both the UV-cured epoxy-coating and sol gel coating has been developed for insulating YBCO coated conductors and steel co-winding tapes. Long length steel tapes have been insulated for 32 T test coils using both techniques. The issues of corner coverage and the thickness build-up at the edges are being addressed.

Acknowledgements

This work was supported by the National Science Foundation under Grant No. DMR-0654118.

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Superconductivity – Applied

The full potential of Bi2212 high temperature superconducting round wire is masked by void space that forms inside the conductor during the thermal processing that is required to form a well aligned current carrying crystal structure. The authors achieved a technological breakthrough by devising a processing scheme that significantly reduces the void space in the conductor and at least doubled the critical current density in a series of short wire samples consistently.

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Doubled Critical Current Density in Bi-2212 Wires by Reduction of Gas Bubble Density


Introduction

The filament density of Bi-2212 wire in the as-drawn state is much less than 100%, typically about 70% of the theoretical density of Bi-2212. In order to better understand the effects of this less than full density on the critical current density \( I_c \), we quenched samples of Bi-2212 wires just after they entered the melt phase and observed many large gas bubbles, most as big as the filament diameter. Although the overall effect of melt processing on \( I_c \) is highly positive, \( I_c \) is certainly lowered by formation of these bubbles which of course do not support a supercurrent.

Experimental

In order to fill the filaments with \( O_2 \) gas, which can diffuse through the Ag sheath, Bi-2212 wire samples were heated at 400 °C for 48 h under a vacuum of 20 mtorr. After cooling, the samples were filled with 1 bar oxygen and held for 16 h. When the wires were removed from the furnace, their ends were immediately sealed by dipping in molten Ag or Sn and the filaments were densified under a cold isostatic pressure (CIP) of 2 GPa before the following melt processing step.

Results

The longitudinal cross sections of the quenched samples are shown in Figure 1. Gas bubbles in the as-received wire are big, being 2 to 3 times as long as their diameter, while the bubbles in the CIPped wire are much shorter, round and are smaller than the filament diameter. Table 1 compares the values of \( I_c \) \((4.2 \text{ K, 5 T})\) and the resistive transition index \( n \) for fully-processed as-received and CIPped wires. The \( I_c \) \((4.2 \text{ K, 5 T})\) values for the CIPped samples were more than doubled, and their \( n \) values are also much higher than for the as-received wires, consistent with an increase in the longitudinal uniformity of the \( I_c \). \( J_c \) \((4.2 \text{ K, 5 T})\) was increased from 1667 to 3600 A/mm\(^2\) for the CIPped wire.

Conclusions

We found a significant improvement of \( J_c \) in recent Bi-2212 round wires by replacing residual air in the filament by pure oxygen and cold isostatic pressing them before melt-processing. The fewer and smaller bubbles formed in the melt allowed the critical current \( I_c \) \((4.2 \text{ K, 5 T})\) to be doubled. Controlling the formation of bubbles through approaches like CIPping was shown to be a very effective pathway to achieve very high \( J_c \) in Bi-2212 wires.

Acknowledgements

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*888 °C gave the maximum \( I_c \) for AR wire.

Table 1. \( I_c \) \((4.2 \text{ K, 5 T})\), \( J_E \) \((4.2 \text{ K, 5 T})\), \( J_c \) \((4.2 \text{ K, 5 T})\) and \( n \) value for fully processed as-received (AR) and CIPped samples of 37x18 wire.

Figure 1. SEM images of longitudinal cross sections of filaments from an inner bundle of quenched wires. (a) As-received and (b) CIPped wire. All filaments show a continuous amorphous solid structure containing bubbles (B), alkaline earth cuprates (A) and copper free (CF) phases.

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Superconductivity – Applied

To integrate high-temperature superconductors (HTS) in sizeable high field magnets, like a 60 T DC Hybrid magnet, HTS cables are required. Of the three concepts that seem viable at this time, this is the first to be tested in realistic conditions. The results under hoop stress at low temperature and high magnetic field are very encouraging.


Critical Current Measurement at 4.2 K Up to 20 T of REBa$_2$Cu$_3$O$_{7-\delta}$ Coated Conductor Cables Designed for High-Field Magnet Applications

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Introduction
The next generation of high-field magnets requires operating fields exceeding 20 T and that cannot be reached with low-temperature superconductors, such as NbTi or Nb$_3$Sn, and high-temperature superconductors (HTS), such as REBa$_2$Cu$_3$O$_{7-\delta}$ (REBCO) coated conductors, are the only option. We have introduced a new cabling method that enables the construction of round, HTS cables that meet the requirements for high-field magnets$^{1,2}$ and performed the first cable tests at 4.2 K at magnetic fields up to 20 T at the user facility of the NHMFL.

Experimental
Several REBCO coated conductors cables were constructed using the method as outlined in Reference 1. The cables were mounted into the support structure (see Figure 1a) to support them against the high Lorenz force that occurs at 20 T. The critical current ($I_c$) of each cable will be measured at 4.2 K, at magnetic fields of up to 20 T.

Results and Discussion
The critical current as a function of magnetic field at 4.2 K up to 20 T of one of the cables is shown in Figure 1b. The critical current could not be measured at fields below 2 T because of the 3500 A current supply limit. The cable $I_c$ that was measured at 76 K in self-field is also included in the figure and, as expected, is comparable to that at 4.2 K and 20 T. No degradation in cable performance due to the high Lorenz force was measured.

Conclusions
We successfully performed the world’s first measurement of an HTS cable at a field of 20 T. The results show the feasibility of HTS cables for high-field magnets.

Acknowledgements
This work was supported in part by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability under award number DE-AI05-98OR22652.

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Seven new cyclic depsipeptides were identified in a marine cyanobacteria, which is a validated source organism of potent and structurally diverse antiproliferative agents.

• Published in Journal of Natural Products 74, 917-927 (2011).

Veraguamides A–G, Novel Cyclic Hexadepsipeptides with Antiproliferative Activity from the Marine Cyanobacterium Symploca cf. hydnoides from Guam

L.A. Salvador, H. Luesch (Univ. of Florida, Medicinal Chemistry); J.S. Biggs (Univ. of Guam Marine Laboratory); V.J. Paul (Smithsonian Marine Station)

Introduction

Marine cyanobacteria of the genus Symploca are validated source organisms of potent and structurally diverse antiproliferative agents, yielding the HDAC inhibitor largazole and microtubule depolymerizers dolastatin 10 and symplostatin 1. We aim to find new classes of bioactive metabolites from Symploca sp. through a bioactivity-directed purification method.

Experimental

$^1$H and 2D NMR spectra were recorded on a Bruker Avance II 600 MHz spectrometer equipped with a 5 mm TXI cryogenic probe using residual solvent signals as internal standards.

Results and Discussion

Cytotoxicity-directed purification of a S. cf. hydnoides collection afforded seven new cyclic depsipeptides, veraguamides A–G (1–7), characterized by an invariant proline residue, multiple $N$-methylated amino acids, an $\alpha$-hydroxy acid, and a C$_8$-polyketide derived $\beta$-hydroxy acid moiety with a characteristic terminus as either an alkynyl bromide, alkyne, or vinyl group. These compounds and a semisynthetic analog (8) showed micromolar antiproliferative activity against HT29 colorectal adenocarcinoma and HeLa cervical carcinoma cell lines.

Conclusions

We identified new antiproliferative agents from the marine cyanobacterium Symploca cf. hydnoides.

Acknowledgements

NIGMS grant P41GM086210, J. R. Rocca, and J. Quiñata.

REFERENCES

Chemistry

This work deals with magnetic interactions of Cr(IV) ions in a Cr-Cr dimer. It is important, as Cr(IV) is a largely unexplored oxidation state of chromium. Second, it probes the basic spin-spin interactions that are responsible for the phenomena of molecular magnets, and particularly molecular nanomagnets.

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High Frequency EPR Study of a Cr(IV)-O-Cr(IV) Dimer Complex


Introduction

The 4+ oxidation state of Cr, with a 3d² configuration remains unexplored. This work details the assignment of the 4+ oxidation state of Cr in a Cr-O-Cr dimer, using high frequency EPR, as reported recently. The autocatalytic oxidation of the trianionic pincer CrIII complex [tBuOCO]CrIII(THF)₃, 1, by [tBuOCO]CrV(O)-(THF), 2, produces the intermediate CrIV-O-CrIV complex [{[tBuOCO]CrIV(THF)}₂(μ-O)], 3 (Figure 1); where tBuOCO = [2,6-(tBuC₆H₃O)₂C₆H₃]₃⁻ and THF = tetrahydrofuran. 240 GHz EPR is used to determine of the electronic structure of 3.

Experimental

Variable temperature, high frequency (240 GHz), powder EPR measurements were made using the 240 GHz EPR spectrometer and 12.5 T SC magnet at the National High Magnetic Field Laboratory, Tallahassee, FL.

Results and Discussion

The experimental powder EPR spectrum of 3 (Figure 2b) indicates the presence of weak signals from CrIII (1, S=3/2) along with those of 3 (S=2). Computer simulation of the spectrum using the standard spin Hamiltonian of a paramagnetic dimer with two spin fragments S₁ and S₂ did not reproduce all the observed lines. However, considering that 3 is in equilibrium with the monomeric complexes 1 and 2, we included 1 in the simulation. A combination of 3 and 1 (in the ratio 2.5:1) yielded a good fit to the observed resonances marked by the numbers 1 through 9 (Figure 2a). Signals from complex 2 (S=1/2) are difficult to be distinguished among the resonances 5, 6 and 7 (Figure 2a), and it is present in < 10%, thus we excluded 2 in the simulation. The spin Hamiltonian parameters for the CrIV-O-CrIV dimer (S=2) are giso = 1.976, D = 10500 G and E = 3000 G. Figure 3 shows the simulated energy levels of 1 and 3.

Conclusions

The good fit between the experimental and simulated spectra permits a conclusive assignment of the 4+ oxidation state for each Cr ion in complex 3. This is the first evidence of EPR in a CrIV-O-CrIV complex.

Acknowledgements

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REFERENCES

Open shell organic molecules have low energy scales that make them susceptible to tuning with various external stimuli such as temperature, pressure, and magnetic field. In this work, J.L. Musfeldt et al. combine magneto-optical spectroscopy with first principles electronic structure calculations to understand the field-induced color change in 1,4-phenylenedinitrene. They show that the magnetochromic response is a sensitive measure of the field-tunable singlet-triplet equilibrium and present an optical Curie-like analysis that can be used to reveal the spin gap.


### Manipulating the Singlet-Triplet Equilibrium in Organic Biradical Materials

**J.L. Musfeldt, O. Gunaydin-Sen, J. Fosso-Tande, P. Chen, J. L. White and R. J. Harrison** (Univ. of Tennessee); **T. L. Allen and P. M. Lahti** (Univ. of Massachusetts); **J. Cherian, T. Tokumoto and S. McGill** (NHMFL)

**Introduction**

The photophysics of small organic molecules is of foundational importance to the field of physical organic chemistry. One very useful aspect of small molecule photochemistry is the ability to create and stabilize trapped spin states via low temperature photolysis. Open-shell molecules created in this way display unique electronic structure and magnetic exchange interactions that allow investigation of the interplay between charge, structure, and magnetism. A ground or thermally accessible paramagnetic state provides insight into behavior that is very promising for light harvesting, controllable reactivity, and spin valve applications. 1,4-Diazidobenzene attracted our attention in this regard. Like several other aromatic azides, it undergoes a photochemical reaction to yield 1,4-phenylenedinitrene. The latter is persistent spin singlet biradical (T < 90 K) with a low-lying triplet state as shown schematically in Figure 1a. The singlet-triplet gap Δ0 is small enough to allow population changes with temperature and potentially support tuning by magnetic field.

**Results and Discussion**

Figure 1 summarizes our magneto-optical investigation of 1,4-phenylenedinitrene. The rich magnetochromic response occurs because applied field increases the concentration of the triplet state species, which has a unique optical signature by comparison with the singlet biradical and the precursor molecule. Ordinarily, one does not expect a low energy tuning parameter like magnetic field to impact high energy properties like electronic structure. Things are different here because a small spin gap allows an applied field to manipulate the population and (at high enough fields) drive the system into the fully polarized triplet state. A Curie-like analysis of the magneto-optical properties allows us to extract the spin gap, which is much smaller than previously supposed. These measurements establish the value of local-probe photophysical techniques for magnetic property determination in open-shell systems like biradicals where a traditional Curie law analysis has intrinsic limitations.

**Acknowledgements**

This work was supported by the National Science Foundation (DMR-1063880 and CHE-0834011).

**REFERENCES**

Chemistry

First documented case of extreme biomarker enrichment in a production deposit and identification of perylene as the biomarker that is responsible for the blue color of the oil.


Analysis and Identification of Biomarkers and Origin of Color in a Bright Blue Crude Oil

P. Juyal, A.B. Andrews, A. Yen, S.J. Allenson, O.C. Mullins (NALCO); A.M. McKenna (NHMFL, Chemistry); R.P. Rodgers, A.G. Marshall (Florida State Univ., NHMFL, Chemistry); C.M. Reddy, R.K. Nelson, (Woods Hole Oceanographic Institute); E. Atolia (NHMFL)

Results and Discussion

We describe the detailed analysis and characterization of an unusual blue crude oil (Figure 1) and a deposit from the monoethylene glycol (MEG) regeneration unit (MRU) on an offshore crude oil production platform. To characterize the deposit and the components in the crude oil that give it such a distinct blue hue, we investigated the samples with comprehensive two-dimensional gas chromatography (GCxGC), Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS), and two-dimensional (2D) fluorescence spectroscopy. Perylene, a polycyclic aromatic hydrocarbon, known to fluoresce, was identified in the crude oil with all three of these techniques. On the basis of its photochemical properties and abundance (55 ppm), we infer perylene to be the most likely source of the blue color. In addition, we were able to conclusively identify by GCxGC a suite of pentacyclic triterpenoids, of which the most abundant species was 17R(H),21β(H)-25-norhopane. The deposit is greatly enriched in these species. The presence of 25-norhopanes in a crude oil is considered as an indication for severe biodegradation.

Acknowledgements

The authors thank Anadarko Petroleum Corporation for providing the samples and permission to publish the results. Helpful discussions with Bob Buck (Anadarko) are sincerely appreciated. FT-ICR MS was supported by the National Science Foundation (NSF) (DMR-06-54118) and the State of Florida. GCxGC analysis was supported by the Department of Energy (DOE) DE-FG02-06ER15775.

REFERENCES

Geochemistry

The Gulf Oil Spill will undoubtedly be the most studied natural disaster in history. In an initial report by Chanton et al., radiocarbon contents were tracked in the Gulf of Mexico and provide a radiocarbon map of the massive amount of oil that was introduced into the Gulf ecosystem. The oil provides a unique radiocarbon dead organic matter tracer that will be used in future studies to refine the resolution of the path of the oil spill and aid other analytical methods.

Radiocarbon Analysis of the Gulf Oil Spill

J. Chanton (Florida State Univ., Earth, Ocean and Atmospheric Sciences); S. Bosman, A. Mickel (FSU Coastal and Marine Laboratory); S. Joye (Univ. of Georgia, Marine Sciences); C. Brunner (Univ. of Southern Mississippi, Marine Sciences); J. Cherrier and J. Sarkodee-Adoo (Florida A&M Univ., Environmental Science); D. Hollander, (Univ. of South Florida Marine Sciences)

Introduction

The Gulf Oil Spill injected a unique tracer into the Gulf of Mexico, radiocarbon-free fossil organic matter. Most Gulf organic matter is fixed at the surface with a modern radiocarbon (14C) content. We have traced the input of petro-carbon into the Gulf by following input of radiocarbon dead organic matter into the sediments and fauna.

Experimental

Sediment and muscle tissue were ground to a fine powder using an electric mill. Approximately 500 micro-g of tissue for carbon and nitrogen analysis were wrapped in tin capsules for analysis at the National High Magnetic Field laboratory in Tallahassee, FL. Samples were analyzed by using a continuous flow Thermo Delta Plus Mass Spectrometer coupled to a CHNS analyzer. Subsamples were prepared for radiocarbon analysis on the vacuum line of Dr. Yang Wang at the Magnet Lab and measured at the NSF’s National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS), at Woods Hole, MA.

Results and Discussion

This map shows the radiocarbon content of sedimentary organic matter on the seafloor of the Gulf of Mexico. The brighter colors and more negative values on the Delta-14C scale indicate less radiocarbon (14C) and thus more fossil (oil) carbon in the sediments. The SW trajectory of the plume is evident and the results show that the fossil carbon appears to have drifted as far as 150 km away from the oil blowout site which is marked with an x. Fossil carbon inputs are also observed in sediments to the north of the site towards Gulfport. Radiocarbon depleted tissue has been observed in Gulf plankton samples and in oysters from Terrebonne Bay in South Louisiana.

Acknowledgements

We than the Gulf of Mexico Research Initiative, the Northern Gulf Institute and the Florida Institute of Oceanography for funding this work.
Geochemistry

The dominant rocks of the upper part of the Earth’s mantle (peridotites) are much different in isotopic signature than the basalts (extrusive volcanic rock from melting of the Earth’s mantle) although data suggests that the peridotites heavily contributed to the basalts. The current data identifies the most extreme radiogenic isotopic compositions in all of the ocean mantle, confirming proposed ultra depleted and highly heterogeneous regions. The work will provide information on the degree of melting and age of these regions in the Earth’s crust.

Ultra Depleted Mantle at the Gakkel Ridge Based on Hafnium and Neodymium Isotopes

V. Salters, A. Sachi-Kocher (NHMFL & Florida State Univ., EOAS); H. Dick (Woods Hole Oceanographic Institute)

Introduction

The Gakkel Ridge is one of the slowest spreading ridge segments in the global ridge system with some of the thinnest oceanic crust. In some locations there is little or no evidence for volcanic activity and the oceanic mantle is exposed directly to the ocean floor. This provides an excellent opportunity to investigate the heterogeneity of the oceanic mantle in situ.

Experimental

We have analyzed a number of peridotites from the western end of the Sparsely Magmatic Zone (3° to 28°E) for Hf and Nd isotopic compositions by multi-collector ICP-MS. In addition we analyzed diopsides for major and trace element analysis using the single collector magnetic sector ICP-MS. All analyses were conducted at the NHMFL.

Results and Discussion

The samples (red symbols) we analyzed range to extremely radiogenic isotopic composition; i.e. the most radiogenic in Nd and Hf-isotopic composition of all ocean mantle. All but two samples are more radiogenic in either Nd or Hf than MORB. Four samples lie in the extension of the OIB MORB array with εNd up to 23.7 and εHf up to 54.6. The remainder of the data falls above the OIB-MORB array and its extension with εNd values up to 27.4 and εHf values up to 291! This data confirms the ultra depleted nature of the Gakkel Ridge mantle proposed by Stracke et al.1 and its highly heterogeneous nature as proposed by Liu et al.2 Since the Hf and Nd system is expected to have correlated fractionations during melting we can add melt back into the peridotites until the Hf and Nd model age coincide. This will provide information on both the degree of melting and the age. Gakkel Ridge peridotites seem to have very little melt extracted from them (<1%) and have model ages that ranges from 2.4Ga to future ages with most between 600Ma and 1.2 Ga.

The Hf and Nd isotopes are best correlated with Sm/Yb whereby high Sm/Yb samples have unradiogenic Hf and Nd. The Cr# of the spinel is relatively low for all the samples (<30), although all samples have a LREE depleted character with Yb(N) between 8 and 3 and La(N) between 0.8 and 0.1. The Gakkel Ridge basalts form the radiogenic Hf-end of the MORB field (S. Goldstein pers.comm.), and although the peridotites are far out of isotopic equilibrium with the basalts, Hf-Nd systematics indicates that the peridotites have contributed to the basalts. The relatively depleted nature of the peridotites requires that a relatively large amount of peridotite has to contribute to the melts. Apart from documenting the heterogeneous nature of the MORB mantle, it also indicates that in addition to MORB-like mantle a far more depleted mantle exists. Based on abyssal peridotite trace element compositions and on melting calculations, these extreme peridotites could have an unusually complicated history, and this might not be the first time they are passing through a ridge melting regime. It is likely that they may represent ancient residual lithosphere. Because these peridotites are already depleted they will contribute little in terms of major elements or incompatible trace elements to the melts. The Hf-Nd isotope variations in MORB, whereby MORB from individual ridge segments form parallel arrays, can also be explained by the existence of a highly depleted component like residual lithosphere: ReLish3.

Acknowledgements.

This research was supported by NSF OCE 0930429 to Salters.

REFERENCES
Magnetic Resonance Technique Development

Lithium-ion batteries have been the power sources of choice for portable electronics and are of growing use for large scale devices such as plug-in and hybrid electric vehicles. Solid state NMR spectroscopy has been used as a powerful tool for characterization and development of new electrode materials. The following report presents a new NMR technique developed jointly by scientists at the NHMFL and University of Cambridge for obtaining high-resolution magic-angle spinning spectra of many paramagnetic lithium-ion battery materials. The new technique can average anisotropic paramagnetic broadening up to 1MHz, far beyond any practically achievable sample spinning rate. The technique also solves a general problem solid state NMR at high magnetic fields, that of increasing anisotropic broadening.


Obtaining Isotropic NMR Spectra of Paramagnetic Battery Materials with Large Anisotropic Broadening

I. Hung, Z. Gan (NHMFL); L. Zhou, F. Pourpoint, C.P. Grey (Cambridge)

Introduction

The use of Li-ion batteries as power sources for portable electronic devices such as laptops and cell phones, has grown dramatically. New positive and negative electrodes have been developed during the past 30 years to address issues of stored energy density, charge and discharge rates and service life1,2 and solid-state 6/7Li NMR has played an important role in characterizing these materials and the changes of the Li local environment during charge and discharge processes3. Many Li-ion battery materials are paramagnetic and their solid-state NMR (ssNMR) spectra are often crowded with overlapping spinning sidebands (ssbs) due to the large anisotropic paramagnetic shift even under very fast magic-angle spinning (MAS). This report presents the use of a magic-angle turning phase-adjusted sideband separation (MATPASS)4,5 method under fast spinning frequencies to separate ssbs and yield ssNMR spectra as if MAS is infinitely fast6. This MAT experiment only employs π/2-pulses, providing a broad excitation bandwidth, and is thus suitable for application to paramagnetic lithium battery materials with anisotropy of >1 MHz.

Experimental

Experiments were performed on a 19.6 T superconducting magnet equipped with a Bruker DRX console and a home-built 1.8 mm single-resonance probe at 30-34 kHz MAS.

Results and Discussion

Figure 1a shows a fast MAS (34kHz) spectrum of a cathode material Li2FeSiO4 after four charge-discharge cycles. The spinning is not fast enough to enhance the resolution of the broad signal centered at ~300 ppm (the sharp peaks are from impurities). The MATPASS experiment separates the ssbs according to their order (Figure 1d). A subsequent shearing and projection results in an isotropic MAS spectrum.

![Figure 1](image-url)

**FIGURE 1.** a. 7Li MAS spectrum of charged Li2FeSiO4 following four charge-discharge cycles. b. Expansion of the resonances from 0 to 720 ppm from the (c) isotropic spectrum of charged Li2FeSiO4 obtained from summation of the ssbs after F2 shearing of the (d) 2D MATPASS spectrum. e. 31P NMR stimulated-echo spectrum of Li3Fe2(PO4)3 obtained by taking the skyline projection of several spectra acquired at carrier intervals of 300 kHz. f. Isotropic projection obtained after F2 shearing of the (c) 2D MATPASS spectrum. The 2D MATPASS spectrum was acquired as two segments using the carrier positions Tx1 and Tx2. Dashed circles enclose aliased spinning sidebands due to insufficient number of t2 increments.
spectrum without any sidebands, as if the spinning speed is infinitely fast. The expansion around ~300 ppm (Figure 1b) reveals that the broad and featureless signal in Figure 1a is actually comprised of multiple isotropic resonances that spread over a range of about 800 ppm (>250 kHz). The result demonstrates that this new NMR technique can be applied for paramagnetic battery materials to resolve lines with width and anisotropy far larger than practically achievable MAS speeds. Fig 1e-g show an application to the 31P nuclei in Li3Fe2(PO4)3 that have even shorter T1 and T2 relaxation times than 7Li. Using the 2D MATPASS experiment at a single B0 field and MAS frequency, three isotropic resonances can be identified in the broad spectrum of Figure 1e (>1.2 MHz), allowing for chemical shift measurement of individual peaks. Previously, multiple B0 fields and varying MAS frequencies were necessary to resolve the interplay between the effects of sample heating and spinning sideband positions upon change of spinning speed just to identify the peaks form the spinning sidebands6. The sideband-less feature of the MATPASS technique should greatly facilitate the use of 31P NMR as an additional probe for the characterization of phosphorus-containing Li-ion battery materials.

Conclusions
It has been shown that isotropic spectra for 7Li and 31P nuclei with very short T1 and T2 relaxation times due to paramagnetic shift anisotropy can be obtained using the projection-MATPASS technique.

Acknowledgements
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REFERENCES
**Magnetic Resonance Technique Development**

This report is interesting in its application of ultrashort TE (UTE) imaging to a novel problem. UTE imaging is generating a tremendous amount of excitement in the imaging community due to its ability to observe at protons with very short TEs typically representing bound water in bone, cartilage, or in this case in solid foams. UTE measurements require special imaging sequences and coils (which do not produce significant background at these short echo times). Whereas the application is of general interest due to the NASA connection, what is of real value is showing that the 900MHz can be used to perform UTE imaging opening up a host of different future user applications.


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**MRI of Absorbed Water in Solid Foams Using 21.1 T**

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**Introduction**

In a number of practical situations there is a critical need to evaluate the distribution of small amounts of water absorbed throughout a solid foam sample. One of these pertains to Spray On Foam Insulation (SOFI) NCFI 24124, a thermal insulation material used on the liquid hydrogen and oxygen tanks of the Space Shuttle at Kennedy Space Center (KSC). However, several problems including infinitesimal amounts of water and inevitable water binding to the foam makes the MR signal weak especially for high resolution MRI. The 900 MHz Ultra wide bore (UWB) NMR spectrometer provides a unique opportunity to perform this evaluation due to its high MRI sensitivity at 21.1 T and its ability to examine large volume samples. The recent upgrade of the UWB 900 MHz MRI scanner (August, 2010), allows for ultra-short echo time (UTE) 3D MRI performance. The standard MR imaging technique in this case is not suitable, as it will yield a zero signal. Here we report the first 3D MR images of bound water and water content in solid foam NCFI 24124 samples conditioned to match launch pad conditions. Full Paper published in *International Journal of Heat and Mass Transfer* 3.

**Experimental**

Foam samples were launch pad conditioned (LPC) for either 69 hours or 9.5 hours in a rig that subjects one side of the foam to 34 ± 2 °C (mean ± standard deviation) air with a relative humidity greater than 75% with the other side in contact with a cold plate at 77 K. These conditions are similar to those experienced by the foam on the NASA-KSC launch pad. The foam requires low thermal conductivity and durability. However, the cold surface is thought to draw water from the humid ambient air into the insulation, which KSC studies have shown can increase the weight of the insulation by as much as 30%-85%. This water adsorption translates to several thousand additional pounds on the shuttle1. A new RF coil was constructed with materials lacking free protons, which dramatically reduced previously noticed background signals.

**Results and Discussion**

The average unprepared (as received) foam sample mass was 46.5 ± 2.2 mg. The 69-hour LPC samples gained an average 132 mg of water while a 9.5-hour conditioned sample resulted in an average gain of 23 mg. Sections void of water can be seen in 1a as two black bands, known as knit lines, dense areas between foam layers created in the application process. The dimensions of the majority of the cells range from 150-450 μm, and are elongated in the rise direction. Many of the cells near the knit lines decrease in size to less than 50 μm. The experiment has been successfully repeated with a larger RF coil bore of 20 mm.

**Conclusions**

The capability for ultra short echo time MRI with TE ~ 50 µs is expanding the area of MR imaging analysis which can be performed at the NHMFL. The first experiments demonstrated accumulation of water in the insulation foam and represent an opportunity to perform an evaluation of the new insulation materials. Transitions in the knit lines layering are constrictions in the water flow path and
if increased in number, might be used as tools in minimizing water absorption. An overall pore size reduction may also reduce water absorption but the advantages must be balanced with the disadvantages of increased weight in denser foam.

Acknowledgements

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REFERENCES

Biochemistry

Knowing structure and dynamics is essential to understand the functioning of proteins and other bio-molecules. Polenova's group at U. Delaware uses solid-state NMR to gain atomic-level insight on the structure and dynamics of HIV-1 protein assemblies and their interactions with host proteins and small-molecule inhibitors. They have found that the tubular assemblies of capsid CA protein and capsid-spacer peptide 1 (CA-SP1) of Gag polyprotein from HIV-1 virus yield better spectral resolution than the conical and spherical shaped assemblies. They have obtained high-resolution multi-dimensional spectra of the tubular proteins using the 900MHz field and low-E triple resonance MAS probe, both are important for spectral assignment and dynamics measurement of the 231-residue protein stabilized in high-salt concentration.

• Supported by the MagLab User Collaboration Grants Program

Solid-State NMR Structural and Dynamics Studies of HIV-1 Protein Assemblies Using 21T and Low-E Probe

Y. Han, G. Hou, C. Suiter, T. Polenova (Univ. of Delaware, Dept. of Chemistry & Biochemistry); Z. Gan, W. Brey, I. Hung, P. Gor'kov (NHMFL)

Introduction
Gag polyprotein from HIV-1 virus is responsible for the assembly of virions from infected cells. Gag and its two products, capsid CA protein and capsid-spacer peptide 1 (CA-SP1) are the focus of this research. CA organizes and protects the viral genome by assembling into conical capsids. Following viral entry into the host, CA disassembles to allow release of the viral genetic material into the host cytoplasmic compartment (uncoating). CA and the Gag processing intermediate CA-SP1 have recently become attractive targets of HIV-1 uncoating and capsid maturation inhibitors. Despite the promise of targeting CA maturation and uncoating processes by novel inhibitors, the current research is hampered by lack of understanding of the molecular mechanisms of the maturation and uncoating and of their temporal regulation, and detailed atomic-resolution structural and dynamics information of the assembled Gag, CA, and CA-SP1 is still lacking. The objective of our ongoing work is to gain atomic-level insight on structure and dynamics of these HIV-1 protein assemblies and their interactions with host proteins and small-molecule inhibitors through state-of-the-art solid-state NMR spectroscopy.

Experimental
Solid-state NMR spectra were acquired at 21.1 T (900 MHz) on the ultra-wide bore 105 mm NMR magnet, outfitted with a 3.2 mm Low-E triple-resonance HXY probe developed and built at NHMFL. 2D MAS homo- and heteronuclear correlation spectra (DARR, NCA, and NCACX) were acquired on U-13C,15N-labeled CA and CA-SP1 assemblies of tubular morphology. All spectra were processed in NMRPipe and analyzed in Sparky.

Results and Discussion
In vivo, the 231-residue CA protein assembles into cone-like capsid structures containing about 1500 copies of the protein and enclosing the viral RNA genome. Significant heterogeneity in shape and in size of CA capsids has been observed in mature HIV-1 virions. In vitro, both CA and CA-SP1 proteins exhibit structural polymorphism, and assemblies of conical, tubular, and spherical shapes can be produced. We have established the conditions for the assembly of CA into the main three morphologies for solid-state NMR spectroscopy, have assigned two thirds of the residues and characterized the secondary structure of the conical CA assembly. Despite the generally high resolution of the 900 MHz spectra of conical capsids, lines are somewhat broader than in microcrystalline proteins, making it challeng-
ing to perform detailed structural characterization in U-^{13}C,^{15}N isotopically enriched protein. We have turned our attention to tubular assemblies of the above proteins and discovered that those yield lines as narrow as those in microcrystalline proteins. Most recently, thanks to the enhanced-design Low-E triple-resonance MAS probe developed at NHMFL we have collected excellent-quality homo- and heteronuclear 2D correlation spectra of CA and CA-SP1 assemblies (Figure 1) at 21.1 T. With these data in hand, we expect to gain detailed structural and dynamics information of CA alone and interacting with host cell proteins and small-molecule inhibitors.

**Conclusions**

Excellent-quality 2D MAS NMR spectra were collected at 21.1 T for tubular CA and CA-SP1 assemblies that will permit detailed structural and dynamics characterization of HIV-1 protein assemblies.

**Acknowledgements**

This work was supported by the National Institute of General Medical Sciences (NIH Grant P50GM082251) and is a contribution from the Pittsburgh Center for HIV Protein Interactions.

**REFERENCES**

Introduction

Cellular membranes are comprised of a diverse set of lipids (>1,000 different lipid species), and exhibit lateral heterogeneity (e.g. lipid rafts, lipid microdomains), transbilayer asymmetry, chemical and electrical gradients, dynamics, and various shapes. Furthermore, biological membranes are crowded and contain as much protein as they do lipid. Although the unique lipid environment is a major determinant of membrane protein conformation and function, information about protein structure in biological environment is scarce. Here, we demonstrate the feasibility of characterizing the structure of the transmembrane domain (TM) of a human APP binding protein, LR11, in situ in E. coli membranes by using solid-state magic-angle spinning (MAS) NMR.

Experimental

The preparation of LR11 TM in E. coli membranes has been described. NMR spectra were collected on a NHMFL 600 MHz spectrometer with a Bruker 4 mm or a homemade 3.2 mm low-E MAS probe.

Results and Discussion

Using $^{13}$C-$^{13}$C PARIS data (Figure 1a) collected with different mixing times on a sample of LR11 TM in native E. coli membranes, we have readily assigned 12 out of 23 residues of the LR11 TM. All assigned residues show characteristic secondary shifts of an α-helix and are in agreement with the secondary shifts of LR11 TM in DPC micelles (Figure 1b) except for residue Ala2156. This residue is near the C-terminus of the predicted TM domain and resides in the membrane-solution interface region, where there are substantial differences between bilayers and micelles and where structural discrepancy likely occurs.

Acknowledgements

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REFERENCES

The most common hereditary peripheral neuropathies are the axonal form of Charcot–Marie-Tooth (CMT) diseases caused by mutant proteins which gain new functions due to their altered protein structure. Despite this, previous crystal structures showed little conformational difference between dimeric wild-type and CMT-causing mutant proteins. In this report different mutant proteins were investigated in solution by hydrogen-deuterium exchange (monitored by mass spectrometry) and small-angle X-ray scattering to uncover structural changes that exposed the same conformational cleft that is mostly buried in the wild-type protein.


Results and Discussion

The question of how dispersed mutations in one protein engender the same gain-of-function phenotype is of great interest. Here we focus on mutations in glycyl-tRNA synthetase (GlyRS) that cause an axonal form of Charcot–Marie-Tooth (CMT) diseases, the most common hereditary peripheral neuropathies. Because the disease phenotype is dominant, and not correlated with defects in the role of GlyRS in protein synthesis, the mutant proteins are considered to be neomorphs that gain new functions from altered protein structure. Given that previous crystal structures showed little conformational difference between dimeric wild-type and CMT-causing mutant GlyRSs, the mutant proteins were investigated in solution by hydrogen-deuterium exchange (monitored by mass spectrometry) and small-angle X-ray scattering to uncover structural changes that could be suppressed by crystal packing interactions. Significantly, each of five spatially dispersed mutations induced the same conformational opening of a consensus area that is mostly buried in the wild-type protein (see Figure 1). The identified neomorphic surface is thus a candidate for making CMT-associated pathological interactions, and a target for disease correction. Additional results showed that a helix-turn-helix WHEP domain that was appended to GlyRS in metazoans can regulate the neomorphic structural change, and that the gain of function of the CMT mutants might be due to the loss of function of the WHEP domain as a regulator. Overall, the results demonstrate how spatially dispersed and seemingly unrelated mutations can perpetrate the same localized effect on a protein.

Acknowledgements

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REFERENCES

Biology

Acquired Immunodeficiency Syndrome (AIDS) is a world-wide epidemic caused by HIV-1. Although numerous pharmaceuticals that are inhibitors against viral replication are effective in controlling AIDS, there is currently no cure or vaccine to prevent AIDS. Towards the goal of developing a vaccine for AIDS, the structural organization of viral envelope proteins within membranes was determined. These structural hierarchies form the basis of vaccine development for the prevention of virus entry into host cells.

- Supported by the MagLab User Collaboration Grants Program

Antibody-Mediated Mechanics on a Membrane-Embedded HIV gp41 Segment by EPR

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**Introduction**

A vaccine capable of stimulating protective anti-viral antibody responses is needed to curtail the global Acquired Immunodeficiency Syndrome (AIDS) epidemic caused by HIV-1. Broadly neutralizing antibodies (BNAbs) such as 2F5 are directed against the HIV-1 gp41 membrane proximal external region (MPER) and recognize well-defined linear core sequences\(^1\). How 2F5 interacts with its lipid-embedded epitopes and mediate anti-viral activity is unclear. Here, site-directed spin labeling and electron paramagnetic resonance spectroscopy (SDSL-EPR) were used to define 2F5 induced conformational changes in the MPER relative to the membrane, and the effect of key residue mutations.

**Results and Discussion**

EPR was used to determine membrane immersion depth changes of spin-labeled MPER residues upon wild type (wt) and mutant 2F5 Fabs binding. 2F5 wt lifts deeply buried residue L669R\(^1\) and W670R\(^1\) from the acyl chain region of lipid into the aqueous phase and the head group region, respectively (Figure 1A, only W670R\(^1\) is shown). In contrast to wt 2F5, 2F5 mutants (F100BS, L100AS and I100FS) - induced immersion depth changes of L669R\(^1\) and W670R\(^1\) were attenuated. The reduced immersion depth changes by 2F5 mutants are correlated well with their decreased neutralization potency comparing to wild type 2F5 (not shown). Of note, comparable EPR mobility spectra changes found for L669R\(^1\) and W670R\(^1\) indicate the presence of similar MPER conformations at the antibody binding interface for the wt and three 2F5m Fabs (Figure 1B). These results have been published in *Nature Struct. Mol. Biol.*\(^2\).

**Conclusions**

The results suggest that mutations at different positions in 2F5 antibody differentially affect the degree of reorientation of the N-helix in the MPER. The apex of the 2F5 CDRH3 loop, including F100B, L100A and I100F, is critical for mediating MPER reorientation and epitope extraction from membrane. The results have important implications for structure-aided HIV vaccine design.

**Acknowledgements**

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**REFERENCES**

Biology

During cancer progression, especially after drug interventions, tumors develop new mechanisms permitting them to resist chemotherapeutic interventions. Consequently, there is a crucial need for a method to detect changes in tumor resistance. This study represents a discovery that sodium MRI has the capability to promptly and noninvasively detect changes in drug resistance prior to the initiation of tumor therapy. Thus, the method can predict and, therefore, avoid implementation of unsuccessful tumor therapies.

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Tumor Resistance and in vivo Sodium MR Imaging at 21.1 T

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Introduction
Cancer progression, especially drug intervention, triggers tumors’ cellular mechanisms permitting them to resist chemotherapeutic interventions. The same type of tumor in the same anatomical place can have a wide range of resistance to therapy. Unfortunately, resistance is usually diagnosed long after drug administration by noting changes in tumor volume. To formulate prompt and individualized treatments, it is important to evaluate tumor resistance before therapy. Mitochondria play a central role in energy metabolism as well as apoptosis and are directly associated with the changes in tumor resistance. We hypothesize that a shift to more efficient energy metabolism in resistant tumors is affecting tumor sodium homeostasis. In this way sodium MRI (Figure 1, left) has a unique potential to detect changes in tumor resistance. It is of the utmost importance that alterations in tumor resistance can be detected noninvasively and quickly prior to treatments.

Experimental
Six male CDF rats (weight ~ 150 g) were implanted intra-cranially with two types of 9L gliosarcoma cells. Later, in 10 days, the MRI experiments were conducted at the NHMFL 21.1 T MRI scanner using an NHMFL-designed double tuned sodium/proton in vivo MRI probe. Sodium 3D back-projection MRI scans with resolution of 0.5x0.5x0.5 mm, FID acquisition delay ~0.1 ms and scan time of 27 min were acquired using the Bruker Avance III console. All experiments were conducted according to the animal protocols approved by The Florida State University ACUC.

Results and Discussion
Sulforodamine assay of the resistant glioma cells (Fig. 1, center) performed before tumor implantation to animal showed a carmustine resistance of 24.7 µM, while for naïve glioma it was 7.8 µM. In vivo, sodium concentration in tumor from resistant tumor cells was 127% relative to a normal contra-lateral brain, while in tumor from the naïve glioma it was 173% (Fig. 1, right).

Conclusions
Changes in tumor resistance can be sensitively detected by sodium MRI and tumor response can be predicted prior to treatments, thus helping to avoid unsuccessful therapies. The suggested approach is based on the energy status of tumors, indicating it may have a predictive capability for different chemotherapeutic drugs beyond carmustine used in this study. The finding warrants further investigation and confirmation for other tumor types.

Acknowledgements
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REFERENCES
Introduction

The two most common forms of cognitive disorders that induce dementia are Alzheimer’s disease (AD) and diffuse Lewy Body disorder (DLBD). Although these conditions differ histopathologically such that AD is associated with amyloid (Aβ) plaques and neurofibrillary tangles while DLBD is an α-synucleinopathy, clinical similarities make it difficult to distinguish between them. In pathological animal and human tissue, Aβ plaques appear to coincide with iron-induced hypointensities observed in T2- and T2*-weighted MR images. Similarly, the presence of Lewy bodies, or rather α-synuclein, also has been linked to increases in iron content.

Experimental

Fixed postmortem specimens harvested from sex- and age-matched patients displaying AD (n=13) and DLBD (n=7) were compared to healthy subjects (n=6). MR data were acquired using a 21.1-T, ultra-widebore (105-mm) vertical magnet. Utilizing a 33-mm birdcage coil, 3D Fast Low Angle Shot (FLASH) images were acquired at an isotropic resolution of 50 μm over 4.3 hours at 14 °C. T2- and T2*-weighted multiple gradient recalled echo (GRE) and T2-weighted spin-echo (SE) sequences were acquired over a range of echo times to generate relaxation maps. Multi-slice diffusion-weighted spin echo (DWSE) sequences with four diffusion weightings (b values = 0-1500 s/mm2) also were acquired. Separate manually drawn regions of interest (ROIs) were traced over the temporal lobe white matter (TLWM), parahippocampal gyrus (PHCG), subiculum (Sub), CA1 and the entire hippocampus (HC). Histology included stains for iron (Prussian Blue, PB) and ferritin-L. Neural density and vacuolation were quantified with hematoxylin & eosin (H&E).

Results and Discussion

High resolution datasets, parametric relaxation maps and regional quantification of T2 and T2* provided significant distinctions between healthy and pathological specimens diagnosed with AD or DLBD. With respect to T2 and T2*, the largest difference from...
controls and AD was identified TLWM while DLBD showed the largest impact on the PHCG. This data suggests that lower T₂ and T₂* times are correlated with chronic DLBD rather than chronic AD or control sections while increased relaxation values and ADC coincide with chronic AD pathology. H&E for vacuolization indicated a larger loss of cells and neuropils in AD compared to both controls and DLBD. While T₂ times correlated with vacuolation in TLWM, PHCG and CA1 and inversely with ferritin in TLWM and CA1, neural count did not correlate with either T₂ or T₂*.

**Conclusions**

This work suggests that it is possible to differentiate quantitatively between neurologically healthy brain tissue and pathological specimens diagnosed with AD or DLBD. Though histological findings correlate well with relaxation, relatively low %PB and high %Fer detected in AD and DLBD cases may indicate chronic brain iron deficiencies.

**Acknowledgements**

Funding was provided by the NSF (NHMFL User Collaborations Grant Program to SCG).

**REFERENCES**

The International Conference on Molecule-based Magnets (ICMM) is the largest international conference on the research field of “Molecule-based Magnetism.” This meeting focuses on the magnetism of molecules and molecular-based materials, i.e. the design, synthesis and evaluation of artificial spin systems composed of organic radicals, transition metal complexes, and composite materials.

This “field” of research has grown tremendously over the past two decades and is an enormously interdisciplinary endeavor. In keeping with tradition, this meeting will cover a diverse range of topics including (but not limited to): synthesis of magnetic molecules and materials; magnetic properties of organic radicals, coordination complexes, metal-radical systems; nanomagnetism; multi-property magnetic materials; theoretical approaches.

ICMM is a highly interdisciplinary conference that attracts around 400 physicists, chemists and materials scientists. Attendees are usually a mix of theorists and experimentalists, and many are users of the MagLab.

DATES TO REMEMBER

June 15, Friday
- Full registration starts

August 15, Wednesday
- Abstract submission ends

September 1, Saturday
- Final circular (Final program announced)
- Online registration ends

October 7, Sunday
- Conference, on-site registration and proceedings submission

CHAIRMED BY

Stephen Hill (MagLab) and Enrique del Barco (UCF)

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http://icmm2012.us
The MagLab Renewal Proposal: What’s in it anyway?

DC Field Initiatives

32 T HTS Magnet
A 32 T all-superconducting magnet will be made available for users partnered with a 20mK dilution refrigerator to provide unprecedented fields for ultra low noise, low temperature measurements. A second 32 T HTS magnet will be built and commissioned for 0.3-300 K user operations.

28 MW Resistive Magnets
New resistive magnets will be built that will push peak fields in the workhorse resistive magnets to 41T in a 32 mm bore and 36T in a 50 mm bore magnet.

Series Connected Hybrid Magnet
The Series Connected Hybrid will be built with 36 T high homogeneity inserts (40 mm bore) and 41 T high-field insert (32 mm bore). This magnet will consume only 14 MW of power, making it a cost effective platform for lengthy high field measurements such as NMR and heat capacity.

Operations and hours
Weekend operations will be phased in on a limited basis for experiments that will benefit from long uninterrupted run times up to 48 hours. The Series Connected Hybrid will run in parallel with the 45 T hybrid, extending the number of users that can be run. This, together with limited weekend operation, will extend the availability of user time by 25%.

Infrastructure Replacement
Aging infrastructure in the DC facility will be replaced and upgraded, improving reliability and limiting unplanned downtime.

Nuclear Magnetic Resonance

900 UWB magnet
To take additional advantage of the 900 UWB magnet, Ultra-Low-E probes, developed at the MagLab, will reduce the destructive heating caused by the high radio-frequency fields and lead to a reduction in signal averaging time by a factor of two allowing for more than 50% increase in experiments and users on this world-unique instrument.

Dynamic Nuclear Polarization
We propose to develop DNP technologies by combining existing MagLab expertise in NMR, EMR and probe construction to significantly enhance the NMR capabilities. The first step is to implement DNP magic angle spinning (MAS) solid state NMR experiments at 9.4 T at temperatures of ≤25 K, where several orders of magnitude less microwave power will be needed than is typical of commercial DNP operation at 90 K.

Electron Magnetic Resonance

This renewal will expand the capabilities of continuous-wave spectrometers and probes to function in the 45 T Hybrid Magnet, the direct-optical-access 25 T Split Magnet and the 36 T/1 ppm Series Connected Hybrid, which will enable user research on strong spin-orbit coupled metal ions and bring increased resolution to EMR of spin labeled- macromolecules and biochemically relevant radicals.
Pulsed Field Facility

100 T Magnet
We will develop a 100 tesla operating field for qualified users. We need to ensure that users get reliable fields for every shot. An engineering margin will be developed to make 100 tesla pulses routine in our big multi-shot magnet. The outer coils will be upgraded with 21st century wire technology to achieve this goal.

200 T Magnet
A single turn magnet is way for users to get to magnetic field far in excess of 100 tesla. The NHMFL-PFF has a single turn magnet that will be integrated into the NHMFL user program. The magnet is intentionally destroyed each shot but the user’s sample survives the 6 microsecond trip to fields beyond 200 tesla.

HiVCap
Advances in pulsed magnet design and materials technology can be taken advantage of by using higher voltage power supplies coupled with our large magnet outer magnet systems. We will develop a high voltage power supply to take advantage of these elements and bring users even higher magnetic fields without destroying the magnet coils.

GenControl
We will update the controls of the system that is used to deploy the massive amounts of pulsed energy to our biggest user magnet systems. Reliability of our 1.43 Gigawatt generator system is of paramount importance to our user program. The controls of the system will be modernized to accomplish reliability and advances in generator control hardware.

HiStrength
We will advance pulsed magnet wire technology by developing new materials that are commercially available.

Duplex
By taking advantage of a capacitor driven outer magnet system higher fields can be achieved for our users while keeping the Joule heating to a minimum. A new Duplex magnet has been developed and we will deploy the new system.

Ion Cyclotron Resonance

New instrumentation
Projected applications for the new FT-ICR instruments will focus on complex mixtures best addressed by high resolution mass spectrometry: petroleomics, lipidomics, proteomics, metabolomics, environmental contamination, etc.; and H/D exchange to map contact surfaces in protein complexes larger than currently accessible.

New ionization methods
The ICR program will continue to complement our instrumentation developments with parallel pursuit of new ionization methods. Promising current directions include novel combinations of laser-induced acoustic desorption, chemical ionization, and corona discharge ionization.

High B/T

Expanded access
We will open a third nuclear demagnetization station capable of carrying out experiments to 0.1 mK in 10 T. The third station will be include high level screening for an ultra-quiet environment. This expansion will reduce the waiting time for users to obtain magnet time.

High pressure capability
The current parameter space will be expanded from ultra-low temperatures and high fields (up to 16 T) to include high pressure capability (2-3 GPa) for user experiments at millikelvin temperatures.
