<Advanced Energy Generation Division> Quantum Radiation Energy Research Section

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1. Introduction

Coherent-radiation energy with a wide wavelength tunability and a high power is an indispensable tool for exploiting a 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. A 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 turn-ability 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 40 mJ in a 2-μs macro-pulse at the wavelength of 4.9 μm. The FEL is routinely operated and opened for internal and external users.

Another topic of KU-FEL development is introduction of photo-cathode RF gun, which enables to generate higher peak power and wider tunable range MIR-FEL. Development of a UV-laser system for illuminating photo-cathode has been completed under collaboration with Dr. R. Kuroda, Researcher of AIST. In FY2014, we have achieved FEL lasing with photo-electron beam generated from LaB_6 cathode. In FY2018, the laser system has been upgraded under the Q-LEAP project organized by MEXT. This upgrade increases the macro-pulse duration of the photocathode operation. Under the photocathode operation, the world highest extraction efficiency of the oscillator-type FEL has been achieved.

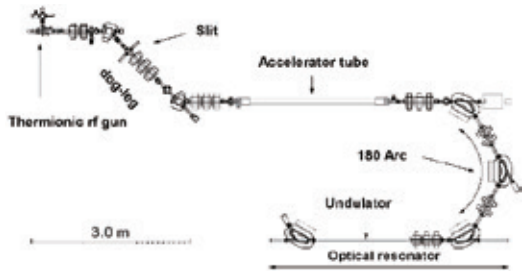

Fig. 1 Schematic drawing of the KU-FEL

2.2 THz Coherent Undulator Radiation Source

A new compact terahertz coherent undulator radiation source (THz-CUR) 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. Schematic view of the proposed system is shown in Fig 2. 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.

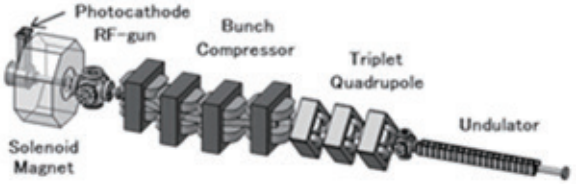

Fig. 2 3D image of THz coherent undulator radiation source.

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 space charge effect can be successfully 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 has been performed under the Joint Usage/Research Center for Zero Emission Energy Research of our Institute. In JFY2020, 14 external user groups used KU-FEL.

3. Bulk HTSC 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. Magnetic performance of bulk MgB_2 sample was measured using a new solenoid and a magnetic field scanner as shown in fig. 3.

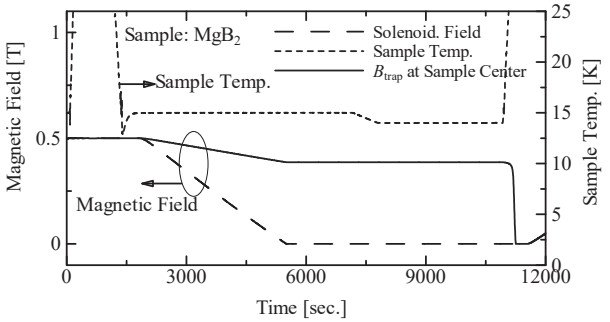

Fig. 3 Trapped magnetic field of MgB_2 sample.

4. Isotope Imaging for Nuclear Security

A Nuclear Resonance Fluorescence (NRF) method is a powerful tool for an isotope selective imaging. In 2020, we tried to obtain a 3D image of the CT target, which consists of two enriched isotope targets, ^{206}Pb (>93.3%) and ^{208}Pb (>97.8%), with an aluminum target holder. The LCS gamma-ray beam with a maximum energy of 5.528 MeV and a 10 photon·s^{-1}·eV^{-1} flux density was developed

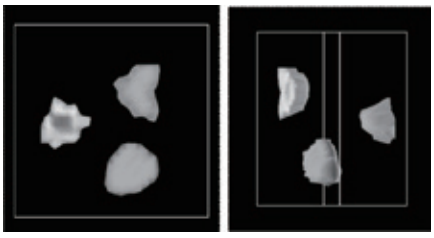

Fig. 4 3D NRF-CT image.

in UVSOR. The NRF transmission technique was employed. The transmission gamma-rays have also been measured to give a density distribution of the sample target at the same time. After suppressing the non-resonant absorption process, the NRF-CT images, which indicate the distributions of ^{208}Pb, were obtained as shown in Fig. 4.

5. Study on Social Aspect of Renewable Energy

Electrification projects using renewables in rural settings are essential to achieve SDG7. These projects can positively influence several other aspects of community development. Our group investigates the effects of electrification in rural contexts of ASEAN region comparing the process and outcomes of different electrification systems.

Fig. 5 Case studies since 2016

Our group has conceived a novel method to evaluate the social impact of electrification in SEA using quality of life (QoL) measures. With this approach, we assessed the conditions prior and after electrification in communities in Malaysia, Cambodia, Myanmar, Indonesia and The Philippines (Fig. 5). We also study on the relation between energy services and human well-beings in Japanese and Mexican communities.

Acknowledgment

These works were partially supported by the KAKENHI, Q-LEAP(MEXT), JASTIP(JST), UVSOR Collaboration Research, Heiwa Nakajima Foundation, Hitachi Zaidan, DASUnit, Kyoto University, and the Laboratory for Complex Energy Processes Collaboration Research, IAE.

Collaboration Works

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大垣英明，NSTDA（タイ），JASTIP，WP2

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大垣英明，森井孝，片平正人，野平俊之，モンゴル国立大学，インドネシア大学，フィリピン大学ディリマン校，ベトナム国家大学ハノイ校，ラオス国立大学，王立プノンペン大学，アジア新興国産天然資源を由来とする機能性物質創生のための高度分析研究拠点の形成

大垣英明，分子科学研究所共同利用研究，UVSOR-BL1U からの LCS ガンマ線を用いた NRF 同位体 3D イメージング法の高分解能化

大垣英明分子科学研究所共同利用研究，UVSOR-BL1U からの LCS ガンマ線を用いた NRF 同位体 3D イメージング法の高分解能化

Financial Support

1. Grant-in-Aid for Scientific Research

大垣英明，基盤研究(A)，直線偏光ガンマ線のデルブリュック散乱（分担金）

大垣英明，基盤研究(B)，LCS-NRF による同位体 3D イメージング法の基盤確立

紀井俊輝，基盤研究(A)，新材料ＭｇＢ２と超伝導電流流体解析による新型アンジュレータ精密磁場制御法の確立

全炳俊，基盤研究(A)，直線偏光ガンマ線のデルブリュック散乱（分担金）

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