Electric Field of Coherent Synchrotron Radiation Generated Using Laser Bunch Slicing Technique

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Terahertz region has been attracting much attention in the viewpoints of solid-state physics, chemistry, and even biology, because its energy scale is of fundamental importance for the phenomena occurring at or slightly below the room temperature. Recent development of the ultrashort laser technology enables us the generation and detection of phase-locked terahertz waves, which is now applied to the coherent spectroscopy such as terahertz time-domain spectroscopy, and nonlinear terahertz spectroscopy. Especially, the nonlinear terahertz spectroscopy was difficult before the invention of recent laser-based terahertz technologies [1], which requires intense and tunable terahertz light sources.

Coherent terahertz synchrotron radiation (CSR) is a promising light source for such nonlinear terahertz spectroscopy because it potentially has ultrahigh power, and the spectrum can be tuned from broadband to monochromatic in low-terahertz region [2]. In UVSOR, we recently demonstrated generation of CSR by applying the laser bunch slicing technique [2, 3]. However, the electric field detection of the CSR from laser bunch slicing has not been realized. In this report, we show that the electric field of CSR can be observed by using electro-optic sampling method, and that the longitudinal density profile of electron bunches can be characterized by using the electric field waveform [4].

We used a large mode-area photonic-crystal fiber to deliver the probe pulses to the detection port from the laser systems for the laser bunch slicing. The output of the seed oscillator was sent through the fiber and then compressed to about 180 fs by using a grating-pair compressor. The probe and CSR were focused on an electro-optic crystal (ZnTe), and the polarization rotation due to the CSR electric field was detected with electro-optic sampling method.

By using this method, it becomes possible to measure the electric field of the terahertz pulses as shown in Fig. 1(a). The observation of the pulsed electric field means that phase of the CSR is indeed very stable, which is a promising characteristic for the coherent nonlinear terahertz spectroscopy. The Fourier transform of the waveform is in good agreement with the FTFIR measurement of the same radiation at the same port [3, 4].

Because the generated CSR reflects the longitudinal density profile of the electron bunch, we can estimate it from the observed electric field profile. Fig. 1(b) is the result of such calculation, illustrating the formation of a dip structure in the electron bunch. We reproduced the symmetric structure of the dip expected in the theory [3], and showed that the duration of the dip depends on the duration of the slicing laser pulse [4].

In summary, we have demonstrated the electric field detection of the CSR generated by using the laser bunch slicing technique. From the observed electric field waveform, it becomes possible to estimate the longitudinal density distribution of electron bunches. Therefore, the technique demonstrated in this study is promising for monitoring bunch profiles, as well as for coherent terahertz spectroscopy using CSR.

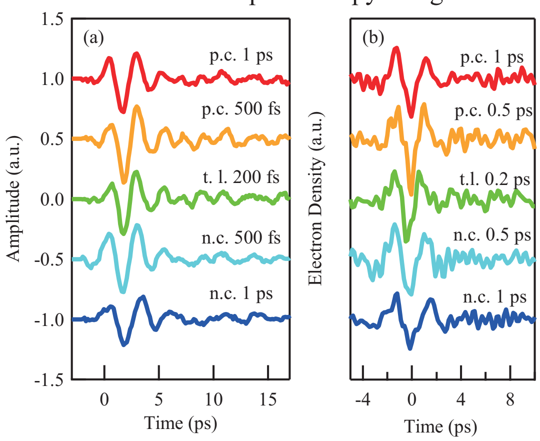

Fig. 1. (a) Observed electric field waveforms of the CSR generated with various pulses of different chirp and pulse durations: p.c.: positive chirp, t.l.: transfer limited and n.c.: negative chirp. (b) Reconstructed electron density profile of electron bunches.

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Generation of Polarized Gamma Rays by Laser Compton Scattering

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Gamma rays with excellent features can be generated via laser Compton scattering (LCS [1]), where incident laser photons are scattered by a relativistic electron beam circulating in an electron storage ring. LCS gamma rays are tunable in energy, quasi-monochromatic, intense, and highly polarized. Highly polarized gamma rays can be generated via LCS because gamma rays preserve polarization of an incident laser. Circularly polarized gamma rays are used in development polarized positron beam for future electron-positron linear colliders and solid state physics using magnetic Compton scattering. Linearly polarized gamma rays are used in nuclear science.

In this paper, we have demonstrated that the spatial image of the polarized gamma rays is reflected in the polarization effect and have evaluated the degree of linear polarization of LCS gamma rays.

The point of collision between the electron beam and the laser was in a vacuum chamber along a straight section. Linearly and circularly polarized laser was injected into the electron beam from the horizontal 90-degree direction. The polarization was controlled by a wave plate. The spatial profile of the gamma rays was recorded with an imaging plate (BAS-IP MS) located 5.4 m away from the collision point.

Figures 1 and 2 show the spatial images of LCS gamma rays generated by linearly (horizontal direction) and circularly polarized laser, respectively. For the linear polarization, the root mean square (rms) of the LCS gamma rays is 0.245 mrad and 0.300 mrad along the horizonrtal (x) and vertical (y) direction, respectively. For the circular polarization, the rms of the LCS gamma rays is 0.294 mrad and 0.261 mrad along the x and y direction, respectively.

The spatial distribution was calculated using a Monte Carlo simulation code, EGS5. In this simulation, the divergence, and spatial distribution of the electron beam were included in the calculation. The rms of the linearly polarized gamma rays is 0.227 mrad and 0.282 mrad along the x and y direction, respectively. The divergence is lower along the horizontal direction due to polarization effects. The rms of the circularly polarized gamma rays is 0.261 mrad and 0.230 mrad along the x and y direction, respectively. The divergence is lower along the vertical direction due to spatial distribution of the electron beam.

We also calculated the spatial distribution of LCS gamma rays with different degree of linear polarization. The degree of linear polarization of LCS gamma rays shown in Fig. 1 was found to be further than 88 % by comparing the ratio of the rms along the x and y directions between the experimental data and calculated values.

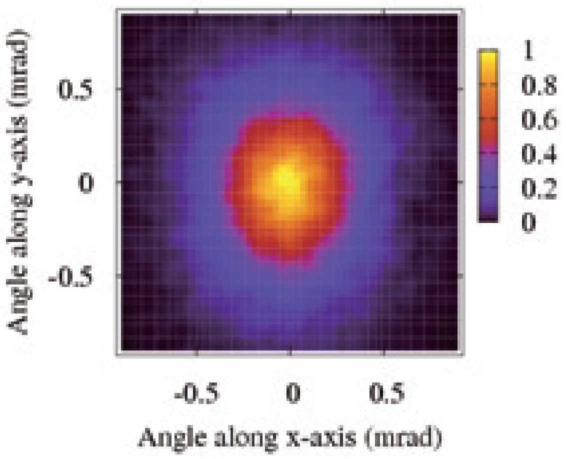

Fig. 1. Spatial image of LCS gamma rays generated by linearly polarized laser.

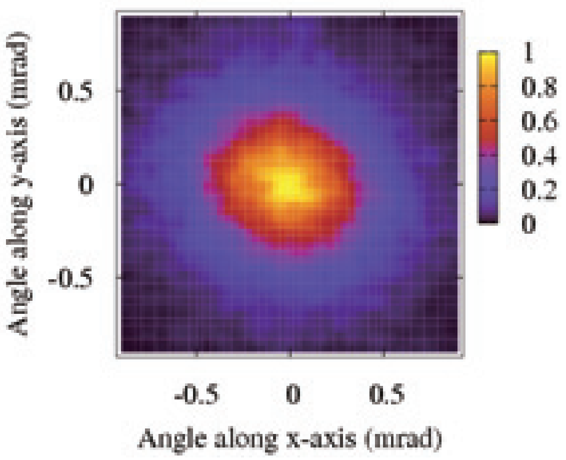

Fig. 2. Spatial image of LCS gamma rays generated by circularly polarized laser.

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Consideration on Using Higher Harmonics of Ti:Sa Laser for Coherent Harmonic Generation at UVSOR

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Development of new coherent light sources using a relativistic electron beam and laser is underway at the UVSOR storage ring. We have already succeeded in generation of coherent synchrotron radiation (CSR) in THz region [1] and coherent harmonic generation (CHG) [2]. So far fundamental wave of a mode-lock Ti:Sa laser is employed as a seed for the CHG experiment. In parallel with those experiments, we are considering using high harmonics of the laser as a seed for the CHG experiment and made numerical calculations and basic experiments.

CHG is a method to produce coherent harmonics of laser light by using a relativistic electron beam and an optical klystron type undulator. With increasing harmonic number of the CHG, the conversion efficiency rapidly decreases and therefore short-wavelength coherent light is difficult to obtain. On the other hand, if higher harmonics of the laser is applied for the seed, the harmonic number can be much reduced and generation of shorter wavelength coherent light up to soft-X ray region can be expected. In order to evaluate the effectiveness, we made numerical calculations. The spectral intensity of CHG is approximately expressed using the CHG form factor f_n as:

$$P_{CHG}(n) \approx N f_n P_{Sp}(n),$$

where N is number of electrons interacted with the laser and $P_{Sp}(n)$ is spectral intensity of incoherent spontaneous radiation. As CHG spectral intensity is proportional to the form factor, we estimate efficiency of the CHG via the form factor. Figure 1 shows calculated form factor as a function of the harmonic number of the fundamental laser (not of the seed laser) under various conditions of the seed laser [3]. Parameters of electron beam from UVSOR-II storage ring and of the new optical klystron are employed in the calculation. For 2nd and 4th harmonics generation, we assume 200 μJ pulse energy and 100 fsec-FWHM pulse width, which can be provided by harmonic generation with a nonlinear crystal. For 15th harmonics of laser, we assume the high harmonic is produced with Gas and much reduced pulse energy of 5 μJ. As seen in the figure, 2nd and 4-th harmonics of laser has advantages in producing coherent light in the VUV and soft X-ray region over fundamental wave and 15-th harmonics.

We performed experiment to deduced conversion efficiency and properties of the 2nd harmonics from non-linear crystal. No-linear crystals of BBO of thickness of 0.1 mm, 0.5 mm, 1 mm and 2 mm are irradiated by a mode-lock Ti:Sa laser with 2.5 mJ pulse energy and 100 fsec. The measured efficiency of 2nd harmonics is around 50 % for crystals with thickness more than 0.5 mm. We constructed a compact auto-correlator system to measure pulse width of the 2nd harmonics [4]. Slightly increase of pulse width is observed in the second harmonics, but degradation to the peak power is small. We also measured spectra of the 2nd harmonics using the crystals and conclude that 0.5 mm thickness BBO is the most suitable for our CHG experiment.

Near future we plan to make the CHG experiment using 2nd harmonics of the Ti:Sa laser. We also plan to make basic experiment on production of 3rd and 4th harmonics for the CHG experiment.

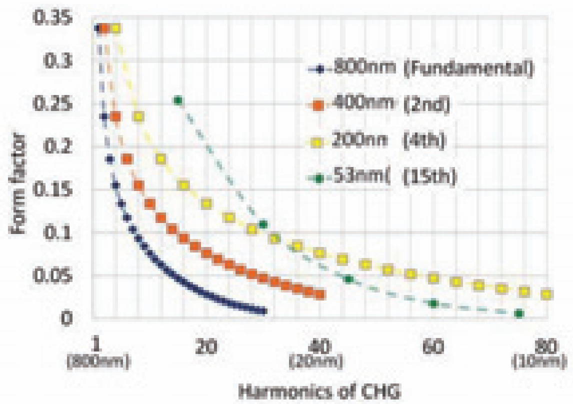

Fig. 1. Calculated CHG form factor as a function of harmonic number.

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Chirality Formation of Amino Acids by Circularly Polarized UV Irradiation

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Science obtaining the first evidence of extraterrestrial amino acids in a carbonaceous chondrite (*e.g.*, Murchison meteorite), a great number of laboratory experiments have been reported to study possible abiotic formation of bioorganic compounds including amino acids and their precursors from possible astrophysical media by irradiation with high-energy particles [1] or ultraviolet (UV) light [2]. It is plausible that considerable number of organic compounds, including amino acids and their precursors, were brought to primitive planets by micrometeorites (MMs), comets, and interplanetary dust particles (IDPs). Moreover, amino acids in several meteorites (*e.g.,* Murchison, Murray, Orgueil) have been found to have L-enantiomeric excess, the same handedness as observed in some biological amino acids. Therefore, it has been suggested that life on Earth was seeded by the delivery of organic compounds from outer space during the intense bombardment period of the primitive Earth [3]. On the other hand, the origin of homochirality in terrestrial biological molecules (dominant L-body amino acids and D-body sugars) remains an unresolved important problem in the study for the origins of life. One of the most attractive hypotheses for the origin of homochirality is nominated as "Cosmic Scenario"; some chiral impulses from asymmetric excitation sources in space triggered asymmetric reactions on the surfaces of such space materials as meteorites or interstellar dusts. According to this scenario, the enantiomeric excesses in terrestrial amino acids can be advocated that asymmetric reactions of complex organic molecules including amino acid precursors were induced by circularly polarized light (CPL) from synchrotron radiation (SR) source in space prior to the existence of terrestrial life. Recently, a wide-field and deep near-infrared circularly polarized light has been observed in the Orion nebula, where massive stars and many low-mass stars are forming [4]. This observation results strongly support the "Cosmic Scenario" with CPL in space for the origin of homochirality in terrestrial bioorganic compounds.

Currently, ground simulation experiments for the extraterrestrial scenario by using CPL from SR facilities as a simulating polarized energy source is being conducted. Aqueous solutions of DL-isovaline (Ival), DL-histidine (His) and DL-5-ethyl-5methylhydantoin (EM-Hyd, a precursor of Ival) were irradiated with UV-CPL at 215 nm from an free electron laser source of UVSOR-II (IMS, Japan). Now, the circular dichroism (CD) spectra of the UV-CPL irradiated compounds are being measured at the beamline-15 of Hiroshima Synchrotron Radiation Center (HiSOR, Hiroshima University, Japan).

After UV-LCPL and UV-RCPL irradiation of His, Ival and EM-Hyd, no D- and L-excess was observed (Fig. 1), although very small D- and L-excess was investigated by high performance liquid chromatography. As it is very difficult to examine the asymmetric photodecomposition of UV-CPL irradiated amino acids in aqueous state, we are now planning to enlarge their enantiomeric excess (e.e.) which will be investigated in near future.

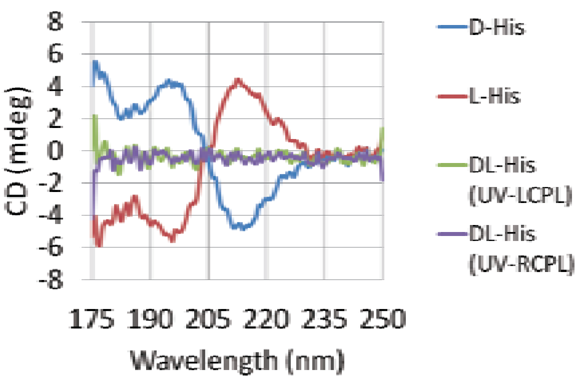

Fig. 1. CD spectra of non-irradiated and irradiated (UV-CPL) Histidine.

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