Quantum Radiation Energy Research Section

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1. Introduction

Coherent-radiation energy with a wide wavelength tunability and high power is an indispensable tool for exploiting cutting-edge energy science. The research in this section aims to generate and apply 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, 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. We have been developing several new approaches to improve our FEL system and application research by using a collaboration research program.

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 tunability for basic research 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 80 mJ in a 2-μs macro-pulse at the wavelength of 8.5 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's 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). In addition, nonlinear compression of 8.6-μm FEL pulse was achieved, and the pulse duration was compressed from 146 to 106 fs (from 5.1 to 3.7 cycles) by passing through a 30-mm thick Ge plate.

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 commissioning of the new RF gun was successfully finished and FEL lasing with the electron beam generated from the gun with higher bunch charge than the 4.5-cell RF gun has been achieved.

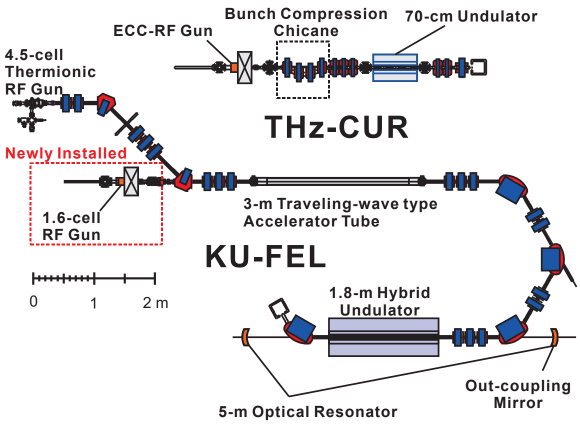

Fig. 1 Schematic drawing of the KU-FEL and THz-CUR

2.2 THz Coherent Undulator Radiation Source

A compact terahertz coherent undulator radiation source (THz-CUR in Fig. 1) has been constructed. It consists of an energy-chirping-cell-attached 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 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 JFY2024, 15 external user groups used KU-FEL.

One of the many applications achieved using MIR-FEL is mode-selective phonon excitation. In strongly correlated systems, it is beneficial to understand the role of each phonon mode's impact on the material properties. Due to the widely tunable wavelength range of MIR-FEL, many phonon modes in the mid-infrared region are accessible. Selective excitations of Raman active phonon modes (LO mode of 6H-SiC, A_1 (LO) mode of GaN), Raman inactive mode (LO3 mode of $SrTiO_3$), and even, infrared inactive mode (T_{2g} of single crystal diamond) have been successfully observed through pump-probe experiments. Most recently, the antiferromagnetic domain pattern change has been observed when 2TO phonon mode of nickel oxide is excited. The domain patterns were visualized via magnetic linear birefringence using ns-Nd: YAG laser. Temporal evolution of the phonon induced pattern changes has been recorded by controlling the ns laser via electronic delay generator.

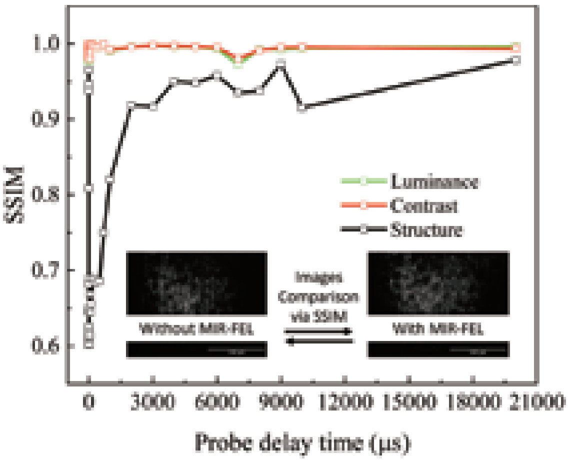

Fig. 2 Measurement results of structural similarity index measure (SSIM) of antiferromagnetic domain pattern changes without and with MIR-FEL irradiation

3. Isotope Imaging for Nuclear Safety and Security

Multi-isotope imaging method has been developed at BL1U beamline in UVSOR, Institute of Molecular Science. However, a quantitative evaluation has not been achieved yet because of a high spatial dependence of the Laser Compton Gamma-ray beam. We proposed a new method to generate a flat spatial distribution with a beam size of a few mm in diameter, called a flat-LCS gamma-ray beam. The Proof-of-Principle experiment has been performed, and we are trying to measure the abundance of natural lead target by using Flat-LCS gamma-ray beam in UVSOR. Enriched $^{206, 207, 208}Pb$ rods of 6 mmϕ were used for witness targets and natural lead absorber target was irradiated by normal LCS and Flat-LCS gamma-ray beams. The NRF gamma rays emitted from the witness were measured with two Ge detectors. The evaluation of the abundance in a natural lead absorber is undergoing.

4. Social aspects of energy use

In Southeast Asia, significant progress has been made toward universal electrification. Yet, today, around 35 million people remain without access. Most research on electrification challenges has focused on regions like Africa and South Asia, primarily examining economic, technological, and institutional factors while neglecting social dimensions. In response, our group has explored the social impacts of various electrification projects from a quality-of-life perspective since 2016. We have assessed changes in living conditions and social disparities across different contexts in Southeast Asia (Fig. 3). Utilising mixed methods from the social sciences, our findings indicate that renewable electrification offers several benefits. These include reduced reliance on expensive kerosene lamps and car batteries, improved educational opportunities for students, and enhanced social interactions. However, a limited number of households have utilized these systems to increase their economic activities. Additionally, the transition to electrification may unintentionally reinforce existing inequalities, favouring those with higher socio-economic status before the change. Other critical factors identified in the electrification process include changing lifestyles and limited system capacity. Furthermore, we are actively engaged in additional research projects that focus on energy justice and the clean and sustainable energy transition.

Fig. 3 Rural electrification fieldwork locations 2016-2025

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Collaboration Works

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