

Quantum Radiation Energy Research Section

H. Ohgaki, Professor
 T. Kii, Associate Professor (concurrent)
 H. Zen, Assistant Professor
 Jordi Cravioto Caballero, Program-Specific Assistant Professor

1. Introduction

Coherent-radiation energy with a wide wavelength tunability and a high power is an indispensable tool for exploiting cutting-edge science. The research in this section aims at generating and application of new quantum-radiation energy. Free-electron laser (FEL) is one of such radiation. We have been developing a mid-infrared FEL, KU-FEL. To extend study field wider wavelength region, a coherent A compact THz source, high Tc undulator for X-ray generation, and Laser Compton Gamma-ray (LCS) for isotope imaging have been carried out. Transdisciplinary research on renewable energy has also been promoted through international collaborations.

2. Free-electron Laser

FEL is a next generation light source because of its wide wavelength tunability where the conventional lasers cannot reach, potential high efficiency, and high peak power. However, the system is usually much larger and the cost is higher than conventional lasers. We are going to overcome these difficulties by exploiting an RF (radio-frequency) gun, a high Tc undulator, etc.

2.1 KU-FEL

The target wavelength of KU-FEL is MIR (Mid infra-red) regime, from 5 to 20 μm , with high-power and turnability for basic researches on energy materials. Figure 1 shows a schematic drawing of the KU-FEL system. The KU-FEL consists of a 4.5-cell thermionic RF gun, a 3-m travelling wave accelerator tube, a beam transport system, and a 1.8-m undulator and a 5-m optical resonator. The FEL device now can cover the wavelength range from 3.4 to 28 μm . The maximum macro-pulse energy which can provide is around 60 mJ in a 2- μs macro-pulse at the wavelength of 9.8 μm . The FEL is routinely operated and opened for internal and external users.

For increasing the peak power of the KU-FEL, the photocathode operation of the 4.5-cell thermionic RF gun has been established. Under the photocathode operation, the micro-pulse energy of 100 μJ and the world highest extraction efficiency (9.4%) of the oscillator-type FEL has been achieved. Then the micro-pulse duration was shortened down to 150 fs

(~ 4.2 cycles at 11 μm).

For further increase of the peak power of KU-FEL, newly fabricated 1.6-cell RF gun has been installed at the upstream side of the accelerator tube. The initial commissioning of the new RF gun was successfully finished and FEL lasing with the electron beam generated from the gun has been achieved. Currently a copper cathode is used and the electron bunch charge is small and the FEL intensity is not so high. The cathode will be exchanged to CsTe to increase the FEL intensity.

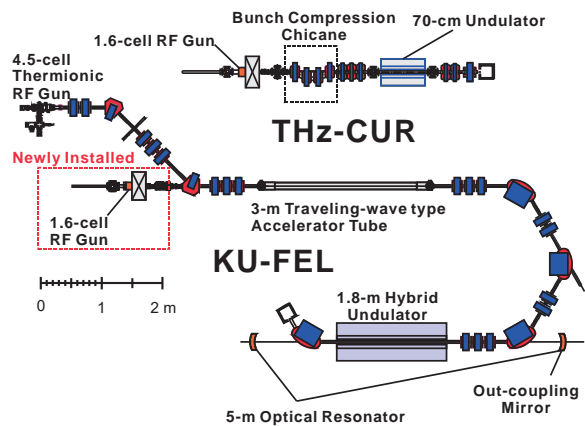


Fig. 1 Schematic drawing of the KU-FEL and THz-CUR

2.2 THz Coherent Undulator Radiation Source

A new compact terahertz coherent undulator radiation source (THz-CUR in Fig. 1) has been constructed. It consists of a 1.6-cell RF-gun, a solenoid magnet, a magnetic chicane bunch compressor, a triplet quadrupole magnet, a planar undulator, and a laser system for photocathode. In this device, short electron bunches are generated by the photocathode RF gun and the bunch compressor. The electron bunches are injected to the undulator and intense coherent undulator radiation can be generated.

The 1.6 cell RF gun used for the THz-CUR was replaced with an energy chirping cell attached RF gun for improving its performance under collaboration with Dr. Sakaue, Tokyo University. The gun utilizes a velocity bunching scheme for generating ultra-short electron bunch. A commissioning experiment has been done and the saturation of THz peak power due to the space charge effect can be success-

fully suppressed.

The polarization control method of the THz-CUR has been developed under collaboration with Dr. Kashiwagi, Tohoku University. The polarization state of the THz-CUR can be easily controlled from linear to left-handed circular and right-handed circular without significant power loss.

2.3 Application of MIR-FEL and THz-CUR

Many application researches of MIR-FEL and THz-CUR have been performed under the Joint Usage/Research Center for Zero Emission Energy Research of our Institute. In JFY2022, 18 external user groups used KU-FEL.

3. Bulk SC Staggered Array Undulator

An undulator with strong magnetic field will play an important role in future synchrotron light sources and FELs. We have developing a new undulator which consists of stacked bulk high critical temperature superconductors array and a solenoid magnet. As a next prototype of this type of undulator, we have developed new prototype consists of a new solenoid whose maximum field was 6 T and GM cryocooler. In order to reduce field amplitude fluctuation and to increase field strength, hybrid structure with vanadium permendur has been tested (Fig. 3).

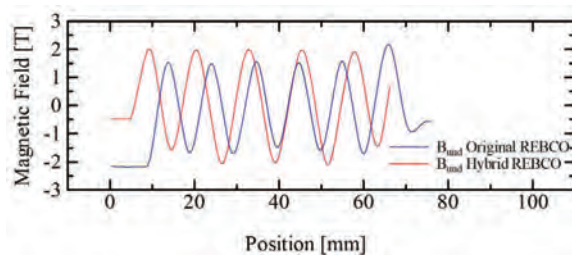


Fig. 3 Undulator field using the GdBaCuO bulk superconductor and vanadium permendur (red line: Hybrid REBCO) is stronger than that of conventional GdBaCuO bulk superconductor (blue line: Original REBCO). Fluctuation of peak field strength is slightly reduced.

4. Isotope Imaging for Nuclear Safety and Security

We have proposed the F-LCS beam which has broader energy bandwidth with a small beam size and a spatially uniform energy spectrum. By using a helical undulator installed in a storage ring, such as the APPLE-II undulator in the BL1U beamline of UVSOR synchrotron facility, a circular motion of electrons stored in the storage ring can be excited. This circular motion of electrons widens the electron beam size and divergence. Due to the LCS interaction principle, broader bandwidth and a wider spatial distribution of the scattered gamma-ray beam can be expected. A simulation with EGS5 code has been performed and the proof of principle experiment car-

ried out in the BL1U of UVSOR.

5. Social aspects of energy use

Despite the enormous efforts, more than 775 million people remain without electricity in 2023, of which 31 million live in Southeast Asia. Electrification can positively influence poverty eradication and development as well as exacerbate already existing inequalities in those communities. Our group investigates such effects with a perspective focused on quality of life, comparing the process and results of different electrification systems in rural contexts in SE Asia (Fig. 5). Applying qualitative techniques, our most recent studies have found that PV systems have improved the capabilities for education in rural households, reduced reliance on kerosene lamps and car batteries, and helped social and family interaction. Also, how the system's capacity can limit economic development or create concerns about the shift in lifestyle and sleep cycles, given the extended use of lighting at homes.



Fig. 5 Rural electrification survey sites 2016-2022

In urban contexts of ASEAN, our group has analysed how household roles affect efficient appliance purchasing intention. Finally, in the context of Latin America, we also study geographical and socio-cultural characterizations of household energy services.

Acknowledgment

All our research work have been supported by the KAKENHI, Q-LEAP(MEXT), JASTIP(JST), UVSOR Collaboration Research, The Heiwa Nakajima Foundation, The Murata Foundation, Hitachi Zaidan, CSEAS DASU (Kyoto University), and the Laboratory for Complex Energy Processes Collaboration Research (IAE).

Collaboration Works

大垣英明, University of Malaya (マレーシア), 倉田奨励基金

大垣英明, NSTDA (タイ), JASTIP「日 ASEAN 科学技術イノベーション共同研究拠点—持続可能開発研究の推進」

大垣英明, University of Malaya (マレーシア), JASTIP-net

Financial Support

1. Grant-in-Aid for Scientific Research

大垣英明, 基盤研究(B), F-LCS レーザーコンプトン散乱 γ 線による同位体イメージングの高度化に関する研究

全炳俊, 基盤研究(B), 共振器型自由電子レーザーの引き出し効率飛躍的向上に関する研究

全炳俊, 基盤研究(B), 超短パルス自由電子レーザーによる長波長赤外強光子場科学の開拓 (分担金)

金城良太, 若手研究, 高温超伝導クランクリングを用いたアンジュレータ

Cravioto Jordi, 基盤研究(B), 包括的 QoL 評価法の確立: 東南アジアの僻地電化における幸福度と不公平

2. Others

大垣英明, 理化学研究所, 次世代アンジュレータのための高温超伝導体の評価研究

大垣英明, Paul Scherrer Institute (スイス), Testing of REBCO bulk undulator prototype

大垣英明, 東京大学, 「先端レーザーイノベーション拠点「次世代アト秒レーザー光源と先端計測技術の開発」部門」「自由電子レーザーで駆動する高繰り返しアト秒光源のための基礎基盤技術の研究」)

大垣英明, 科学技術振興機構, 日 ASEAN 科学技術イノベーション共同研究拠点—持続可能開発研究の推進—

大垣英明, 科学技術振興機構, サトウキビ収穫廃棄物の統合バイオリファイナリー

大垣英明, (公財) トヨタ財団, 異なる国・セクターを繋ぐ科学技術イノベーションコーディネーションに関する学びあい: 人材育成プログラムの開発と政策提言

Publications

R. Kinjo, C. Marco, K. Zhang, X. Liang, T. Schmidt, M. D. Ainslie, A. R. Dennis, J. H. Durrell, Inverse analysis of critical current density in a bulk HTS undulator, *Physical Review Accelerators and Beams*, 25, 043502, 2022

RG. Ochoa, DI. Avila-Ortega, J. Cravioto, Energy services' access deprivation in Mexico: A geographic, climatic and social perspective, *Energy Policy*, 164, 112822, 2022

T. Kawasaki, H. Zen, T. Sakai, Y. Sumitomo, K. Nogami, K. Hayakawa, T. Yaji, T. Ohta, T. Nagata, Y. Hayakawa, Degradation of Lignin by Infrared Free Electron Laser, *Polymers*, 14, 12, 2401, 2022

Z. Ihama, I. Subramaniam, A.A. Jamaludin, W.A.A. Qadr I. Wan-Mohtar, S.A. Halim-Lim, H. Ohgaki, K. Ishihara, M.R.A. Mansor, Analysing dimensions and indicators to design energy education framework in Malaysia using the analytic hierarchy process (AHP), *Energy Reports*, 8, 1013-1024, 2022

R. Miyagawa, D. Kamibayashi, H. Nakamura, M. Hashida, H. Zen, T. Somekawa, T. Matsuoka, H. Ogura, D. Sagae, Y. Seto, T. Shobu, A. Tominaga, O. Eryu, N. Ozaki, Crystallinity in periodic nanostructure surface on Si substrates induced by near- and mid-infrared femto-second laser irradiation, *Scientific Reports*, 12, 20955, 2022

河野哲朗, 寒河江登志朗, 境武志, 全炳俊, 大垣英明, 早川恭史, 岡田裕之, 自由電子レーザーの齒科分野での利用—LEBRA-FEL・KU-FEL での研究から—, *レーザー加工学会誌*, 29, 3, 166-171, 2022

N. Sei, H. Zen, and H. Ohgaki, Deformation of an electronic bunch caused by free-electron lasers, *Physica Scripta*, 98, 025510, 2023

Y. Uozumi, T. Furuta, Y. Yamaguchi, H. Zen, T. Kii, H. Ohgaki, E. Velicheva, V. Kalinnikow, Z. Tsamalaidze, P. Evtoukhovitch, Study of crystalline scintillator response with development of single-electron beam of 2–6 MeV at KU-FEL, *Journal of Nuclear Science and Technology*, 2023

H. Negm, H. Zen, H. Ohgaki, Comprehensive simulation study on CT isotope imaging beyond the experiment on the Pb-208 based on nuclear resonance fluorescence, *Journal of Nuclear Science and Technology*, 59, 7, 875-887, 2022

V. Vai, S. Eng, C. Chhlonh, H. Ohgaki, Economic Anal-

ysis of a Grid-Connected Rooftop PV System for a Factory in Phnom Penh, Regional Conference in Mechanical Manufacturing Engineering, 1177-1186, 2022

S. Sukara, K. Kongmali, S. Rimjaem, H. Ohgaki, Design and Simulation of the MIR-FEL Generation System at Chiang Mai University, IPAC2022 - Proceedings, TUPOPT030, 2022

H. Ohgaki, K. Ali, T. Kii, H. Zen, M. Fujimoto, Y. Taira, T. Hayakawa, T. Shizuma, Generation of Flat-Laser Compton Scattering Gamma-ray Beam in UVSOR, IPAC2022 - Proceedings, THPOMS046, 2022

J. Bo, H. Zen, R. Akasegawa, K. Hachiya, K. Yoshida, H. Ohgaki, Selective excitation of LO_3 phonon mode of $SrTiO_3$, 47th International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz, 2022

羽島良一, 全炳俊, 大垣英明, 長波長赤外領域における数サイクル FEL パルスによる気体、固体の発光現象, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 771-774, 2023

Y. Zhao, H. Ohgaki, H. Zen, Simulation of a new photocathode RF gun in KU-FEL, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 115-117, 2023

坂本文人, 全炳俊, 平義隆, 加藤政博, 山川清志, 近藤祐治, 佐々木昭二, 細谷潤, 今野弘樹, 光クライストロン用バンチャー電磁石の性能改善に関する検討, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 775-779, 2023

全炳俊, 山崎潤一郎, 藤本將輝, 林憲志, 太田紘志, 平義隆, 加藤政博, UVSOR-FEL の再立上げと Intra-cavity Compton Scattering によるガンマ線発生, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 949-952, 2023

全炳俊, 紀井俊輝, 大垣英明, 京都大学自由電子レーザ施設の現状, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 1079-1083, 2023

紀井俊輝, 富田優, 赤坂友幸, バルク MgB_2 を用いた超伝導アンジュレータ試験機の開発, Proceedings of the 19th Annual Meeting of Particle Accelerator Society of Japan, 545-547, 2023

Anugerah Yuka Asmara, AR. Rohman Taufiq Hidayat, B. Kurniawan, H. Ohgaki, T. Mitsufuji, J. Cravioto, Building a Sustainable Photovoltaic Innovation System in Indonesia Through Network Governance Perspective, Environment & Policy, Environmental Governance in

Indonesia, A. Triyanti et al. (eds.), 61, 463-485, 2023

Presentations

H. Ohgaki, Current biogas-to electricity Status, pilot case and funding opportunities, Biogas-to-Electricity Focus Group Discussion (FGD) in ASEAN, Online, 2022.3.17

紀井俊輝, 富田優, 赤坂友幸, バルク MgB_2 アレイを用いた周期交替磁場の生成, 2022 年度第 103 回春季低温工学・超伝導学会研究発表会, タワーホール船堀, 2022.6.21

H. Ohgaki, Accelerator and Photon Sources, 2022 UST Global Mentoring Conference, Online, 2022.6.22

H. Ohgaki, Electron Accelerators and Generation of Quantum Radiations, The 11th Korea-Japan Summer School, Kyeongju, 2022.8.1

H. Ohgaki, Current Global Energy Situation and Carbon-Neutral 2050, The 9th International Symposium on the Fusion of Science & Technologies and The 2nd Rajamangala University of Technology Suvarnabhumi International Conference, Rajamangala University of Technology Suvarnabhumi, 2022.8.17

H. Zen, H. Ohgaki, R. Hajima, Observation of Burnham-Chiao ringing with pi-phase jumps in a high-efficiency superradiance FEL oscillator, The 40th International Free Electron Laser Conference (FEL2022), Trieste Convention Center, Trieste, Italy, 2022.8.23

H. Zen and H. Ohgaki, Origin of the complex beam profile of a hole-coupled free electron laser oscillator, The 40th International Free Electron Laser Conference (FEL2022), Trieste Convention Center, Trieste, Italy, 2022.8.22

J.Y.H. Bo, H. Zen, R. Akasegawa, K. Hachiya, K. Yoshida, H. Ohgaki, Selective Excitation of LO_3 Phonon Mode of $SrTiO_3$, 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz) 2022, The Aula Conference Center of Delft University of Technology, Delft, Netherland, 2022.8.29

H. Zen, H. Ohgaki, R. Hajima, High extraction efficiency operation of oscillator-type Free Electron Laser driven by a normal conducting linac, 31st International Linear Accelerator Conference LINAC2022, The Arena Convention Center, Liverpool, United Kingdom, 2022.9.1

大垣英明, Khaled Ali, 紀井俊輝, 全炳俊, 早川岳人, 静間俊行, 藤本将輝, 平義孝, Generation OF Flat-Laser Compton Scattering Gamma-Ray Beam in UVSOR: Simulation Study, 日本原子力学会 2022 年秋の大会, 茨城大学日立キャンパス, 2022.9.8

H. Zen, R. Hajima, H. Ohgaki, Few cycle pulse generation from a high efficiency free-electron laser oscillator operated in super radiance regime, 11th International Workshop on Infrared Microscopy and Spectroscopy with Accelerator Based Sources, Grand Prince Hotel Hiroshima, Hiroshima Japan (Hybrid), 2022.10.7

全炳俊, 紀井俊輝, 大垣英明, 京都大学自由電子レーザー施設の現状, 第 19 回日本加速器学会年会, Online, 2022.10.18-19

太田紘志, 平義隆, 杉田健人, 林憲志, 山崎潤一郎, 水口あき, 全炳俊, 加藤政博, UVSOR 光源加速器の現状 2022, 第 19 回日本加速器学会年会, Online, 2022.10.18-19

紀井俊輝, 富田優, 赤坂友幸, バルク MgB₂ を用いた超伝導アンジュレータ試験機の開発, 第 19 回日本加速器学会年会, Online, 2022.10.18-19

平義隆, 杉田健人, 岡野泰彬, 平出哲也, 遠藤駿典, 全炳俊, 静間俊行, UVSOR-III におけるガンマ線源開発と利用研究, 第 19 回日本加速器学会年会, Online, 2022.10.19

全炳俊, 大垣英明, 羽島良一, 京都大学中赤外自由電子レーザーの更なる引き出し効率向上に向けた検討, 第 19 回日本加速器学会年会, Online, 2022.10.19

趙宇皓, 全炳俊, 大垣英明, 光陰極高周波電子銃の導入による KU-FEL の性能向上に関するシミュレーション研究, 第 19 回日本加速器学会年会, Online, 2022.10.20

全炳俊, 大垣英明, 羽島良一, 中赤外自由電子レーザーの分散制御によるパルス圧縮, 第 19 回日本加速器学会年会, Online, 2022.10.20

羽島良一, 全炳俊, 大垣英明, 長波長赤外領域における数サイクル FEL パルスによる気体、固体の発光現象, 第 19 回日本加速器学会年会, Online, 2022.10.20

坂本文人, 全炳俊, 平義隆, 加藤政博, 山川清志, 近藤祐治, 佐々木昭二, 細矢潤, 今野弘樹, 光クライストロン用バンチャー電磁石の性能改善に関する検討, 第 19 回日本加速器学会年会, Online, 2022.10.20

全炳俊, 山崎潤一郎, 藤本将輝, 林憲志, 太田紘志,

平義隆, 加藤政博, UVSOR-FEL の再立上げと Intra-cavity Compton Scattering によるガンマ線発生, 第 19 回日本加速器学会年会, Online, 2022.10.20

R. Onbuddha, S. Papong, J. Mugkalsiri, B. Thanomnim, H. Ohgaki, S. Ogata, Life cycle thinking for sugarcane trash management toward a circular economy, 8th International Conference on Sustainable Energy and Environment, The Knowledge Xchange, Bangkok, Thailand, 2022.11.8

H. Ohgaki, Y. Ueda, Environment-friendly water treatment by fine bubbles, COP27 Japan Pavilion Seminar, SHARM EL-SHEIKH, 2022.11.10

H. Ohgaki, Panel Discussion: Electronics and Automotive, Cambodia Tech Expo 2022, Koh Pich Exhibition Center, Phnom Penh, Cambodia, 2022.11.12

全炳俊, 自由電子レーザーの開発と利用, 分子研研究会「UVSOR-III における多様な量子ビームの発生と先端利用に関する研究会」, 岡崎コンファレンスセンター, 2022.11.28

大垣英明, ガンマ線を用いた原子核物理実験とその応用, 分子研研究会「UVSOR-III における多様な量子ビームの発生と先端利用に関する研究会」, 岡崎コンファレンスセンター, 2022.11.28

大垣英明, Flat Laser Compton Gamma-ray Beam Generation in UVSOR, 15th Eco-Energy and Materials Science and Engineering Symposium, Dusit Thani Pattaya, Chonburi, Thailand, 2022.12.8

Ju Yoon Hnin Bo, Nonlinear Vibrational Spectroscopy Study in KU-FEL, 15th Eco-Energy and Materials Science and Engineering Symposium, Dusit Thani Pattaya, Chonburi, Thailand, 2022.12.8

S. Sukara, Development of MIR Free-electron Laser Oscillator at Chiang Mai University, 15th Eco-Energy and Materials Science and Engineering Symposium, Dusit Thani Pattaya, Chonburi, Thailand, 2022.12.9

Y. Zhao, Start-to-End Study of KU-FEL with New Photocathode RF Gun, 15th Eco-Energy and Materials Science and Engineering Symposium, Dusit Thani Pattaya, Chonburi, Thailand, 2022.12.9

H. Yoshida, Development of THz-wave Parametric Generator Seeded by Synchronously Pumped Parametric Oscillator, 15th Eco-Energy and Materials Science and Engineering Symposium, Dusit Thani Pattaya, Chonburi, Thailand, 2022.12.9

J. Cravioto, H. Ohgaki, M. Napao, J. QUIÑONES, J.A.

Cabrera, Solar Home Systems & Quality of Life: Narratives from Rural Households in the Philippines, Grand Renewable Energy 2022 International Conference, Online, 2022.12.14

羽島良一, 川瀬啓悟, KogaJamesK, 全炳俊, 大垣英明, 長波長赤外パルスによる機体の放電発光, 第36回日本放射光学会年会・放射光科学合同シンポジウム, 立命館大学びわこ・くさつキャンパス, 2023.1.9

全炳俊, 羽島良一, 大垣英明, 中赤外自由電子レーザーのパルス圧縮, 第36回日本放射光学会年会・放射光科学合同シンポジウム, 立命館大学びわこ・くさつキャンパス, 2023.1.9

川崎平康, 清紀弘, 山口裕資, 境武志, 木下輝, 住友洋介, 野上杏子, 早川建, 家路豊成, 太田俊明, 永田崇, 全炳俊, 入澤明典, 早川恭史, 谷正彦, 築山光一, 赤外自由電子レーザーとジャイロトロンを用いたリグノセルロースの構造研究, 第36回日本放射光学会年会・放射光科学合同シンポジウム, 立命館大学びわこ・くさつキャンパス, 2023.1.9

H. Ohgaki, RE Implementation: Study on Rural Electrification in ASEAN, The 8th JASTIP-WP2 Annual Workshop, NSTDA, Puthumthani. Thailand, 2023.1.9

全炳俊, 大垣英明, 光取り出し真空窓変更によるKU-FEL利用効率の向上, 第29回FELとHigh-Power Radiation 研究会, 量子科学技術研究開発機構関西光科学研究所, 2023.2.22

大垣英明, 全炳俊, 紀井俊輝, 早川岳人, 静間俊行, 平義隆, 藤本将輝, アリカレド, UVSOR におけるF-LCSガンマ線ビーム発生に関する研究: 実験, 日本原子力学会 2023年春の年会, 東京大学駒場キャンパス, 2023.3.14

坂本文人, 南野冠汰, 全炳俊, コヒーレント高調波の観測に向けた小型高分解能紫外分光器の構築, 日本原子力学会 2023年春の年会, 東京大学駒場キャンパス, 2023.3.14

元木貴則, 三輪将也, 仙波実怜, 近藤莉帆, 下山淳一, 紀井俊輝, SDMG法REBCO溶融凝固バルクの中低温捕捉磁場特性, 第70回応用物理学会春季学術講演会, 上智大学 四谷キャンパス+オンライン, 2023.3.16

宍倉文夫, 全炳俊, 早川建, 小松崎良将, 早川恭史, 境武志, 野上杏子, 高橋由美子, 田中俊成, 紀井俊輝, 大垣英明, ザリガニの複眼からコオロギの複眼へ: 中赤外線反応の普遍性と反応の生物学的意義を求めて, 令和4年度LEBRAユーザーミーティング, 日本大学理工学部船橋校舎, 2023.3.22

小林進二, 永岡賢一, 稲垣滋, 長崎百伸, 伊藤龍志, 藤田智大, 山戸瞭雅, 大垣英明, 紀井俊輝, 全炳俊, 岡田浩之, 大島慎介, 門信一郎, 南貴司, 木島滋, 水内亨, ヘリオトロン型磁場配位で観測される統計加速現象におけるエネルギー拡散過程, 日本物理学会 2023年春季大会, Online, 2023.3.23

羽島良一, 川瀬啓悟, James K. Koga, 全炳俊, 大垣英明, 長波長赤外FELパルス列による気体のカスケード電離, 日本物理学会 2023年春季大会, Online, 2023.3.25