2024年台日雙邊磁性技術研討會-尖端磁性應用中的物理

Taiwan-Japan Joint Symposium 2024 – Exploring Physics in Cutting -Edge Magnetic Applications


Koki Takanashi


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January 25
National Central University,
Taoyuan City, Taiwan

物理研究推動中心

會場(Venue)

The conference will be held at the National Central University (國立中央大學), Taoyuan City, Taiwan. No. 300, Zhongda Rd., Zhongli District, Taoyuan City 320317, Taiwan (R.O.C.)

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Taiwan-Japan Joint Symposium 2024 – Exploring Physics in Cutting -Edge Magnetic Applications

Program

Time	Speaker	Topic
9:00-9:20	**Registration**	
9:20-9:40	**Opening**	
9:40-10:10	Speaker: Yasushi Takemura (Yokohama National University) Chair: Chao-Ming Fu (NTU)	Transient and steady-state dynamics of magnetic nanoparticles
10:10-10:40	Speaker: Chao-Ming Fu (NTU) Chair: Yasushi Takemura (Yokohama National University)	Approach of preparing Fe_3O_4 magnetic nanoparticles for hyperthermia application.
10:40-11:00	**Break**	
11:00-11:30	Speaker: Yukio Nozaki (Keio University) Chair: Chao-Ming Fu (NTU)	Gyromagnetic Spin current generation in solids
11:30-12:00	Speaker: Chih-Huang Lai (NTHU) Chair:Yukio Nozaki (Keio University)	Spin-orbit-torque switching in a ferromagnet/antiferromagnet system.
12:00-13:30	**Lunch**	
13:30-14:00	Speaker: Takeshi Kato (Nagoya University) Chair: Chi-Feng Pai (NTU)	Planar Patterning of Magnetic Materials by Ion Implantation.
14:00-14:30	Speaker: Chi-Feng Pai (NTU) Chair: Takeshi Kato (Nagoya University)	SOT-MRAM for next generation artificial intelligence
14:30-15:00	Speaker: Takeshi Seki (Tohoku University) Chair: Yuan-Chieh Tseng (NYCU)	Metallic Superlattices Revisited
15:00-15:20	**Break**	
15:20-15:50	Speaker: Yuan-Chieh Tseng (NYCU) Chair: Takeshi Seki (Tohoku University)	Scalable SOT Devices with Nanopatterning and Antiferromagnetic SOT for Neuromorphic Computing
15:50-16:20	Speaker: Teruo Ono (Kyoto University) Chair: J.C.A. Huang (NCKU)	Superconducting diode effect
16:20-17:00	Discussion	

Name: **Yasushi Takemura**
Title: Professor
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Research: magnetic nanoparticles, magnetic sensor.

Biography:

Yasushi Takemura received the B.S., M.S., and Ph.D. degrees in Electrical and Electronic Engineering from Tokyo Institute of Technology, Japan, in 1988, 1990, and 1993, respectively. He is a Professor in Faculty of Engineering, Yokohama National University, Japan.

Publications: 190 papers in international journals, 5 books (chapters), and invited speaker for 40 international conferences.

He has been Tokyo Chapter Chair of Institute of Electrical and Electronics Engineers (IEEE) Magnetics Society and is currently President of Magnetics Society of Japan.

Selected Publications

[1] S. B. Trisnanto, Y. Takemura, "High-frequency Neel relaxation response for submillimeter magnetic particle imaging under low field gradient", *Phys. Rev. Appl.*, 14, 064065, 2020. DOI: 10.1103/PhysRevApplied.14.064065

[2] S. Ota, Y. Takemura, "Characterization of Neel and Brownian relaxations isolated from complex dynamics influenced by dipole interactions in magnetic nanoparticles", *J. Phys. Chem. C*, 123, 28859, 2019. DOI: 10.1021/acs.jpcc.9b06790

[3] Y. Takemura, S. B. Trisnanto, S. Ota, "Dynamic magnetization process of magnetic nanoparticles for biomedical applications", *J. Mag. Soc. Jpn.*, 27, 84, 2023. DOI: 10.3379/msjmag.2307R001

[4] S. B. Trisnanto, T. Kasajima, T. Akushichi, Y. Takemura, "Magnetic particle imaging using linear magnetization response-driven harmonic signal of magnetoresistive sensor", *Appl. Phys. Exp.*, 14, 095001, 2021. DOI: 10.35848/1882-0786/ac1d63

[5] F. Iob, S. Saggini, M. Ursino, Y. Takemura, "A novel wireless charging technique for low-power devices based on Wiegand transducer", *IEEE J. Emer. Select. Topics Power Elect.*, 11, 372, 2023. DOI: 10.1109/JESTPE.2021.3089680

[6] Y. Takemura, N. Fujinaga, A. Takebuchi, T. Yamada, "Battery-less Hall sensor operated by energy harvesting from a single Wiegand pulse", *IEEE Trans. Magn.*, 53, 4002706, 2017. DOI: doi: 10.1109/TMAG.2017.2713837

Transient and steady-state dynamics of magnetic nanoparticles

Yasushi Takemura[a], Suko Bagus Trisnanto[a], and Satoshi Ota[b]

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We report magnetization dynamics of magnetic nanoparticles responding to applied pulse and alternating magnetic fields. The magnetization dynamics is essential and determines characteristics in applications of magnetic nanoparticles. Static and dynamic magnetization curves of magnetic nanoparticle samples both of liquid and solid states exhibiting a superparamagnetic feature. We clarified the fast magnetization reversal of Néel relaxation followed by Brownian relaxation. The Brownian relaxation of the magnetic nanoparticle is accompanied by particle rotation which is measured as the response of the magnetization easy axis of the particle. We can quantify the heating ability of magnetic nanoparticles by measured AC hysteresis loops, which are conventionally determined by temperature measurements.

We also performed the magnetization measurement using a high-sensitive magnetic sensor. The sensitivity of sub-pT range was achieved in the measurement of magnetic nanoparticles, which was expected to develop fundamental characterizations of magnetic nanoparticles as well as to contribute applications, e.g., the magnetic particle imaging.

Acknowledgements: This study was partially supported by JSPS KAKENHI JP20H05652, JP20H02163, JP22K14268.

References

1) S. B. Trisnanto, Y. Takemura, "High-frequency Neel relaxation response for submillimeter magnetic particle imaging under low field gradient", *Phys. Rev. Appl.*, 14, 064065, 2020.
2) S. B. Trisnanto, S. Ota, Y. Takemura, "Two-step relaxation process of colloidal magnetic nanoclusters under pulsed fields", *Appl. Phys. Express.*, 11, 075001, 2018.
3) S. Ota, Y. Takemura, "Characterization of Neel and Brownian relaxations isolated from complex dynamics influenced by dipole interactions in magnetic nanoparticles", *J. Appl. Chem. C*, 123, 28859, 2019.

Name: **Chao-Ming FU**
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Research:
Nano-magnetic particles and biomedical applications

Biography

Vice President, Fo Guang University (2021/08-)

Professor, Physics Department, National Taiwan University (2006/07-)

Director, Center of Teacher Education, National Taiwan University (2019/08- 2021/07)

Director, Science and Technology Division at Moscow, Ministry of Science and Technology (2014/10- 2018/09)

Professor and Department Chair, Applied Physics Department, National University of Kaohsiung, Taiwan (2006/07- 2005/08)

Professor, Associate Professor, Physics Department, National Kaohsiung Normal University, Taiwan (1995/08-2006/07)

Visiting Researcher, Tokyo Institute of Technology, Japan (2001/08-2002/06)

Selected Publications

1. Shih-Yin Ho, I-Chun Chen, Yi-Jyun Chen, Chien-Hsing Lee, Chao-Ming Fu, Fei-Chih Liu, Horng-Huei Liou, **Static magnetic field induced neural stem/progenitor cells early differentiation and promote maturation**, Stem Cell International, Volume 2019, Article ID 8790176, 10 pages (2019).
2. Lei-Ching Huang · Chao-Ming Fu*, **Spontaneous Polarization and Dielectric Relaxation Dynamics of Two Novel Diastereomeric Ferroelectric Liquid Crystals**, Acta Physica Polonica Series A129, V1, p97-102, Jan (2016).
3. Shih-Chi Lee, Chao-Ming Fu*, and Fu-Hsiung Chang, "**Effects of core/shell structure on magnetic induction heating promotion in Fe3O4/-Fe2O3 magnetic nanoparticles for hyperthermia**", Applied Physics Letters 103, p.163104-163106 (2013).
4. Ming-Feng Chung, S. E. Chou, Chao-Ming Fu*, " **Time-dependent dynamic behavior of light diffraction in ferrofluid**", Journal of Applied Physics, **111**, 07B333 (2012).
5. Chao-Ming Fu, Yuh-Feng Wang, Yu-Feng Guo, Li-Shin Wang, May-Haw Chuang, and Thau-Ming Cham, "**Pharmacokinetics of intravenously injected Tc-99m labeled ferrite nanobeads**", Journal of Applied Physics **105**, 07B311 (2009).

Approach of preparing Fe_3O_4 magnetic nanoparticles for hyperthermia application

Chao-Ming Fu[1,2], Jen-Hsiang Wu[2], Jun-Ting He[2], Hong-Yi Lin[2], Liang-Chao Chang[2], Wen-Hsin Ko[2]
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Corresponding Author: Chao-Ming Fu

Fe_3O_4 nanoparticles with superparamagnetic properties have been widely used in biomedical applications. In this study, Fe_3O_4 magnetic nanoparticles are synthesized through co-precipitation, and the samples are subjected to heating by an AC magnetic field for hyperthermia applications. The specific absorption rate (SAR) of the samples is influenced by the process parameters involved in the chemical co-precipitation. To optimize the SAR within various experimental ranges, orthogonal experimental designs are employed to investigate the impact of process parameters on the AC magnetic field heating of Fe_3O_4 nanoparticles. The results will be presented in this report.

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Research: Spintronics, Spin dynamics, Spin mechatronics

Biography:

Dr. Yukio Nozaki is a Professor of Physics at Keio University in Yokohama, Japan. He obtained his bachelor's and master's degrees in Science from Keio University in Japan in 1993 and 1995, respectively. He received his Ph.D. in Physics from Keio University in 1998. After completing his Ph.D., he joined the Graduate School and Faculty of Information Science and Electrical Engineering of Kyushu University as a Assistant Professor in 1998 and was promoted to Associate Professor in 2006. Then, he returned to Department of Physics of Keio University as an Associate Professor in 2010 and was promoted to Professor in 2016. Since 2023, Professor Nozaki is serving as a Director for International Affairs of the Magnetics Society of Japan (MSJ) which is a sister society of IEEE Magnetic Society, and as a council member of Asian Union of Magnetic Society (AUMS).

His current research interests range from the fundamental physics of spintronics phenomena to the development of novel spintronics materials that can produce spin current efficiently for next-generation spintronics devices.

Selected Publications

[1] Kobayashi, YN et al. PRL **119**, 077202 (2017).
[2] Okano, YN et al., PRL **122**, 217701 (2019).
[3] Kurimune, YN et al., PRL **124**, 217205 (2020).
[4] Tateno, YN et al., PRB **102**, 104406 (2020).
[5] Kurimune, YN et al., PRB **102**, 174413 (2020).
[6] Tateno, YN et al., PRB **104**, L020404 (2021).
[7] Nakayama, YN et al., PRB **107**, (2023).

Gyromagnetic Spin Current Generation in Solids

Y. Nozaki[a]

[a] Department of Physics, Keio University, Japan

The gyromagnetic effect was discovered by Einstein, de Haas, and Barnett about a hundred years ago. They found that macroscopic rotation and magnetization of a macroscopic ferromagnet are convertible with each other. Strong gyromagnetic effect appears by increasing rotation frequency, implying that.a rotation frequency is equivalent to a magnetic field. The magnetization is originated from microscopic angular momentum of electrons in solid, i.e. spin angular momentum and orbital angular momentum. Therefore, the macroscopic rotation can give a torque on microscopic angular momentum of electrons via conservation law of angular momentum in a rotationally symmetric system.

From the microscopic point of view, the gyromagnetic effect is understood as an inertial effects of Dirac particles, which appears when a local inertial frame rotates. Hehl and Ni deduced the Hamiltonian in a rotating frame and found the spin rotation coupling (SRC) given by the inner product between spin angular momentum and angular velocity of rotation. It is noted that such a spin rotation coupling remains in the Hamiltonian under a nonrelativistic limit. The mechanical rotation $\boldsymbol{\Omega}$ in the SRC is coupled with spin angular momentum σ similarly to the magnetic field in the Zeeman effect. The amplitude of emergent magnetic field, so called “Barnett field”, is given by $\boldsymbol{\Omega}/\gamma$, where γ is the gyromagnetic ratio. Such a Barnett field is very weak so that we can observe the effect only in ferromagnetic materials so far. However, recent state of art technologies enable us to observe the Barnett field in non-magnetic elements.

In this talk, we provide three topics on the gyromagnetic effect, which can be applied to spintronics devices. First one is an acoustic gyromagnetic effect in ferromagnetic NiFe thin film, where we have observed phenomena based on magnon-phonon coupling via gyromagnetic effect. Second topic is associated with another acoustic gyromagnetic effect in nonmagnetic Cu films, whose spin orbit interaction is much weaker than platinum. Here, we will show some experimental results on an alternating spin current generation due to a gradient of acoustic Barnett field in Cu films. Third topic is related to the experimental study on current-induced spin torque via spin vorticity coupling in composition gradient interface.

Name: **Chih-Huang Lai**
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Research: SOT, antiferromagnets and spintronics

Biography

Professor Chih-Huang Lai received his Ph.D. degree in materials science and engineering at Stanford University in 1997. He returned to National Tsing Hua University (NTHU) in 1998. His research mainly focuses on novel materials for memory, information storage and renewable energy, especially on MRAM, magnetic storage and thin film solar cells. He has published more than 230 papers and awarded 50 patents. Prof. Lai's research does not only bring several significant breakthroughs on the fundamental understanding but result in substantial impacts on industrial applications. Therefore, he has received many prestigious awards, including Asian Union of Magnetics Societies (AUMS) Award, IEEE fellow and MRS-T fellow. Prof. Lai is the Associate Dean of College of Semiconductor Research and was Dean of College of Engineering, NTHU.

Selected Publications

[1] Rudis Ismael Salinas, Po-Chuan Chen. Chao-Yao Yang & Chih-Huang Lai, "Spintronic materials and devices towards an artificial neural network: accomplishments and the last mile", Materials Research Letters, 11, 2023.

[2] Po-Hung Lin, Bo-Yuan Yang, Ming-Han Tsai, Po-Chuan Chen, Kuo-Feng Huang, Hsiu-Hau Lin & Chih-Huang Lai , "Manipulating exchange bias by spin–orbit torque" *Nature Materials* 18, 335–341 (2019)

Spin-orbit-torque switching in a ferromagnet/antiferromagnet system

Chih-Huang Lai

[a]Department of Materials Science and Engineering, National Tsing Hua University, Taiwan, R.O.C.

Exchange bias, a shift in the hysteresis loop of a ferromagnet arising from interfacial exchange coupling between adjacent ferromagnetic (FM) and antiferromagnetic (AFM) layers, is an integral part of spintronic devices. Here, we show that spin–orbit torque (SOT) generated from spin current, a promising approach to switch the ferromagnetic magnetization of next-generation magnetic random-access memory, can also be used to manipulate the exchange bias. Applying current pulses to a Pt/Co/IrMn perpendicular magnetized trilayer causes concurrent switching of ferromagnetic magnetization and exchange bias. Using time-resolved magneto-optical Kerr microscopy, we further show that the FM as well as exchange bias can be either partially or completely switched by sub-nanosecond current pulses, which enables us to achieve well controlled multi-levels. Combing electrical and spectroscopic analysis, we also reveal that the spin configurations of bulk AFM can be manipulated by SOT.

Name: **Takeshi KATO**
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Research: Magnetic thin films

Biography:

Dr. Takeshi Kato is a Professor of Institute of Materials and Systems for Sustainability at Nagoya University, Japan. He obtained his bachelor's and master's degrees in Engineering from Nagoya University in 1993 and 1995, respectively. He received Doctor of Engineering from Nagoya University in 1998. In 1998, he became an assistant professor of the Department of Electronics, Nagoya University, and in 2007 he was an associate professor of the Department of Quantum Engineering, Nagoya University. Since 2020, he is a professor of Institute of Materials and Systems for Sustainability, Nagoya University.

He is working on magnetic thin films for storage and sensor applications, such as bit-patterned media fabricated by ion irradiation, thermally assisted STT switching, SOT switching, and GMR sensor devices. He has also studied about magnetization dynamics of magnetic thin films for efficient STT and SOT switching. He has authored or coauthored over 140 journal articles and made 18 invited presentations at the international conferences. He serves as a member of IEEE Magnetics Society Administrative Committee and a chair of IEEE Magnetics Society Nagoya Chapter. He has been a chair of international advisory committee of the MORIS 2024 conference.

Selected Publications

[1] T. Kato et al., J. Appl. Phys. **105**, 07C117 (2009).
[2] T. Kato et al., Crystals **9**, 27 (2019).
[3] N Roschewsky et al., Appl. Phys. Lett. **109**, 112403 (2016).
[4] T. Kato et al., IEEE Trans. Magn. **48**, 3288 (2012).

Planar Patterning of Magnetic Materials by Ion Implantation

T. Kato[a, b] and D. Oshima[b]

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[b] Department of Electronics, Nagoya University, Japan

Nano-patterned magnetic materials are quite important for industrial applications such as hard disk drives (HDDs), magnetic random access memories (MRAMs), and magnetic sensors. Conventionally, the magnetic materials has been patterned by ion milling and lift-off techniques. Ion beam irradiation technique provides an alternative method to pattern magnetic thin films without changing the surface topography of the media [1]. This technique is quite attractive for the fabrications of HDD bit patterned media and skyrmion racetrack memories. We have studied the ion beam patterning of $L1_0$ phase MnGa films, since the MnGa exhibits large perpendicular anisotropy and its ferromagnetism is suppressed by quite low dose ion irradiation [2, 3]. This paper reviews ion irradiation to $L1_0$-MnGa films and magnetic patterning by the ion irradiation. Moreover, we briefly introduce our recent study on the fabrication of magnetic patterned structure with laterally modified magnetic property.

[1] C. Chappert et al., Science **280**, 1919 (1998).
[2] D. Oshima et al., IEEE Trans. Magn. **49**, 3608 (2013).
[3] D. Oshima et al., IEEE Trans. Magn. **54**, 3200207 (2018).

Name: **Chi-Feng Pai**
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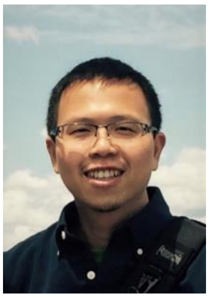
Research: spintronics, spin-orbit torque, MRAM



Biography

Professor Chi-Feng Pai is an IEEE Senior Member and an active researcher/educator in the field of spintronics and magnetism. He received his Ph.D. in Applied & Engineering Physics (AEP) from Cornell University in 2014. His graduate studies focused on the giant spin Hall effect in transition metals and the spin-orbit torques (SOTs) in magnetic heterostructures. After graduating from Cornell, he worked at the Massachusetts Institute of Technology as a postdoctoral research associate in the Department of Materials Science and Engineering on developing various types of advanced SOT characterization techniques. He is currently a faculty member in the Department of Materials Science and Engineering at National Taiwan University (2016-present), the elected Chair of IEEE Magnetics Society Taiwan Chapter (2022-present), and Researcher in the Corporate Research of Taiwan Semiconductor Manufacturing Company (2022-present). He is also the recipient of Asian Union of Magnetics Societies (AUMS) Young Researcher Award in 2016 and the co-author of “Magnetic Memory Technology: Spin-Transfer Torque MRAM and Beyond” published by Wiley-IEEE Press (1st Edition, 2021).

Selected Publications

[1] T.-Y. Chen, H.-I. Chan, W.-B. Liao, and C.-F. Pai, "Current-induced spin-orbit torque and field-free switching from Mo-based magnetic heterostructures," Physical Review Applied 10, 044038 (2018).

[2] T.-Y. Chen, C.-W. Peng, T.-Y. Tsai, W.-B. Liao, C.-T. Wu, H.-W. Yen, and C.-F. Pai, "Efficient Spin-Orbit Torque Switching with Nonepitaxial Chalcogenide Heterostructures," ACS Appl. Mater. Interfaces 12, 7788 (2020).

[3] Y.-H. Huang, C.-C. Huang, W.-B. Liao, T.-Y. Chen, and C.-F. Pai, "Growth-dependent Interlayer Chiral Exchange and Field-free Switching," Physical Review Applied 18, 034046 (2022).

[4] Denny D. Tang and Chi-Feng Pai, Magnetic Memory Technology: Spin-Transfer Torque MRAM and Beyond, Wiley-IEEE Press, 1st Edition (January 7, 2021).

SOT-MRAM for next generation artificial intelligence

Chen-Yu Hu[a], Chun-Yi Lin[a], Mingyuan Song[b], Xinyu Bao[b], and Chi-Feng Pai[a]

[a] Department of Materials Science and Engineering, National Taiwan University, Taiwan

[b] Corporate Research, Taiwan Semiconductor Manufacturing Company, Taiwan

In recent years, the pursuit of efficient computing architectures for next generation artificial intelligence applications has led to the exploration of novel memory technologies. Spin-orbit torque magnetic random-access memory (SOT-MRAM) emerges as a promising candidate, exhibiting rapid operation speeds and non-volatile characteristics. In this presentation, I will first address the potentials of using SOT-MRAM devices for neuromorphic computing with a simple artificial neural network. Next, I will showcase the first successful integration of SOT-MRAM into the paradigm of Compute-in-Memory (CIM), a transformative approach aiming to perform computations directly within memory units. A novel SOT-MRAM device structure with 10ns write speed and >100x scalable resistance and read current are demonstrated to address the persistent problems of the traditional 2D crossbar array, leveraging its read/write path separation nature. Lastly, I will discuss the possibility of using SOT-MRAM devices for quantum-inspired machine applications, providing a tentative approach to construct an efficient Ising machine for solving combinatory-hard problems.

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Research: Magnetic materials, spintronics

Biography:

Koki Takanashi received his BS, MS, and Ph.D. degrees in Physics from the University of Tokyo. After postdoctoral research at Tohoku University, he joined the faculty there and became a Professor (2000) and the Director (2014) of the Institute for Materials Research at Tohoku University. In 1994-1995 he was an Alexander von Humboldt Research Fellow at the Forschunszentrum Jülich in Germany. He is now a Professor Emeritus at Tohoku University, and the Director General at the Advanced Science Research Center, Japan Atomic Energy Agency. He has published over 500 original or review papers in internationally reputed journals, has given nearly 90 invited talks at international conferences, and 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), MSJ Award (2019, Magnetic Society of Japan), Murakami Memorial Award (2021, Japan Institute of Metals), and AUMS Award (2022, Asian Union of Magnetic Societies). He was the leader of a national project in Japan: "Creation and Control of Spin Current" (2007-2011). He also served as the President of Magnetics Society of Japan (2017-2019), Asian Union of Magnetics Societies (2018-2019), and Japan Institute of Metals (2020-2021), and as a General Cochair of INTERMAG2023. His research interests include magnetism and magneto-transport in nanostructures, magnetic materials for spintronics, and spin current phenomena.

Selected Publications

[1] "Giant spin Hall effect in perpendicularly spin-polarized FePt/Au devices"
T. Seki, Y. Hasegawa, S. Mitani, S. Takahashi, H. Imamura, S. Maekawa, J. Nitta and K. Takanashi, Nature Materials, Vol. 7, No. 2, pp. 125-129 (2008).

[2] "Large interface spin-asymmetry and magnetoresistance in fully epitaxial $Co_2MnSi/Ag/Co_2MnSi$ current-perpendicular-to-plane magnetoresistive devices"
T. Iwase, Y. Sakuraba, S. Bosu, K. Saito, S. Mitani, and K. Takanashi
Applied Physics Express, Vol. 2, No. 6, pp. 063003/1-3 (2009).

[3] "Fabrication and characterization of $L1_0$-ordered FeNi thin films" (*Topical Review*)
K. Takanashi, M. Mizuguchi, T. Kojima and T. Tashiro
J. Phys. D: Appl. Phys., Vol. 50, No. 48, pp. 483002/1-9 (2017).

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Research: Magnetic materials, Spintronics

Biography:

Takeshi Seki received B.Eng. in 2002, M.Eng. in 2003, and Ph.D. in 2006 from Tohoku University, Japan. From 2006 to 2008, he was a postdoctoral researcher at Institute for Materials Research (IMR) in Tohoku University. Then, he moved to Graduate School of Engineering Science in Osaka University, Japan as a postdoctoral researcher. He became an Assistant Professor of IMR, Tohoku University in 2010, and promoted to an Associate Professor of IMR in 2016. From December 2023, he is a professor of IMR. His research interests include the materials development for spintronics and nanomagnetism, physics of spin transfer phenomena and spin current, and control of magnetization reversal and spin dynamics. He was awarded the Japan Institute of Metals and Materials 22nd Young Researcher Award in 2012, The Magnetics Society of Japan Outstanding Research Award in 2016, The 40th Honda Memorial Young Researcher Award in 2019, The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, The Young Scientists' Prize in 2019, and The Japan Institute of Metal and Materials, 80th Meritorious Award in 2022.

Selected Publications

[1] "Enhancement of the anomalous Nernst effect in Ni/Pt superlattices"
T. Seki, Y. Sakuraba, K. Masuda, A. Miura, M. Tsujikawa, K. Uchida, T. Kubota, Y. Miura, M. Shirai, and K. Takanashi, Phys. Rev. B **103**, L020402-1-7 (2021).

[2] "Large spin anomalous Hall effect in L10-FePt: Symmetry and magnetization switching"
T. Seki, S. Iihama, T. Taniguchi, and K. Takanashi, Phys. Rev. B **100**, 144427-1-8 (2019).

[3] "Spin Wave-Assisted Reduction in Switching Field of Highly Coercive Iron-Platinum Magnets"
T. Seki, K. Utsumiya, Y. Nozaki, H. Imamura, and K. Takanashi, Nature Communications, **4**, 1726, doi: 10.1038/ncomms2737 (2013).

Metallic Superlattices Revisited

Koki Takanashi[a] and Takeshi Seki[b]
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Metallic superlattices consisting of different metal layers alternated periodically in a nanometer scale, were extensively studied for perpendicular magnetic anisotropy (PMA), giant magnetoresistance (GMR) and interlayer exchange coupling (IEC) in 1980's-90's, giving the basis of spintronics in the 21st century. We worked on magnetic ordered alloys for spintronics, and reported a lot of results including the observation of giant spin Hall effect and the demonstration of spin wave-assisted magnetization switching in device structures with high magnetic anisotropy $L1_0$-FePt, and the enhancement of current-perpendicular-to-plane (CPP) GMR and the observation of high efficiency spin torque oscillation using half-metallic Heusler alloys in previous papers [1].

The recent progress of spintronics shows new developments such as spin orbitronics, antiferromagnetic spintronics, and spin caloritronics. For these emerging research areas, the importance of interfaces has attracted much attention because of the possible enhancement of spin-orbit interaction at interfaces. The metallic superlattice as an assembly of interfaces is useful for the systematic study of interface effects.

In our group, metallic superlattices have been studied from the viewpoint of modern spintronics:

For spin orbitronics, the relationship between PMA and spin orbit torque (SOT) has been investigated in symmetric Pt/Co/Pt and Pd/Co/Pd, and asymmetric Pd/Co/Pt layered systems, revealing a clear correlation between the field-like SOT and the Rashba-type contribution to PMA induced by broken inversion symmetry [2].

For antiferromagnetic spintronics, Cu-Ir alloy has been found to show a large spin Hall effect with definite antiferromagnetic IEC induced when it is sandwiched by two ferromagnetic layers [3,4]. The magnetization switching process induced by SOT has also been investigated in antiferromagnetically-coupled layered systems Pt/Co/Ir/Co/Pt, using domain structure observation and a numerical calculation based on a macrospin model [5]. Furthermore, large antisymmetric IEC in addition to symmetric IEC has been observed [6], and the influence of the antisymmetric IEC on magnetization switching has been discussed.

For spin caloritronics, the enhancement of anomalous Nernst effect has been confirmed in several superlattices with ferromagnetic and nonmagnetic metals alternated [7,8]. Furthermore, the enhanced anomalous Nernst effect and suppressed thermal conductivity have been demonstrated in metallic superlattices.

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Selected Publications

1. T. C. Hsin, H. Y. Lin, Y. L. Lin, J. W. Chen and **Y. C. Tseng***, "Resistive memristor coupled with multilevel perpendicular magnetic states", *ACS Appl. Elec. Mater.* 5, 6315 (2023).
2. Y. H. Huang, C. Y. Yang*, C. W. Cheng, A. Lee, C. H. Tseng, H. Wu, Q. Pan, X. Che, C. H. Lai, K. L. Wang, H. J. Lin and **Y. C. Tseng***, "A spin-orbit torque ratchet at ferromagnet/antiferromagnet interface via exchange spring", *Adv. Func. Mater.* 32, 2111653 (2022).
3. C. W. Cheng, K. M. Chen, J. H. Wei, Y. C. Hsin, S. S. Sheu, C. I. Wu and **Y. C. Tseng***, "Stray field and combined effects on device miniaturization of the magnetic tunnel junctions", *J. Phys. D: Appl. Phys.* 55, 195002 (2022).
4. Y. J. Lin, C. Y. Teng, C.M. Hu, C. J. Su,* and **Y. C. Tseng**,*" Impacts of surface nitridation on crystalline ferroelectric phase of $Hf_{1-x}Zr_xO_2$ and ferroelectric FET performance", *Appl. Phys. Lett.* 119, 192102 (2021).
5. S. J. Chang, C. Y. Teng, Y. J. Lin, T. M. Wu, M. H. Lee, Lee, B. H. Lin, M. T. Tang, T. S. Wu C. M. Hu, E. Y. T. Tang*, and **Y. C. Tseng***, "Visualizing ferroelectric uniformity of $Hf_{1-x}Zr_xO_2$ films using x-ray mapping", *ACS Appl. Mater. & Interf.* 13, 29212 (2021).

Scalable SOT Devices with Nanopatterning and Antiferromagnetic SOT for Neuromorphic Computing

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I will present three subjects in this talk. I will first present a scalable T-shape W/CoFeB inverse spin-Hall (ISH) device with nanopatterning processes. The device exhibited a favorable scaling law as the ISH signal was enhanced by reducing the W channel length. An ultra-thin Cu insertion can reduce switching coecivity without compromising the ISH signal. I will then present a tri-layer spin-orbit torque (SOT) structure with a light metal insertion in the second topic. The tri-layer design can reduce the switching current by ~30% compared to the conventional bi-layer device due to a slightly asymmetric interface caused by the light metal insertion. In the last, I will present neuromorphic devices using perpendicular antiferromagnetic (AFM) SOT with systems of IrMn and NiO. We found that AFM systems favoring field-free switching may not necessarily be desirable for neuromorphic computing regarding digit/image recognition.

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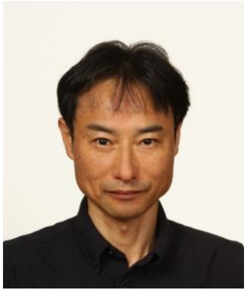

Biography:

Teruo Ono received the B.S., M.S., and D.Sc. from Kyoto University in 1991, 1993, and 1996, respectively. After a one year stay as a postdoctoral associate at Kyoto University, he moved to Keio University where he became an assistant professor. In 2000, he moved to Osaka University where he became a lecturer and an associate professor. Since 2004, he has been working at Kyoto University, where he is now a professor. He has published over 400 technical articles in peer-reviewed journals, including book chapters and review articles, and has given more than 150 invited presentations at international conferences.

Selected Publications

(1) H. Narita et al., "Field-Free Superconducting Diode Effect in Noncentrosymmetric Superconductor/Ferromagnet Multilayers", Nature Nanotechnology 17, 823 (2022).

(2) S. Seki et al., "Direct visualization of the three-dimensional shape of skyrmion strings in a noncentrosymmetric magnet", Nature Materials 21, 181 (2022).

(3) F. Ando et al., "Observation of superconducting diode effect", Nature 584, 373 (2020).

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Superconducting Diode Effect

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The diode effect is fundamental to electronic devices and is widely used in rectifiers and AC-DC converters. However, conventional diodes have an energy loss due to finite resistance. We found the superconducting diode effect (SDE) in Nb/V/Ta superlattices with a polar structure, which is the ultimate diode effect exhibiting a superconducting state in one direction and a normal state in the other [1-3]. SDE can be considered as the nonreciprocity of the critical current for the metal-superconductor transition. We also found the reverse effect, i.e., the nonreciprocal critical magnetic field under the application of the supercurrent [4]. We also found that the polarity of the superconducting diode shows a sign reversal as a magnetic field is increased [5], which can be considered as the crossover and phase transitions of the finite-momentum pairing states predicted theoretically [6]. SDE in Nb/V/Ta superlattices needs an application of an external magnetic field to break the time reversal symmetry, which is a disadvantage in applications. We recently succeeded in demonstrating SDE in a zero-field by introducing ferromagnetic layers in superlattices [7, 8]. The polarity of the SDE is controlled by the magnetization direction of the ferromagnetic layer, leading to development of novel non-volatile memories and logic circuits with ultralow power consumption.

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