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GENERATION AND NRF APPLICATION OF FLAT-LASER COMPTON SCATTERING GAMMA-RAY BEAM IN UVSOR *

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Abstract

Flat-Laser Compton Scattering Gamma-ray (F-LCS) beam, which has a flat distribution in the energy spectrum and a spatial distribution with a small beam size, has been generated by exciting a circular motion of an electron beam with a head-on collision with an external laser beam to study an isotope selective CT Imaging application through Nuclear Resonance Fluorescence (NRF). A proof-of-principle experiment has been carried out at the beamline BL1U in UVSOR-III where a helical undulator was installed. The spatial distribution of an F-LCS gamma-ray energy has been measured by using a 120% Ge detector and the result showed a good agreement with simulation. The F-LCS beam irradiated ^{206,207,208}Pb enriched targets simultaneously and NRF peaks from all three isotopes were observed. The yields of the F-LCS excited NRF peaks below 5300 keV were larger than those by standard LCS beam, which was consistent with the ratio of the energy spectrum of the F-LCS beam to the standard LCS beams.

INTRODICTION

Flat-Laser Compton Scattering Gamma-ray beams (F-LCS), which has a flat distribution in the energy spectrum and the spatial distribution with a small beam size, have been generated in UVSOR [1]. A standard LCS beam has a quasi-monochromatic energy spectrum which is useful for measuring of a single Nuclear Resonance Fluorescence (NRF) peak. However, in general, NRF experiments have been performed to excite several different energy levels. Therefore, LCS beams with a broad bandwidth generated by using a large collimator, have been used. On the other hand, for an LCS beam application of the isotope-selective CT imaging [2], a smaller beam size is preferable for obtaining a good image resolution. It is challenging to excite simultaneously different energy levels in some isotopes with an LCS beam with a small beam size. In addition, due to the LCS generation mechanism, the energy of the LCS gamma-ray has a scattering angle dependency which causes a spatial dependency of the energy of the LCS beam. This spatial dependency causes a difficulty in the absolute cross-section measurement. Therefore, it is desired to generate an LCS beam with a small beam size and broad energy. We have proposed F-LCS beam generation by using a helical undulator to excite a circular motion of an electron beam at the head-on collision region with a laser beam. The conceptual drawing is shown in Fig. 1. An EGS5 [3] based simulation code has been developed for calculation of the F-LCS and the result showed that when we take a larger undulator K-value we could generate a broader bandwidth of an LCS beam [1]. In a proof-of principle experiment carried out in UVSOR, the undulator K-value dependence of the bandwidth of LCS beams has been confirmed [1]. In this paper, we report the measurement of the spatial distribution of the energy spectrum of an F-LCS. We also report on a preliminary result of a NRF experiment on ^{206,207,208}Pb isotopically enriched targets with the F-LCS beam.

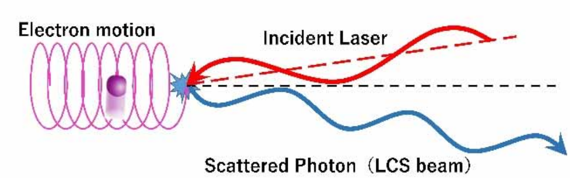

Figure1: Conceptual drawing of F-LCS beam generation [1].

SPATIAL DEPENDENCY OF LCS ENERGY SPECTRUM

The experiment has been carried out at BL1U in UVSOR [4]. The experimental setup was the same in ref. [1]. A stored electron beam with an energy of 746 MeV and a current of about 6 mA was used. LCS beams with a maximum energy of 5.528 MeV were generated by a head-on collision between the electron beam and a laser beam from a Tm-fiber system (TLR-50-AC-Y14, IPG Laser GmbH) with about 1 W CW power with random polarization. The laser wavelength was 1.896 µm and the spectral linewidth was 0.7 nm. A 2-mm diameter collimator of a 20 cm × 10 cm × 10 cm lead block was placed after passing through a

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vacuum window. A high-purity germanium (Ge) detector with an efficiency of 120% relative to a 3" × 3" NaI(Tl) scintillator was used for measuring the energy spectrum of the gamma-ray beams.

First, we measured energy spectra at three different electron-laser collision regions to confirm the collision point of the F-LCS beams. An undulator of APPLE-II type [4] has been installed at BL1U, which consists of two helical undulators (20 periods of 8.8 cm) and a 50-cm dispersive section in its middle. We excited the upstream helical undulator (K_{up}=0.2) while turning off the downstream helical undulator (K_{dn}=0) and dispersive section (K_{disp}=0). By adjusting the focal length of a laser telescope system, the electron-laser collision region can be defined at the center of the upstream helical undulator (Up center), the center of the dispersive section (BL center), or the center of downstream helical undulator (Dn center). The energy spectra of these three-collision regions were measured with the Ge detector. Due to the distance between the collision region and the collimator (different solid angle), the measured gamma-ray yields were different. Therefore, we normalized each energy spectrum by the maximum count [see in Fig. 2 (a)]. The Up center spectrum shows a broadening of the peak of the LCS beam, while the Dn center spectrum shows no significant broadening. The BL center spectrum shows a slight broadening because the incident laser beam had a Gaussian distribution with a deviation of 45 cm, which is almost same as the dispersive section length, and could have a chance to collide with the electron beam in the upstream helical undulator section. In the simulation we take into account the Gaussian distribution of the laser-electron collision region (σ=45 cm) and the Ge detector response. The results agree with the measured spectra [see in Fig. 2 (b)]. Therefore, we confirmed the generation of the F-LCS beam.

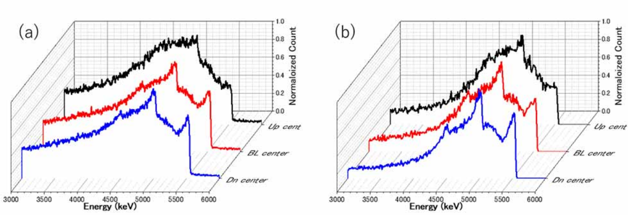

Figure 2: (a) Measured and (b) simulated energy spectra of F-LCS beams generated from different positions (Black: Up center, Red: BL center, Blue: Dn center) in BL1U. The upstream helical undulator section was excited K_{up}=0.2.

Next, the spatial distribution of the F-LCS energy spectrum has been measured at the BL1U. The 1-mmϕ collimator was put on a 3-axis movable table which moved vertical and horizontal direction in 1-mm step and the energy spectrum was measured with the Ge detector. The downstream helical undulator was excited to K_{dn}=0.2 to generate an F-LCS beam. Then this undulator was turned off (K_{dn}=0) to generate a standard LCS beam. The collimator position was moved from the center position to +1 or +2 mm. Figure 3 (a) shows the measured LCS (K_{dn}=0) energy spectra with the center position, +1 mm, and +2 mm. At +1 and +2 mm, the LCS peaks disappeared compared to the center position, and the top energies shifted to lower energy. It is obvious that the energy spectrum has a significant spatial dependency. Figure 3 (b) shows the EGS5 result for the three collimator positions that agrees with the measured spectra. Figure 3 (c) shows the measured F-LCS (K_{dn}=0.2) energy spectra with the center position, +1 mm, and +2 mm. The simulation results are also shown in Fig. 3 (d). Figure 3 (c) and (d) showed slight changes in the energy spectra with different collimator positions. This suggests that there is still slight spatial dependence of the energy spectra of the F-LCS beams.

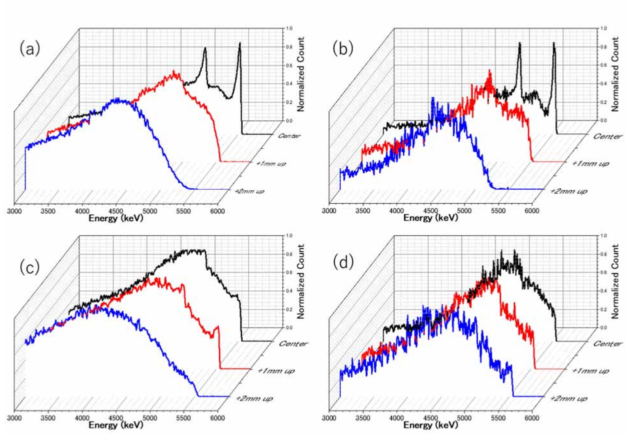

Figure 3: Spatial dependence of gamma-ray energy spectra for three different collimator positions in vertical direction (Black: center, Red: +1mm, Blue: +2mm), with (a) measured LCS beam (K=0), (b) simulated LCS beam, (c) measured F-LCS beam (K_{dn}=0.2), and (d) simulated F-LCS beam.

NRF EXPEIMENT USING F-LCS BEAM

Next, we tried to irradiate simultaneously the three isotopically enriched targets ^{206,207,208}Pb. The ^{206}Pb target was 93.3% enriched and had a rod shape of 6 mmϕ and 10 mm hight. The ^{208}Pb was 97.8% enriched and had a rod shape of 6 mmϕ and 12 mm hight. The ^{207}Pb target was 98.10% enriched and a rod shape of 8 mmϕ and 20 mm hight. These three targets were aligned on the LCS beam in order from ^{206}Pb, ^{207}Pb and ^{208}Pb. The current of the stored electron beam with the top-up operation was increased to about 300 mA. The laser power of the Tm-fiber system was also increased to about 36 W. An F-LCS beam with a maximum energy of 5.528 MeV was generated by exciting the downstream helical undulator with K_{dn}=0.2. The standard LCS and F-LCS beams were collimated by 2 mmϕ The simulated energy spectrum of the LCS beam (K_{dn}=0) and the F-LCS beam (K_{dn}=0.2) are shown in Fig. 4. As shown in Fig. 4, the standard LCS gamma-ray flux was 10 photons/s/eV and the F-LCS gamma-ray flux was 6.1 photons/s/eV at a resonance energy of ^{208}Pb (5512 keV). The flux ratio of the F-LCS beam to the LCS beam at different energies of 5512 keV(^{208}Pb), 5471 keV(^{207}Pb), 5291 keV(^{208}Pb), and 5037 keV(^{206}Pb) were 0.61, 0.71, 1.85 and 4.76, respectively. Therefore, we expect enhancements of NRF events whose excitation energies are in 5000 to 5300

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keV range. During the NRF experiment, the total gamma-ray flux was measured with a 5-mm thickness plastic scintillator placed between the collimator and target rods. Two Ge detectors with an efficiency of 120% and 130% were placed at an angle of 120° to the gamma-ray beam axis and measured the NRF gamma-rays from the three isotope targets. To reduce the dead time of the Ge detectors caused from environmental background events, lead shields were installed around the detectors and Bi absorber plates with a thickness of 1 cm were inserted between each Ge detector and the targets. The signals from each detector were independently recorded by a multichannel analyser USB-MCA4 (APG7400, TechnoAP). The data acquisition time was 105 min for the F-LCS beam and 90 min for the LCS beam.

Tentative results of the NRF experiments with the standard LCS and F-LCS beams are shown in Fig. 5 and Table 1 summarizes the NRF peak analysis result. The ratios in Table 1 were normalized by individual total counts measured with the plastic scintillator. As we expected, the NRF events irradiated by the F-LCS beam were increased at 5037, 5217, and 5291 keV levels. On the other hand, the NRF events of 5471, 5488, and 5512 keV levels were decreased. It should be noted that the qualitative tendency of the NRF yields shows a reasonable result, but the statics is too poor to have more detailed discussion at this stage.

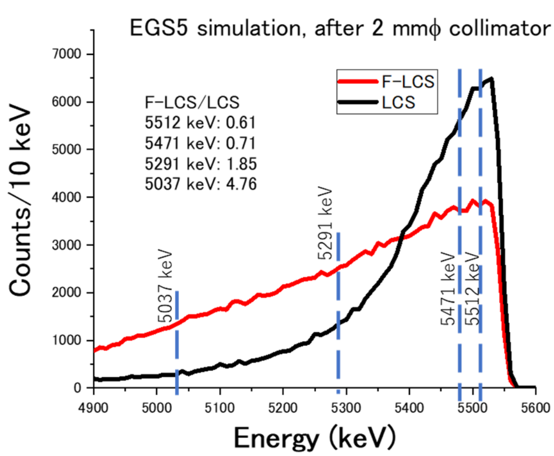

Figure 4: Simulated energy spectrum of the LCS beam (K_{dn}=0) and the F-LCS beam (K_{dn}=0.2) after 2 mmϕ collimation.

Table 1: Summary of Peak Analysis of $^{206,\ 207,208}$Pb NRF Experiment

Isotope	Peak Energy (keV)	Peak area with LCS: A	Peak area with F-LCS: B	Ratio B/A
^{208}Pb	5512	1721.7±3.8	1273±3.4	0.83
^{207}Pb	5488	666.2±3.9	418.8±3.3	0.71
^{206}Pb	5471	128.6±2.9	80.1±2.7	0.48
^{208}Pb	5291	128.6±2.9	230.1±3.5	2.02
^{207}Pb	5217	106.8±3.0	120.6±3.8	1.27
^{206}Pb	5037	77.7±3.6	115.4±3.0	1.67

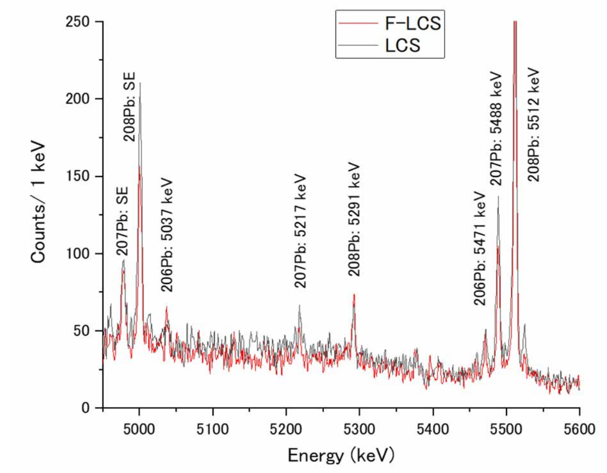

Figure 5: Energy spectra of $^{206,\ 207,208}$Pb NRF experiment with LCS (black line) and F-LCS beam (red line).

CONCLUSION

A proof-of-principle experiment of generation of F-LCS beams has been carried out at the beamline BL1U in UVSOR-III. The spatial distribution of the F-LCS gamma-ray energy has been measured by using a 120% Ge detector and the result showed a good agreement with the simulation. The F-LCS beam irradiated ^{206,207,208}Pb isotopically enriched targets simultaneously and NRF peaks from all three isotopes were measured. As we expected from the energy spectrum of the F-LCS beam, the yields of the NRF peaks with the F-LCS beam were larger than those with the standard LCS beam below 5300 keV. The statics of the NRF peaks are not enough for more detailed analysis and further experiments enabling to quantitative discussion has been continued. We also plan to take three isotopes imaging.

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