Heusler Alloys for Spintronic Devices

July 30 - 31, 2015

University of Minnesota

Minneapolis, MN, USA

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Heusler Alloys for Spintronic Devices

Thank you for attending the “Heusler Alloys for Spintronic Devices” workshop at the University of Minnesota in Minneapolis, Minnesota, July 30 – 31, 2015. The workshop has been organized by The Center for Spintronic Materials, Interfaces, and Novel Architectures (C-SPIN), one of six centers of STARnet, a Semiconductor Research Corporation program, sponsored by MARCO and DARPA.

Materials with 100% spin polarization and high perpendicular magnetocrystalline anisotropy have been the ideal for next generation spintronic memory and logic devices. Heusler alloys are a candidate for such materials and have been extensively studied over the past decade. There have been some promising results, but many roadblocks remain. This workshop candidly discusses these promises and challenges by bringing together leading experts working in this field.

Workshop Organizers

William H. Butler, University of Alabama

Paul Crowell, University of Minnesota and C-SPIN Co-director

Jian-Ping Wang, University of Minnesota and C-SPIN Director

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Center for Spintronic Materials, Interfaces, and Novel Architectures
Department of Electrical and Computer Engineering
University of Minnesota
200 Union Street SE
Minneapolis, MN 55455

Phone: (612) 626-0375
Fax: (612) 625-4583
cspin@umn.edu
www.cspin.umn.edu

Heusler Alloys for Spintronic Devices

July 30-31, 2015
University of Minnesota, Minneapolis, MN

Thursday, July 30

8:30 AM	**Jian-Ping Wang,** University of Minnesota and Director of C-SPIN Welcome and Opening Remarks
8:40 AM	**Gilroy Vandentop,** Director STARnet Program Welcome and Opening Remarks
8:45 AM	**Avram Bar-Cohen,** DARPA Welcome and Opening Remarks
8:50 AM	**Plenary Talk** **Ian Young,** Intel *Spintronic Logic and Memory Devices: Prospects and Challenges*
9:40 AM	**William H. Butler,** University of Alabama *Heusler Alloys*
10:15 AM	**COFFEE BREAK.** Keller Hall, room 3-176.
10:45 AM	**Claudia Felser,** Max Planck Institute for Chemical Physics of Solids *Magnetism in Mn2-Heusler Compounds*
11:20 AM	**Kanta Ono,** High Energy Accelerator Research Organization (KEK) *X-Ray and Neutron Analysis of Heusler Alloys*
11:55 AM	**Günter Reiss,** Center for Spinelectronic Materials and Devices, Department of Physics, Bielefeld University *Heusler Compounds in Magnetic Tunnel Junctions*
12:30 PM	**Lunch** Lunch will be on your own. Please see campus map on pages 26-27 of this program for a list of dining options.
2:00 PM	**Gautam Shine,** Stanford University *Modeling Transport in Heusler-Based Spin Devices*
2:35 PM	**Koki Takanashi,** Tohoku University *CPP-GMR and Related Phenomena in Half-Metallic Heusler Alloy Systems*

Thursday, July 30

3:10 PM	**Oleg Mryasov,** Western Digital *Electronic Structure, Spin Transport, and Magnetic Anisotropy in Selected Cubic Heusler, Tetragonal, and Hexagonal Heusler-like Alloys*
3:45 PM	**COFFEE BREAK.** Keller Hall, room 3-176.
4:15 PM	**Matthew Carey,** Spin Transfer Technologies *Heusler Compounds for CPP-GMR Heads and MRAM*
4:50 PM	**Kazuhiro Hono,** National Institute for Materials Science and University of Tsukuba *Heusler-Alloy-Based Magnetoresistive Devices with High MR Outputs*
5:20 PM	End of Day 1.
6:30 PM	**Social Hour,** The Heritage Room, McNamara Alumni Center. Please see the campus map of pages 26-27 of this program for directions to McNamara Alumni Center.
7:30 PM	**Dinner**

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Friday, July 31

8:30 AM	**Chris Palmstrøm,** University of California, Santa Barbara *Heusler Compound/III-V Semiconductor Heterostructures*
9:05 AM	**Hiroaki Sukegawa,** National Institute for Materials Science *Interface-Induced Perpendicular Magnetic Anisotropy and Giant Tunnel Magnetoresistance in Co_2FeAl Heusler Alloy Based Heterostructures*
9:40 AM	**Paul Crowell,** University of Minnesota *Spin Transport in Epitaxial Heusler Alloy/III-V Semiconductor Heterostructures*
10:15 AM	**Martin Jourdan,** Johannes Gutenberg University, Mainz, Germany *100% Spin Polarized Surface Resonance in the Half Metallic Heusler Compound Co_2MnSi*
10:50 AM	**COFFEE BREAK.** Keller Hall, room 3-176.
11:20 AM	**Richard James,** University of Minnesota *Transformational Multiferroic Heusler Alloys and Energy Conversion*
11:55 PM	**Chris Leighton,** University of Minnesota *Magnetic Phase Competition in Off-Stoichiometric Heusler Alloys: $Ni_{50-x}Co_xMn_{25+y}Sn_{25-y}$*
12:30 PM	**Atsufumi Hirohata,** University of York *Heusler Alloy Films for Spintronic Devices*
1:05 PM	**Paul Crowell,** University of Minnesota and C-SPIN Codirector Closing Remarks
1:10 PM	End of Workshop. Thank you for your participation!

ABSTRACTS

Ian Young, Intel

Spintronic Logic and Memory Devices: Prospects and Challenges

Abstract: Continued scaling of computational efficiency may be achieved via gradual introduction of new materials and computational state variables. In particular, for spin based computing and memory, novel materials and devices are essential to meet the demands of non-volatile embedded memory as well as logic. However, such devices also need to be scalable and have low error rates. We will look at the material requirements for anisotropy and saturated magnetization. We will also place this in the context of RA product scaling for memory. We will give an example of a spin logic device which benefits from improvements in magnetic material properties. We will also comment on non-volatility and retention errors.

Speaker Bio: Ian Young is a Senior Fellow and director of Exploratory Integrated Circuits with the Technology and Manufacturing Group of Intel Corporation, Hillsboro, Oregon. He leads a research group exploring the future options for the integrated circuit in the beyond CMOS era.

He received the B.E.E and the M. Eng. Science, from the University of Melbourne, Australia. He received the PhD in Electrical Engineering from the University of California, Berkeley.

William H. Butler, University of Alabama

Heusler Alloys

Abstract: In collaboration with colleagues at the University of Virginia, our team at the University of Alabama is completing a survey of approximately 1,000 Heusler alloys using density functional theory (DFT). These materials are intriguing, for many reasons, but from the point of view of spintronics they are of interest because of their tendency to form Slater-Pauling phases. These are solutions to the DFT equations with a gap in the center of the s-d band, i.e. a region of zero density of states that occurs with three electron states per atom below the gap. These Slater-Pauling phases can be found for most of the Heusler alloys in our survey, although they are often not the lowest energy solution. The origin of these gaps can be discussed qualitatively in several ways. One view starts from an observation of Slater and Koster in 1954 that A-B transition metal alloys on a B2 lattice considering d-states and nearest neighbor interactions only will have a gap extending from the d-onsite energy of the A atom to the d-onsite energy of the B atom. A quantitative theory of the occurrence and stability of these phases should also include the magnetic polarizability of the transition metal atoms involved and its dependence on volume. The basic picture that emerges is that nature has an “additional” strategy that it can use to reduce the energy of a system of atoms. This strategy consists of shuffling electrons between majority and minority create and maximize a gap in one of the spin channels and then place the Fermi energy into this gap.

Our survey, which will soon be available at http://heusleralloys.mint.ua.edu, should make it easier to test, extend or modify these or other models for the formation and stability of Slater-Pauling

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phases. Experimentalists may be more interested in phases that can be easily fabricated than in phases that can be easily calculated. We have made a start in this direction by calculating formation energies of all of the considered Heusler phases and by testing them for stability against tetragonal distortions. We have also chosen the parameters for our calculations so that they are consistent with the oqmd database of calculated alloy phases, oqmd.org, which currently contains DFT calculations of 285,780 compounds. We include a link that allows one to easily determine whether the Heusler phase is predicted to be stable relative to other binaries and ternaries in the oqmd database. We hope that the database will be useful to the scientific community and solicit its help in finding errors, adding references and making extensions.

Speaker Bio: William H. Butler (as of August 1, 2015) is retired from the University of Alabama (UAT). He served as the Director of the Center for Materials for Information Technology at UAT from August 2001 - April 2010. During this period he also served as director of its NSF-sponsored Materials Research Science and Engineering Center. From August 2001 - July 31, 2015 he was Professor of Physics in the Department of Physics and Astronomy. He received a BS degree (with Highest Honor) in Physics from Auburn University in 1960 and a Ph.D. in physics in 1969 from the University of California San Diego where he studied under Nobelist Walter Kohn. From 1969-1972 he was Assistant Professor of Physics at Auburn University. He joined the Metals and Ceramics Division of Oak Ridge National Laboratory in 1972. He was leader of the Theory Group in the Metals and Ceramics Division of ORNL from 1984-2001. He has received DOE Awards for Outstanding Scientific Achievement and for Outstanding Sustained Research. He was the first recipient of the National Institute of Materials Science Award for Breakthroughs in Materials Science. He has authored more than 200 scholarly papers and is co-author of one book. He is member of the American Physical Society, the IEEE, the Materials Research Society, the American Association for the Advancement of Science. He is a fellow of the American Physical Society. He served as Meeting Chair for the Spring 1990 Meeting of the MRS and currently serves as Program Chair for the American Physical Society Topical Group on Magnetism and its Applications.

Dr. Butler's recent research interests include: physics of magnetic materials, spin-dependent transport in magnetic multilayers and nanostructures, electronic structure of magnetic oxides and chalcogenides, domain wall switched graded media, electronic structure of half-metals, and precessional damping in magnetic materials.

Claudia Felser, Max Planck Institute for Chemical Physics of Solids
Magnetism in Mn2-Heusler Compounds

Abstract: Heusler compounds are a remarkable class of materials with more than 1,000 members and a wide range of extraordinary multifunctionalities including half-metallic high-temperature ferri- and ferromagnets, multiferroic shape memory alloys, and tunable topological insulators with a high potential for spintronics [1], energy technologies and magnetocaloric applications [2]. The tunabilty of this class of materials is exceptional and nearly every functionality can be designed [2]. Recently a high spinpolarisation for spintronic applications was proven by angle resolved photoemission [3]. The development of efficient spintronic devices is based on the spin transfer torque (STT) phenomenon. In 2007 Mn3-xGa was identified as a potential electrode for STT applications [4,5]. In general Manganese-rich Heusler compounds are attracting much interest in the context of spin transfer torque, spin Hall effect, non collinear magnetism and rare-earth free hard magnets. Here we give a comprehensive overview of the magnetic properties of non centrosymmetric Mn2-based Heusler materials, which are characterized by n antiparallel coupling of magnetic moments on Mn atoms. Such a ferrimagnetic order leads to the emergence of new properties that are absent in ferromagnetic centrosymmetric Heusler structures. Tetragonal Heusler compounds with large magneto crystalline anisotropy can be easily designed by positioning the Fermi energy at the van Hove singularity in one of the spin channels. The Mn3+ ions in Mn2YZ cause a Jahn Teller distortion [6]. New properties can be observed such as, large exchange bias, non-collinear magnetism topological Hall effect, spin gapless semiconductivity and Skyrmions [7-10].

[1] C. Felser, et al, Angewandte Chemie, Interna. Ed. 46 668 (2007).
[2] Tanja Graf, et al, Progress in Solid State Chemistry 39 1 (2011).
[3] M. Jourdan, et al, Nature Com. 5 3974 (2014).
[4] B. Balke, G. H. Fecher, J. Winterlik, C. Felser, Appl. Phys. Lett. 90 152504 (2007).
[5] F. Wu, et. al., Appl. Phys. Lett. 94 122503 (2009).
[6] Jürgen Winterlik, et. al., Adv. Mat. 24 6283 (2012).
[7] A. K. Nayak, M. Nicklas, C. Shekhar, Y. Skourski, J. Winterlik, and C. Felser, Phys. Rev. Lett. 110 127204 (2013).
[8] S. Ouardi, G. H. Fecher, J. Kübler, and C. Felser, Phys. Rev. Lett. 110 (2013) 100401.
[9] O. Meshcheriakova, et al., Phys. Rev. Lett. 113 (2014) 087203.
[10] Ajaya K. Nayak, et al. Nature Materials 14 (2015) 679 (2015).

Speaker Bio: Claudia Felser studied chemistry and physics at the University of Cologne and completed her doctorate in physical chemistry there in 1994. After postdoctoral fellowships at the MPI in Stuttgart and the CNRS in Nantes (France), she joined the University of Mainz. She was a visiting scientist at Princeton University (USA) in 1999 and at Stanford University in 2009/2010 and a visiting professor at the University of Caen (France). She became a full professor at the University of Mainz in 2003.

In December, 2011 she became director of the Max Planck Institute for Chemical Physics of Solids. She is the chair of the DFG research group "New Materials with High Spin Polarization" and is the director of the Graduate School of Excellence "Materials Science in Mainz" of the German Science Foundation (DFG). She was honored with the order of merit "Landesverdienstorden" of the state Rhineland-Palatinate for the foundation of a lab for school students at the University of Mainz. The materials under investigation are Heusler compounds and compounds with related structure types. In 2010, she was the distinguished lecturer of the IEEE Magnetic Society, she received the Nakamura lecture award of the UC Santa Barbara and the SUR-grant award of IBM. In July 2014, Prof. Felser received the GRC-Alexander-M-Cruickshank-Lecturer Award at the "Gordon Research Conference" in New London, NH, USA. She has written more than 300 articles and been granted several patents. Her recent research focuses on the rational design of new materials

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for spintronics and energy technologies such as solar cells, thermoelectric materials, topological insulators and superconductors.

Kanta Ono, High Energy Accelerator Research Organization (KEK)
X-Ray and Neutron Analysis of Heusler Alloys

Abstract: Structure and magnetic structure analysis of Heusler alloys are very important to develop novel antiferromagnetic Heusler alloys that replace Iridium. We have performed structure and magnetic structure analysis of Heusler alloys using x-rays and neutrons, such as x-ray diffraction (XRD), neutron diffraction, x-ray magnetic circular dichroism (XMCD), and polarized neutron reflectometry (PNR).

At first, we performed a polarized neutron reflectometry (PNR) experiment at BL-17 of MLF, J-PARC, Japan. We have established an analysis method to estimate spin asymmetry and depth profiles from PNR for thin film samples. The structural and magnetic depth profile of the multilayer structure obtained by PNR is important for fabrication process optimization and magnetic structure analysis of Heusler alloys.

Then we characterize Heusler alloy samples using XRD at BL-8 of Photon Factory, KEK for structure analysis and XMCD at BL-16 for magnetic analysis. As we use two-dimensional x-ray detector (imaging plate IP) in our XRD system, we can obtain both in plane and out of plane diffraction patterns in a short time (~5min.). XMCD measurements were also performed for samples.

For the analysis of antiferromagnetic Heusler alloys, we have performed neutron diffraction experiments for Ni_2MnAl and Mn2(Co,V)Ga bulk samples.

Speaker Bio:

1991 BA University of Tokyo
1993 MS University of Tokyo
1996 Dr.Sc University of Tokyo
1996 ~ 2003 Research Associate, School of Engineering, University of Tokyo
2003 ~ Associate Professor, Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK)

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Günter Reiss, Center for Spinelectronic Materials and Devices, Department of Physics, Bielefeld University

Heusler Compounds in Magnetic Tunnel Junctions

Abstract: Heusler compounds already demonstrated their potential Magnetic Tunnel Junctions (MTJs). Record values are currently a TMR slightly below 2000% at low temperature (around 350% at room temperature) for $Co_2Mn_\alpha Si/MgO/Co_2Mn_\alpha Si$ ($\alpha \approx 1.3$) and a GMR larger than 74% for $Co_2Fe_{0.4}Mn_{0.6}Si$ films sandwiched with Ag. In addition, also inverse Heusler compounds (which lack crystal inversion symmetry) show high TMR ratio. In this contribution, we will address standard CoFeB/MgO tunnel junctions and discuss two aspects of recent developments with Heusler compounds:

i) Systems such as $Mn_{3-x}Ga$, Mn_xX_yGa (X=Co, Fe) or Mn_xGe have a low M_S combined with perpendicular magnetization with a high $K_U^{\perp}$. Thus they can rival the established CoFeB/MgO-system. We discuss tetragonally distorted, highly $L1_0$ textured $Mn_{3-x}Ga$ thin films with $0.1 < x < 2$ with a large $K_U^{\perp}$ and low M_S. However, a direct capping of these films with MgO is problematic due to oxide formation.

Two alternatives to the MnGa-system are Mn_xGe and Heusler compounds that have a perpendicular anisotropy due to their interface with MgO. We show, that the Mn_xGe system does have very large $K_U^{\perp}$. In addition, Co_2FeAl on TiN capped with MgO also shows perpendicular magnetization.

ii) In addition to their TMR, magnetic tunnel junctions also show a spin-dependent Seebeck voltage when the temperatures of the two magnetic electrodes are different. We have shown, that the readout contrast of this spin dependent Seebeck voltage can be drastically increased by adjusting the electronic states on either side of the barrier to obtain a larger DOS-asymmetry at the Fermi level.

Here, we demonstrate that in particular Heusler compounds with half-metallicity could be of strong interest for the Spin-Seebeck-Effect, because their band structure promises both a large Seebeck voltage as well as a strong change of the voltage when the magnetizations change from parallel to antiparallel alignment.

Speaker Bio:

Education

02/1989	PhD in Physics, Regensburg University (with Prof. Horst Hoffmann)
08/1994	Habilitation, Regensburg University

Professional Development

Since 10/1997	Full Professor (C4) of Experimental Physics, Bielefeld University
11/1992 - 09/1997	Head of the Department „Thin Films“, Institute for Solid State and Materials Research (IFW) Dresden e.V.
02/1992 - 10/1992	Post Doc at IBM (T.J. Watson Research Center, Yorktown Heights)
03/1989 – 01/1992	Post Doc (Regensburg University)

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Miscellanous

Coordinator of the M-Era.net Project HeuSpin (since 2014)
Senator at Bielefeld University (since 2011)
Dean of the Faculty of Physics (2004-2006)
Coordinator of the EU STREPs Project MagLog
Head of the Technical and Scientific Council, IFW Dresden (1995-1997)
Gaede Award of the German Vacuum Society (1994)

Gautam Shine, Stanford University
Modeling Transport in Heusler-Based Spin Devices

Abstract: Assessing the technological potential of Heusler alloys requires modeling them under realistic conditions. Here we present a methodology that uses extended Huckel theory to model the electronic structure coupled with non-equilibrium Green's functions to rigorously calculate transport properties. The combination allows us to study the impact of variation and defects as well as determine how Heusler-based devices perform when subjected to high bias.

Speaker Bio: Gautam Shine is a Ph.D. student in electrical engineering at Stanford University. He is advised by Prof. Krishna Saraswat and studies electron and spin transport, with a focus on interfaces and tunneling structures.

Koki Takanashi, Tohoku University
CPP-GMR and Related Phenomena in Half-Metallic Heusler Alloy Systems

Abstract: We have been working on CPP-GMR (current-perpendicular-to-plane giant magnetoresistance) in pillar-type junctions with half-metallic Heusler-alloy electrodes. They attract much interest as not only GMR devices [1-3] promising for read-head application in hard disc drives, but also nano-scale microwave oscillators [4,5], Peltier cooling devices [6], and so on. In my talk, I will make an overview on our recent work on CPP-GMR and related phenomena in pillar-type junctions with half-metallic Heusler-alloy electrodes.

[1] T. Iwase, et al., Appl. Phys. Express 2, 063003 (2009).
[2] Y. Sakuraba, et al., Appl. Phys. Lett. 101, 252408 (2012).
[3] H. Narisawa, et al., Appl. Phys. Express, Vol. 8, 063008 (2015).
[4] R. Okura et al., Appl. Phys. Lett., 99, 052510 (2011).
[5] T. Seki, et al., Appl. Phys. Lett. 105, 092406 (2014).
[6] S. Bosu, et al., Appl. Phys. Express, 8, 083002 (2015).

Speaker Bio: Koki Takanashi received his BS, MS, and Ph.D. degrees in Physics from the University of Tokyo. Then he joined the Institute for Materials Research at Tohoku University and is now a Professor and the Director there. In 1994-1995 he was an Alexander von Humboldt Research Fellow at the Forschunszentrum Jülich in Germany. He has received numerous awards, including the Outstanding Research Award (2004, Magnetic Society of Japan), Outstanding Paper Award (2009, Japan Society of Applied Physics), Masumoto Hakaru Award (2011, Japan Institute of Metals). He was the leader of a national project in Japan: "Creation and Control of Spin Current" (2007-2011). He served as an editorial board member of the Journal of Magnetism and Magnetic Materials (2007-2009) and Journal of Physics D (2009-2011). He was also an AdCom member (2011-2013) and a Distinguished Lecturer (2013) of IEEE Magnetic Society.

His research interests include magnetism and magneto-transport in nanostructures, magnetic materials for spintronics, and spin current phenomena. He has published over 300 papers and made over 100 invited talks at international conferences or seminars related to magnetic materials and spintronics.

Oleg Mryasov, Western Digital

Electronic Structure, Spin Transport, and Magnetic Anisotropy in Selected Cubic Heusler, Tetragonal, and Hexagonal Heusler-like Alloys

Abstract: In this presentation we focus on the following selected key properties of Heusler and Heusler like heterostructures: (1) spin dependence electronic structure (band gap, band matching); (2) dependence of electronic structure on alloying; (3) conductance spin polarization in bulk; (4) conductance spin polarization for CPP-GMR hetero-structures; (5) Curie temperature, magnetization and magnetic anisotropy. The set of high spin polarization materials selected for this presentation include: (i) Ternary and Quaternary cubic symmetry Heusler alloys; (ii) perpendicular anisotropy materials such as hexagonal Heusler like alloys. Spin polarized transport properties calculated Co_2MnGe (CMG)/Ag/Co_2MnGe (CMG) and CMG/Cu_2TiAl (CTA)/CMG. The case of (001) Ag "band folding" enables good band matching with the CMG majority spin, whereas for more practical (110) textured CMG/CTA/CMG combination higher performance can be achieved due to natural band matching effects. We calculate magnetic anisotropy and its temperature dependence cuss hexagonal alloys based combination of Fe, Co, Ge elements. To summarize to discuss mechanisms of high spin polarization and perpendicular anisotropy contrasting different solutions for different prospective devices utilizing spin degrees of freedom.

Speaker Bio: Dr. Mryasov recently has joined Advanced Technology Group at WD as Senior Technologist Systems Architecture. From 2009-2014 he was an Associate Professor of Physics and Graduate Advisor of Materials Science and Engineering Tri-Campus Program at the University of Alabama, Tuscaloosa (UAT). From 2001-2009, he was Principal Research Engineer at Seagate Technology Research Center. From 1999-2001 he held joint appointment of Research Engineer - III Technical Staff at UC Berkeley/Sandia National Laboratories (Livermore). He performed his post-doctoral research at Northwestern University in the group of Professor Arthur Freeman (1994-1999). He received the Ph.D. in Physics and Math from Russian Academy of Sciences in

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1993, under the supervision of Prof. A.I. Lichtenstein and Prof. V. I. Gubanov (1989-1993).

Dr. Mryasov has been awarded by the Irish Science Foundation with the C. T. Walton Fellowship grant and Technology achievement award from Seagate Technology LLC. Dr. Mryasov has pioneering and innovative contributions in the field of novel CPP-GMR heterostructures with high spin polarization Heusler alloys; transparent conductors; constrained density functional theory (CDFT) for magnetic excitations; theory of magnetic anisotropy energy (MAE); and beyond DFT-LDA theory of metal/insulator interface states; constrained density functional theory (CDFT) for magnetic excitations and interactions; beyond DFT-LDA theory of magnetic anisotropy energy (MAE); theory of magnetic tunneling junction including beyond DFT-LDA theory of metal/insulator (Fe/MgO) interface states; Interlayer Exchange Coupling across tunnel barrier; charge-orbital ordering and spin polarized current controlled magnetization states in Spin Valves (SV); multi-scale theory of thermal stability, Heat Assisted Magnetic Recording (HAMR) and Magnetization Process; understanding and utilizing fundamental magnetic properties theory in multi-scale simulations.

Matthew Carey, Spin Transfer Technologies

Heusler Compounds for CPP-GMR Heads and MRAM

Abstract: Many Heusler compounds are predicted to be half-metallic. While in practice 100% spin polarization is at best difficult to achieve, these compounds show much higher spin polarization than standard metallic magnetic alloys. This high spin polarization makes Heusler compounds attractive for applications, most notably in current-perpendicular-to-the-plan giant magnetoresistance (CPP-GMR) read heads for magnetic recording and for magnetic tunnel junctions (MTJ's) for magnetic random access memory (MRAM). A primary reason is that the high spin polarization promises high magnetoresistance (MR). Beyond the high MR, the needs of CPP-GMR and MRAM are very different. For example, the low damping and high susceptibility to spin torque which makes Heuslers attractive for MRAM is a large source or noise in CPP-GMR and limits the sense current that can be used.

Heusler discovered the compounds that share his name in 1903 but it wasn't until 1983 that band structure calculations predicted that a subset might be half metallic. The two decades that followed showed little progress in producing materials and devices that demonstrated the benefits predicted. Together with the rise of spintronics we have seen a rise in interest and success with Heusler compounds. CPP-GMR devices with Heusler compounds can achieve 10x the MR of their standard metal counterparts. MTJs with Heuslers are comparable in MR to standard metal devices, but with lower magnetic damping.

Much of this advance has been made possible by overcoming the practical materials challenges presented in making the various Heusler compounds and the devices that contain them. In this talk I will discuss the challenges of producing thin film Heusler compounds by sputtering. Since these are chemically ordered compounds, thermal treatment and structural characterization are of key importance.

The gains demonstrated by academic groups have been truly impressive. However, more hurdles

present themselves in applying Heusler compounds in applications. Much of the academic work has involved epitaxial thin films with thick Heusler and seed layers. Both MRAM and CPP-GMR require very thin (<3nm) polycrystalline films. Both these factors present challenges in processing and in characterization. For example, even with high intensity X-ray diffraction, 24 hour scans are not uncommon to detect Heusler order peaks. The thermal parameters involved with CPP-GMR and MRAM are quite distinct from each other. Back end of the line (BEOL) processing for MRAM can involve 400C anneals while the magnetic shields for heads limit anneals to below 300C. So while some high temperature stable compounds like Co_2MnSi or $Co_2Fe(AlSi)$ may be promising in MRAM, a lower temperature material such as Co_2MnGe may be more optimal in CPP-GMR. The most studied Heusler compounds are cubic and, thus, have in-plane magnetization. While this is beneficial for CPP-GMR, this is a limitation for MRAM. Some techniques have been attempted to increase perpendicular magnetic anisotropy in these cubic Heusler compounds, but it's unclear that the films are still actual Heusler compounds or retain the low damping that makes them attractive for MRAM.

The past decade has seen an explosion in advances in Heusler compounds. In this talk we will discuss the advantages promised, the advances made and the challenges that remain.

Speaker Bio: Matt Carey has been working in thin film magnetic materials for nearly 30 years. As a graduate student he studied exchange anisotropy and giant magnetoresistance. As part of that work he developed thin film NiO as an antiferromagnetic layer for exchange bias, and this was used in the first spin valve GMR read head. He worked at IBM Research, and Hitachi Global Storage Technologies Research focusing largely on read head magnetic materials. In that time he worked on the development of the GMR spin valve read head, the TMR read head and most recently on CPP-GMR as a potential follow on for TMR. He also contributed to media efforts, including as an inventor of AFC (anti-ferromagnetically coupled) media, which extended in-plane media until perpendicular recording was rolled out.

For the past few years he has worked on magnetic materials for MRAM and is currently with Spin Transfer Technologies.

Kazuhiro Hono, National Institute for Materials Science and University of Tsukuba

Heusler-Alloy-Based Magnetoresistive Devices with High MR Outputs

Abstract: A current-perpendicular-to-plane (CPP) giant magnetoresistance (GMR) device has been considered to be a potential alternative to the tunneling magnetoresistance (TMR) read sensor for future high density hard disk drives (HDD) beyond 2 $Tbit/in^2$ owing to its intrinsically low device resistance. However, the MR outputs of typical CPP-GMR devices have remained insufficient. An appropriate combination of ferromagnet Heusler alloys and a nonmagnetic spacer with a good band matching is expected to enhance MR substantially. We recently found the usage of CuZn and AgZn spacers in combination with $Co_2Fe(Ga,Ge)$ Heusler alloy leads to very large MR outputs. ΔRA exceeding 20 $m\Omega\mu m^2$ with MR ratio of 60% was

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obtained at room temperature. The MR ratio is enhanced to 200% at low temperature, suggesting the improvement of temperature degradation of MR will lead to very high-output MR devices. The underlying physics for the high MR outputs and their temperature degradation will be discussed based on our thorough STEM structural characterization results. We also investigated the effects of the crystal orientation and the development of (100) textured polycrystalline devices, which is of great importance for the development of practical polycrystalline devices.

Speaker Bio: Kazuhiro Hono received his BS (1982) and MS (1984) degrees in Materials Science at Tohoku University and a Ph.D. degree in Metals Science and Engineering at Penn State in 1988. After working as a post doc at Carnegie Mellon for a year, he became a research associate at the Institute for Materials Research, Tohoku University in 1990. He moved to the National Research Institute for Metals (currently National Institute for Materials Science, NIMS) as a senior researcher in 1995, and is now a NIMS Fellow and the Director of the Magnetic Materials Unit. He is also a professor in Materials Science and Engineering at the Graduate School of Pure and Applied Sciences, University of Tsukuba. His major research interest is microstructure-property relationships of metallic materials, in particular magnetic materials.

Chris Palmstrøm, University of California, Santa Barbara

Heusler Compound/III-V Semiconductor Heterostructures

Abstract: Heusler alloys are analogous to the Perovskite complex oxides with over 1,000 possible combinations of elements. Their properties depend on the number of valence electrons per formula unit and have been predicted to be semiconductors, metals, ferromagnets, antiferromagnets, half metals, superconductors and topological insulators. Similar to compound semiconductors, the band structure and lattice parameters of Heusler alloys can also be tuned through alloying but over a much larger range of properties. The half-Heusler compounds can be thought of as a zincblende lattice with additional atoms in the octahedral sites. The lattice parameters and FCC crystal structure make them excellent candidates for integrating with conventional III-V semiconductors. Magnetic tunnel junctions using Heusler alloys that are predicted to be half metals have shown record tunneling magnetoresistance. We have demonstrated record high spin accumulation at Heusler/GaAs interfaces in lateral spin transport device structures and also the growth of semiconducting half-Heusler alloys on III-V semiconductors with comparable electron mobilities to Si. Using a combination of molecular beam epitaxy and in-situ scanning tunneling microscopy and x-ray photoelectron spectroscopy, we have investigated the interface formation and growth mechanisms. Ab-initio theory and ex-situ transmission electron microscopy studies have been used to corroborate the Heusler/semiconductor interfacial atomic structure. In-situ scanning tunneling microscopy and spectroscopy have been used to investigate the electronic structure and compared with angle resolved photoemission spectroscopy studies of the band structure.

Speaker Bio: Professor Chris Palmstrøm, one of the world's leading researchers of electronic materials, joined the ECE faculty at the University of California, Santa Barbara in the fall of

2007. Born in Norway, Palmstrøm received his Ph.D. in Electrical and Electronic Engineering from the University of Leeds (England) in 1979. After five years of research on semiconductor materials and contact technologies at Cornell, he joined Bellcore in 1985. There, he did ground-breaking research on semiconductor surfaces, semiconductor doping, polymer/polymer diffusion and the molecular beam epitaxial growth of metal/semiconductor heterostructures. In 1994, Dr. Palmstrøm went to the University of Minnesota, where he soon became a leading researcher in several fields, including new spintronic materials that combine the functions of electronic and magnetic manipulation and storage on information.

Hiroaki Sukegawa, National Institute for Materials Science

Interface-Induced Perpendicular Magnetic Anisotropy and Giant Tunnel Magnetoresistance in Co_2FeAl Heusler Alloy Based Heterostructures

Abstract: Co-based Heusler alloys Co_2YZ with $L2_1$ or B2 structure have attracted great attention due to their excellent magnetic properties such as perfect spin polarization at the Fermi level, high Curie temperatures, and low Gilbert damping. Therefore, a magnetic tunnel junction (MTJ) with Co-based Heusler alloys could be a promising magnetoresistive element for the spin transfer switching - magnetoresistive random access memories (STT-MRAMs).

Among the Co-based Heusler alloys, Co_2FeAl (CFA) is known to have one of the smallest damping factors (around 0.001 [1]). In addition, we reported a large tunnel magnetoresistance (TMR) ratio over 300% at room temperature using a CFA/MgO/CoFe(001) epitaxial MTJ [2]. The large TMR ratio is mainly due to high spin polarization of the CFA layer and strong spin-dependent coherent tunneling effect. Their remarkable features of CFA will be favorable for ferromagnetic layers of MTJs.

In this talk, I will show recent works on CFA-based spintronic heterostructures. Firstly, I will introduce a perpendicularly magnetized ultrathin CFA film using an MgO interface [3-5]. We found that the strong perpendicular magnetic anisotropy (PMA) was induced at an ultrathin CFA (~ 1 nm)/MgO interface. Interestingly, large PMA energy is observed when a Ru buffer layer with a (02-23) high-index orientation is used [4]. Secondly, I will talk about CFA-based MTJs in combination with a newly-developed spinel $MgAl_2O_4$ epitaxial barrier [6]. $MgAl_2O_4$-based MTJs exhibit giant TMR effect due to the coherent tunneling like MgO-based MTJs. Importantly, the lattice spacing of the $MgAl_2O_4$ can be easily tuned by Mg-Al composition of the layer, which enables us to achieve a lattice-matched $MgAl_2O_4$/bcc-based ferromagnet (or Heusler alloy) interface. In fact, a misfit dislocation-free MTJ with a large TMR ratio over 280% at room temperature was achieved using CFA and $MgAl_2O_4$.

This work was partly funded by ImPACT Program of Council for Science, Technology and Innovation, Cabinet Office, Government of Japan.

[1] S. Mizukami et al., J. Appl. Phys. 105, 07D306 (2009).
[2] W. Wang et al., Appl. Phys. Lett. 95, 182502 (2009).

ABSTRACTS

[3] Z. C. Wen et al. Appl. Phys. Lett. 98, 242507 (2011).
[4] Z. C. Wen et al., Adv. Mater. 26, 6483 (2014).
[5] H. Sukegawa et al., SPIN 4, 1440023 (2014).
[6] T. Scheike et al., Appl. Phys. Lett. 105, 242407 (2014).

Speaker Bio: Hiroaki Sukegawa received his M.S. degree in materials science from Tohoku University, Sendai, Japan in 2004, and his Ph.D. degree in Materials Science from Tohoku University, in 2007. He became a researcher at National Institute for Materials Science in 2007. He is currently a senior researcher of Magnetic Materials Unit, National Institute for Materials Science. His research interests include magnetic thin films and spintronics devices.

Paul Crowell, University of Minnesota
Spin Transport in Epitaxial Heusler Alloy/III-V Semiconductor Heterostructures

Abstract: The prospects for half metallicity as well as favorable conditions for lattice matching to the $In_xGa_{1-x}As$ family of semiconductors make a variety of half and full Heusler alloys desirable candidates for spin injection. I will review recent results on spin injection into GaAs from $Co_2Mn_xFe_{1-x}Si$. Non-local spin valves operating at room temperature have been demonstrated. A combination of magneto-transport, spin transport and ferromagnetic resonance data suggest that Co_2MnSi is highly polarized, allowing for the highest spin accumulations that we have observed in transition metal ferromagnet/III-V heterostructures. Although Co_2FeSi is apparently not half-metallic, the absence of Mn interdiffusion has made it a more reliable material for devices. In particular, the Co_2FeSi-based heterostructures have allowed for a systematic study of the spin lifetime and diffusion length in GaAs at high temperatures.

Speaker Bio: Paul Crowell has been on the faculty of the University of Minnesota since 1997 and is currently a Professor of Physics.

Awards and Honors: McKnight Land Grant Professor, University of Minnesota 1999-2001, Sloan Foundation Fellow, 1999-2001, McKnight Presidential Fellow, University of Minnesota, 2004-2007, Fellow of the American Physical Society, 2008.

Service: General Chair, Joint MMM/Intermag Conference; Chair-Elect of the APS Topical Group on Magnetism and its Applications (2011-2012); Organizer, Focus Session on Spin-Dependent Phenomena in Semiconductors, APS March Meeting, 2010; Program Committee, Conference on Magnetism and Magnetic Materials, 2005-2008, 2010; Program Committee Seventh International School of Spintronics and Quantum Information Technology, Japan (2011); Program Co-Chair, Conference on Magnetism and Magnetic Materials, Austin (2008).

Paul Crowell received his PhD in low-temperature physics from Cornell University in 1994 and was a postdoctoral associate at the CNRS, Grenoble and the University of California at Santa Barbara before joining the faculty of the University of Minnesota in 1997. He is currently a Professor of Physics. Professor Crowell's research focuses on spin dynamics in ferromagnets on sub-nanosecond time scales and spin transport in hybrid ferromagnet-semiconductor and ferromagnet/normal metal systems. He is a fellow of the American Physical Society.

Martin Jourdan, Johannes Gutenberg University, Mainz, Germany

100% Spin Polarized Surface Resonance in the Half Metallic Heusler Compound Co_2MnSi

Abstract: The magnitude of the room temperature spin polarization of ferromagnetic materials is a key property for their application in spin transport-based electronics. Thus Heusler compounds, due to their predicted bulk half-metallic properties, i.e. 100% spin polarization at the Fermi energy, are in the focus of interest. However, for most applications it is not the bulk but the surface or interface of the material, which is relevant.

Investigating optimized thin films of the compound Co_2MnSi by in situ spin-resolved UPS, we were able to demonstrate for the first time half-metallicity in combination with directly measured (93+7-11) % spin polarization at room temperature in the surface region of a Heusler thin film [Jou14]. Our novel band structure and photoemission calculations including all surface-related effects [Bra14, Bra15] show that the observation of a high spin polarization in a wide energy range below the Fermi energy is related to a stable surface resonance in the majority band of Co_2MnSi extending deep into the bulk of the material. Spin-integrated ex situ HAXPES with a photon energy of 6 keV on Co_2MnSi thin films and spin-integrated in situ UPS was carried out. The UPS and the HAXPES results fundamentally agree although the information depth of both experiments varies from less than 1 nm to 20 nm. Nearly quantitative agreement of the calculations with the experiments for both, UV and hard X-ray photon energies, was obtained.

As an outlook, results of HAXPES investigations of epitaxial Co_2MnSi/ (Cr, Ag) interfaces will be shown, which deliver a first insight into the development of the Co_2MnSi surface resonance into interface states.

[Jou14] M. Jourdan et al. Nat. Commun. 5, 3974 (2014).
[Bra14] J. Braun et al., New J. Phys. 16, 015005 (2014).
[Bra15] J. Braun et al., Phys. Rev. B 91, 195128 (2015).

Speaker Bio: Dr. Jourdan is a Senior Scientist at the Institute of Physics, Mainz University.

Studies: Physics, Technical University Darmstadt, Germany 1980 - 1985
Degree: Diploma ("Diplom-Physiker")

Habilitation: Experimental Physics, Mainz University, Germany 2010 (lecturing qual.)
Ph.D. Thesis: Physik, Mainz University, Germany 1999

Research Associate, Mainz University 1995 - 1999
Development engineer, Robert Bosch GmbH, Stuttgart 1999 - 2001
Senior Research Associate (C1), Mainz University 2001 - 2006
Senior Scientist/ Group Leader, Mainz University 2006 -

Heusler Alloys for Spintronic Devices

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Areas of Interest: Unconventional superconductivity, Heavy Fermion compounds, Iron Pnictides, novel materials for spintronics (Heusler compounds, Mn2Au, etc.), epitaxial thin films, photoemission spectroscopy, transport measurements

Richard James, University of Minnesota

Transformational Multiferroic Heusler Alloys and Energy Conversion

Abstract: We discuss the development of Heusler alloys with strongly first order phase transformations, combined with multiferroism, for use in the direct conversion of heat to electricity or, conversely, the direct conversion of electricity to cold. Fundamentally, the discovery of suitable alloys for this purpose exploits the generic lattice parameter sensitivity of "ferroic" properties. Hence, at a phase transformation with a change of lattice parameters, there is the possibility of an abrupt change of ferroic properties. Heusler alloys readily combine these features. We focus in particular on 1) very recent results on spectacular reversibility achieved by tuning lattice parameters to achieve strong conditions of compatibility between phases, and 2) the thermodynamics of energy conversion in these kinds of materials.

Speaker Bio: Dr. Richard James is a Distinguished McKnight University Professor at the University of Minnesota in the Department of Aerospace Engineering and Mechanics. Professor James currently works in two areas. The first involves phase transformations in materials, especially shape-memory, magnetostrictive and multiferroic materials. A recent discovery is a new understanding of the origins of hysteresis and reversibility in phase transformations. Applications of this research range from the development of highly reversible shape memory alloys for use in medical devices to new multiferroic materials that directly convert heat to electricity. His second area of research revolves around the concept of "Objective Structures", a way to look at the structure of matter that includes simple and complex crystals, but also non crystalline structures like viral capsids, buckyballs and carbon nanotubes. Members of his group working on objective structures are discovering quantum mechanical methods to analyze noncrystalline materials, new multiscale methods for molecular dynamics, new x-ray methods for the determination of atomic structure, and are designing molecules that spontaneously self-assemble into useful nanostructures.

Chris Leighton, University of Minnesota

Magnetic Phase Competition in Off-Stoichiometric Heusler Alloys: $Ni_{50-x}Co_xMn_{25+y}Sn_{25-y}$

Abstract: Recently, motivated both by basic scientific interest and technological applications, and utilizing both experiment and theory, a number of research groups have identified a specific group of off-stoichiometric Heusler alloys as having unusually interesting magnetic properties. These alloys take the form $Ni_{50-x}Co_xMn_{25+y}Z_{25-y}$ (Z = Sn, In, Ga, etc.), being Co-doped off-stoichiometric versions of the better-known

Ni_2MnZ full Heusler compounds. In certain critical composition ranges these alloys are found to display unusually reversible martensitic phase transformations, multiferroicity (coexisting ferroelasticity and magnetic order), heightened sensitivity to compositional changes, and acute magnetic phase competition, leading to phenomena such as spontaneous nanoscale magnetic inhomogeneity, superparamagnetism, and intrinsic exchange bias. In terms of applications they exhibit magnetic-field-induced phase transformations, magnetic shape memory behavior, magnetocaloric effects, and remarkably low thermal hysteresis, making them attractive for sensors and actuators, magnetic refrigeration, and energy conversion devices. In this talk we present our recent work on bulk polycrystalline samples around the critical composition $Ni_{50-x}Co_xMn_{40}Sn_{10}$ ($0 \leq x \leq 14$), using magnetometry [1,2], exchange bias [1,2], neutron diffraction [2], small-angle neutron scattering [1], and Mn NMR [3]. In addition to providing detailed phase diagrams, application of these techniques has provided a number of new insights, including the first direct proof of the suspected nanoscale magnetic inhomogeneity, the first measurements of ferromagnetic cluster sizes and densities, and a detailed understanding of the antiferromagnetic interactions in the martensite matrix. The results are interpreted in terms of a chemical disorder picture.

[1] Bhatti, El-Khatib, Srivastava, James and Leighton, Phys. Rev. B. 85, 134450 (2012).
[2] Bhatti, Srivastava, Phelan, James and Leighton, in Heusler Alloys, eds. Hirohata and Felser, Springer (2015).
[3] Yuan, Kuhns, Reyes, Brooks, Hoch, Srivastava, El-Khatib, James and Leighton, in press, Phys. Rev. B. (2015).

Speaker Bio: Dr. Chris Leighton is a Distinguished McKnight University Professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. Electronic and magnetic materials are the central focus of our group's research. We study a wide variety of types of materials such as nanostructures, thin films, multilayered heterostructures, and bulk polycrystals and single crystals. We have interests in several areas including the interplay between electronic transport and magnetism in novel materials, and the study of interfaces between dissimilar materials, particularly metals, oxides, and sulfides. The intention is to focus on topics that are attractive from the viewpoint of fundamental science but lie in close proximity to important technological applications such as information storage and microelectronics. Each of the projects requires fabrication of magnetic/electronic materials and/or structures, detailed atomic level characterization, and in-depth measurement by numerous techniques, particularly electronic transport, magnetometry, and neutron scattering. The work often requires that collaborations be forged, both within the University of Minnesota and with external investigators.

The bulk of our current research can be divided into eight primary categories: magnetism in the perovskite cobaltites, perovskite oxide heterostructures, spin transport in metals, highly spin polarized ferromagnets, sulfide-based heterostructures and photovoltaics, novel magnetic alloys, magnetic nanostructure arrays by block copolymer patterning, and transport in conductive polymers and small molecule systems.

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Atsufumi Hirohata, University of York

Heusler Alloy Films for Spintronic Devices

Abstract: As is commonly understood, epitaxial films have great advantages over polycrystalline films for achieving $L2_1$ ordering with abrupt and smooth interfaces. However, due to the lattice mismatch, epitaxial films always suffer from small activation volumes induced by misfit dislocations at the Heusler-alloy/(buffer)/substrate interface. Polycrystalline films, on the other hand, reveal their activation diameter, which defines the average diameter of a cylindrical volume with domain-wall-free magnetisation switching, to be much larger, on the order of 40 nm. By controlling the sputtering conditions, the grain size of polycrystalline films can be tuned to be of the same size as the activation diameter, thus allowing for extremely fast switching. This is ideal if Heusler alloys are to be utilised in magnetoresistive nano-pillars in the next-generation read heads for hard disk drives and the cells for spin-transfer-torque magnetic random access memories.

Speaker Bio: Dr. Atsufumi Hirohata is a Professor at the Department of Electronics in the University of York. He has over 10 years of experience in spintronics, ranging from magnetic-domain imaging to spin-current interference. Before coming to York in 2007, he was a researcher at RIKEN, a Japanese governmental research institute, where he designed a spin-current interference device. He was before working at Tohoku University and Massachusetts Institute of Technology. He received his Ph.D. in Physics at the University of Cambridge in 2001. He was originally graduated from Keio University for his BSc and MSc studies in Physics.

Heusler Alloys for Spintronic Devices

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PARTICIPANT LIST

Rizvi Ahmed, University of Minnesota
ahmed519@umn.edu

Palak Ambwani, University of Minnesota
palakamb@gmail.com

Yoska Anugrah, University of Minnesota
anugr002@umn.edu

Avram Bar-Cohen, DARPA
avram.bar-cohen@darpa.mil

William Butler, University of Alabama, MINT Center
whbutler2@att.net

Matthew Carey, Spin Transfer Technologies
matthew.carey@spintransfer.com

Junyang Chen, University of Minnesota jychen@umn.edu

Paul Crowell, University of Minnesota
crowell@umn.edu

Vivekanand Dabade, University of Minnesota
dabad001@umn.edu

David Deen, Seagate Technology
david.a.deen@seagate.com

Claudia Felser, Max Planck Institute for Chemical Physics of Solids
office.felser@cpfs.mpg.de

Koustav Ganguly, University of Minnesota
gangu015@umn.edu

Zhiguo Ge, Seagate Technology
Zhiguo.Ge@seagate.com

Javad Ghasemi Azadani, University of Alabama
jghasemiazadani@crimson.ua.edu

Nazila Haratipour, University of Minnesota
harat001@umn.edu

Atsufumi Hirohata, University of York
atsufumi.hirohata@york.ac.uk

Kazuhiro Hono, National Institute for Materials Science
kazuhiro.hono@nims.go.jp

Bharat Jalan, University of Minnesota
bjalan@umn.edu

Richard James, University of Minnesota james@umn.edu

Yanfeng Jiang, University of Minnesota
jiangy@umn.edu

Yongjin Jiang, University of Minnesota
jiang975@umn.edu

Martin Jourdan, Mainz University
jourdan@uni-mainz.de

Wonjoon Jung, Seagate Technology
wonjoon.jung@seagate.com

Sahar Keshavarz, University of Alabama
skeshavarzshahvarani@crimson.ua.edu

Mark Kief, Seagate Technology
mark.t.kief@seagate.com

Ki Wook Kim, North Carolina State University
kwk@ncsu.edu

Steven Koester, University of Minnesota
skoester@umn.edu

Chris Leighton, University of Minnesota
leighton@umn.edu

Xiang Li, UCLA
isaacli@gmail.com

Lynn Li, Seagate Technology
lynn.n.li@seagate.com

Peng Li, Seagate Technology
lipeng@umn.edu

Jinming Liu, University of Minnesota
liux1872@umn.edu

Yang Lv, University of Minnesota
lvxxx057@umn.edu

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Heusler Alloys for Spintronic Devices
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PARTICIPANT LIST

Qinli Ma, Johns Hopkins University
qma7@jhu.edu

Jianhua Ma, University of Virginia
jm9yq@virginia.edu

Mike Manno, University of Minnesota
manno005@umn.edu

Oleg Mryasov, University of Alabama & WD
omryasov@mint.ua.edu

Kamaram Munira, University of Alabama
kmunira@mint.ua.edu

Nariman Naghibolashrafi, University of Alabama
nnaghibolashrafi@crimson.ua.edu

Kanta Ono, High Energy Accelerator Research Organization (KEK)
kanta.ono@kek.jp

Chris Palmstrøm, University of California, Santa Barbara
cpalmstrom@ece.ucsb.edu

Mihir Pendharkar, University of California Santa Barbara
mihir@ece.ucsb.edu

Timothy Peterson, University of Minnesota
tpeterso@physics.umn.edu

Taras Pokhil, Seagate Technology
taras.g.pokhil@seagate.com

Daniel Radack, IDA
dradack@ida.org

Ashutosh Rath, University of Wisconsin-Madison
rath3@wisc.edu

Guenter Reiss, Bielefeld University
reiss@physik.uni-bielefeld.de

Vashisht Sharma, Institute for Defense Analyses
vsharma@ida.org

Gautam Shine, Stanford University
gshine@stanford.edu

Chockalingam Sivakumar, University of Alabama
csivakumar@crimson.ua.edu

Ryo Someya, Canon USA
rsomeya@cusa.canon.com

Hiroaki Sukegawa, National Institute for Materials Science
sukegawa.hiroaki@nims.go.jp

Koki Takanashi, Tohoku University
koki@imr.tohoku.ac.jp

Liwen Tan, Seagate Technology
Liwen.Tan@seagate.com

Serol Turkyilmaz, University of California Riverside
sturk002@ucr.edu

Gilroy Vandentop SRC / STARnet,
Gilroy.Vandentop@src.org

Randall Victora, University of Minnesota
victora@umn.edu

Jian-Ping Wang, University of Minnesota
jpwang@umn.edu

Justin Watts, University of Minnesota
watts@physics.umn.edu

Peter Welsch, Canon USA
pwelsch@cusa.canon.com

Jae Young Yi, Seagate Technology
Jae-Young.Yi@seagate.com

Ian Young, Intel
ian.young@intel.com

Xin Zhang, University of Minnesota
zhan1261@umn.edu

Delin Zhang, University of Minnesota
dlzhang@umn.edu

Zhengyang Zhao, University of Minnesota zhaox526@umn.edu

How to Connect to the UMN Wireless Network

When using your own computer for a UMN wireless connection, you will be required to use a UMN Internet ID and Password to connect to the wireless network. Your wireless username and password can be found on the back of your nametag. Connect to the network named UMN, not UMN Guest.

Follow these steps to configure your computer to use its wireless card.

Windows Vista	**Windows XP**** Windows Service Pack 2 is required	**Macintosh OS 10.5**	**Macintosh OS 10.4 and older**
1. From the Start menu, click on the Connect To option 2. Select UofM Wireless from the list of connections. 3. Click Connect 4. If prompted about connecting to an insecure network, click Connect Anyway 5. You will be asked if you want to Save this network. You can avoid this steps in the future if you choose this option. 6. If asked to set the network location, choose Public Location. 7. Choose the option to Close. 8. Open a Web browser (Firefox, I.E.) 9. The Wireless Network Login page appears. Login with the above Internet ID and password.	1. From the Start menu, select Control Panel 2. Double-click Network Connections 3. Double-click Wireless Network Connection 4. Click View Wireless Networks on the right 5. Select UofM Wireless 6. Click Connect 7. If prompted about connecting to an insecure network, click Connect Anyway 8. Open a Web browser (Firefox, I.E.) 9. The Wireless Network Login page appears. Login with the above Internet ID and password.	1. From the Apple menu, select System Preferences. 2. Click Network. 3. Select AirPort on the left. 4. If “Status: Off” then click Turn AirPort On 5. Click Advanced. . . 6. Click TCP/IP 7. Set the Configure IPv4 field to Using DHCP 8. Click Renew DHCP Lease 9. Open a Web browser (Firefox, Safari) 10. The Wireless Network Login page appears. Login with the above Internet ID and password.	1. From the Apple menu, select System Preferences 2. Click Network. 3. Select AirPort from Show dropdown. 4. Click TCP/IP 5. Set the Configure field to Using DHCP 6. Click Renew DHCP Lease 7. Open a Web browser (Firefox, Safari) 8. The Wireless Network Login page appears. Login with the above Internet ID and password.

For more detailed instructions and other operating systems see: www.umn.edu/adcs/network

Don’t lose your wireless connection. Practice safe computing. If your computer is determined by Network Security to have an infection or to not be following the UM Acceptable Use Policies, your computer may be prevented from connecting to the UMN Network.

At http://safecomputing.umn.edu learn how to keep your computer, Internet account, and Wireless connection secure. Where to go for help: (612)301-4357 or http://1help.umn.edu

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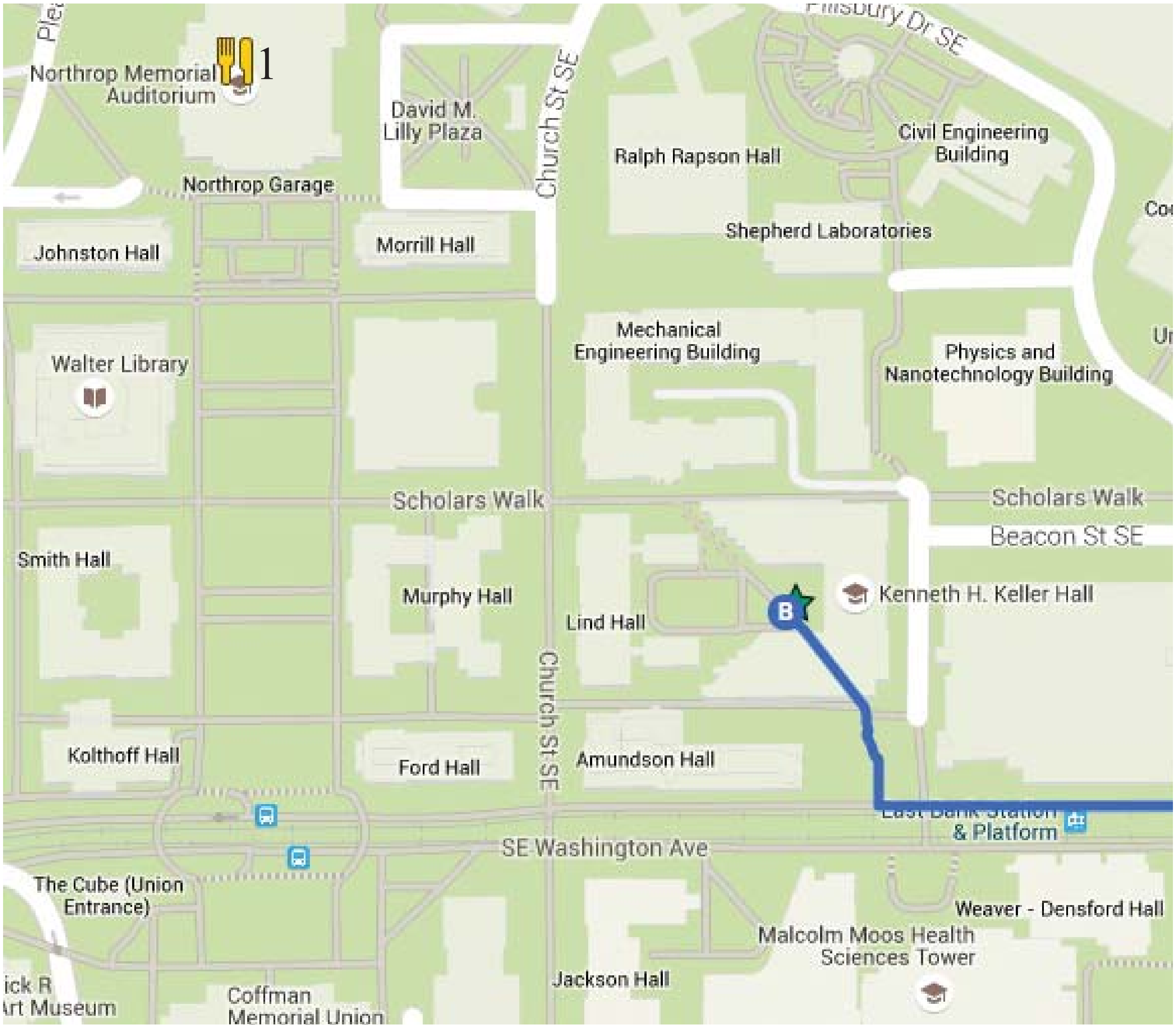
CAMPUS MAP



WORKSHOP LOCATIONS

A. Commons Hotel: Lodging.

B. Kenneth Keller Hall: All talks and coffee breaks. Rooms 3-176 and 3-180.

✧ **McNamara Alumni Center:** Heritage Gallery Room. Social hour and dinner on Thursday, July 30th at 6:30 PM.

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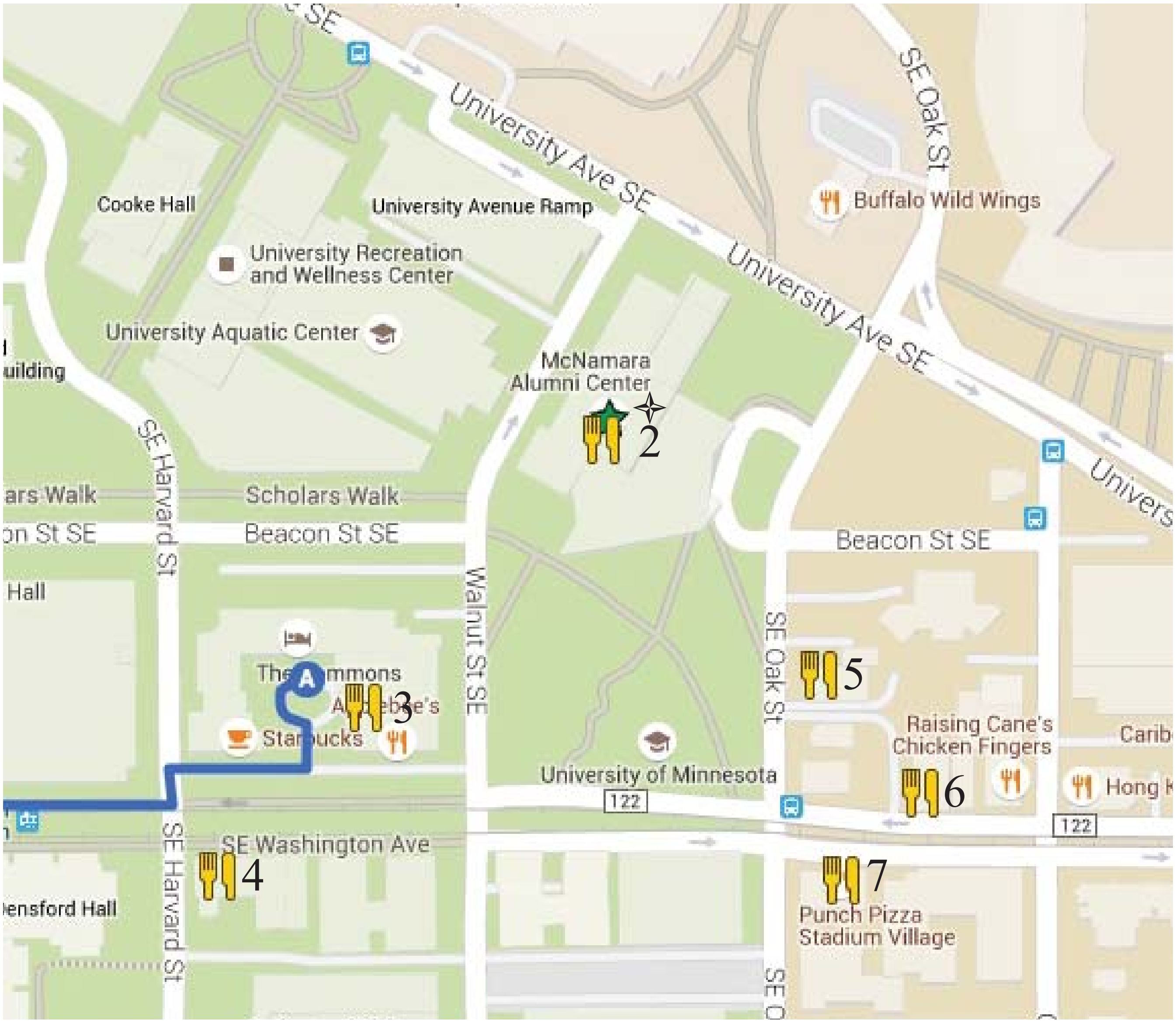
CAMPUS MAP



DINING OPTIONS

1. Surdyk's Northrop Cafe: Speciality deli sandwiches and salads. Outdoor seating on Northrup Mall.

2. D'Amico & Sons Cafe in McNamara: Salads, sandwiches, and hot options.

3. The Beacon Public House at The Commons Hotel: Dine-in, upscale option.

4. Espresso Expose: Across from the Commons Hotel. Worth crossing the street.

5. My Burger: Minneapolis-based. Burgers and fries. To-go or dine-in.

6. Bona Vietnamese Restaurant: UMN staple. Dine-in, but very quick.

7. Punch Pizza: Wood-fired pizzas or salads.

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STARnet is a U.S. based university research program that is guided strategically by industry and the U.S. government, but managed by the U.S. university community. It provides a multi-university, multi-disciplinary, collaborative research environment that is highly leveraged by both industry and U.S. Department of Defense funding. STARnet focuses on beyond CMOS technology options and systems integration and discovery to enable both CMOS and beyond CMOS components. The program also provides access to highly trained university graduate students.

We would also like to thank the UMN's School of Physics and Astronomy (www.physics.umn.edu) and Center for Micromagnetics and Information Technologies (MINT) (www.ee.umn.edu/groups/mint/) for their additional support of the workshop.

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C-SPIN is a world-leading center that brings together top researchers from across the nation to develop technologies for spin-based computing and memory systems.

The center goal is to investigate ground-breaking technologies that will enable computer systems that operate using the spin of an electron, as opposed to its charge, the basis of today's computers.

Spin-based logic and memory systems have the potential to overcome many of the limitations of conventional charge-based computer systems, which are reaching their fundamental limits. Therefore, spin-based computers have the potential to be faster, smaller and more energy-efficient.

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C-SPIN is led by Prof. Jian-Ping Wang and is headquartered in the Electrical and Computer Engineering Department at the University of Minnesota, Twin Cities. The center brings together 32 leading experts from 18 different universities working in a wide range of scientific disciplines. Further information about C-SPIN sponsors can be found at www.cspin.umn.edu.

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