HIGH-FLUX GAMMA-RAY GENERATION BY LASER COMPTON SCATTERING IN THE SAGA-LS STORAGE RING

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Abstract

We constructed an experimental setup for generating high-flux gamma-rays by laser Compton scattering (LCS) in the SAGA-LS storage ring. We employed a 10 W CO_2 laser with a wavelength of 10.6 μm to produce gamma-rays with energies of the order of a few MeV during user time for synchrotron radiation experiments. LCS gamma-rays with a maximum energy of 3.5 MeV were generated by head-on collisions between the laser photons and the 1.4 GeV stored beam. Since the energy acceptance of the storage ring is well in excess of the maximum gamma-ray energy, the LCS experiment can be performed without reducing the beam lifetime. We used dosimetry to measure the LCS gamma-ray flux and measured gamma-ray fluxes of the order of 10^6 photons/s. The maximum gamma-ray flux at the detector was evaluated to be 6×10^6 photons/s with a beam current of 300 mA and a laser power of 10 W, which corresponds to an LCS event rate of 3×10^7 s^{-1} in the interaction region. We confirmed that the present setup can be used to generate gamma-rays with fluxes of the order of 10^6 photons/s without affecting the light source performance of the storage ring.

INTRODUCTION

Intense gamma-rays with energies of the order of a few MeV are receiving increasing attention for photo-nuclear science and industry [1, 2, 3, 4]. To generate high-flux gamma-rays with energies of a few MeV, we constructed an experimental setup for laser Compton scattering (LCS) at the SAGA Light Source (SAGA-LS) storage ring. The SAGA-LS is a synchrotron radiation facility consisting of a 255 MeV injector linac and a 1.4 GeV storage ring [5]. We employed a CO_2 laser with a wavelength of 10.6 μm. LCS gamma-rays with a maximum energy of 3.5 MeV are generated by head-on collisions between electron and laser beams. The advantage of the LCS in the SAGA-LS is a continuous generation of the high-flux gamma-rays with energies of the order of a few MeV during user time for synchrotron radiation research. Since the energy acceptance of the storage ring is well in excess of the maximum gamma-ray energy, LCS experiments can be performed without reducing the beam lifetime. Moreover, the output power of the CO_2 laser is cost effective compared to other lasers. This high-power laser can be used to generate high gamma-ray fluxes.

As a first step in generating high-flux gamma-rays, we employed a small 10 W CO_2 laser. We have performed beam tests at a low beam current of less than 10 mA to confirm the basic concept of the LCS experiments at the SAGA-LS and to investigate the gamma-ray characteristics [6, 7]. We have also used LCS gamma-rays to measure machine parameters such as the beam energy and the momentum compaction factor. After performing the low-current experiment, we generated gamma-rays at the maximum event rate of the present setup.

This paper presents experimental results for evaluating the gamma-ray flux at high currents of up to 300 mA. To evaluate the gamma-ray fluxes up to an order of 10^7 photons/s, we employed a measurement method based on dosimetry, in which the effective flux is derived from the dose rate due to gamma-ray irradiation. We also investigated the effect of the LCS on the stored beam to verify that gamma-ray generation does not affect the light source performance of the storage ring.

EXPERIMENTAL

The experiment was performed using the setup constructed for the LCS at the SAGA-LS storage ring. Figure 1 shows a schematic diagram of this experimental setup. We used a CO_2 laser (Synrad, 48-1) producing the vertical linearly polarized light. The CO_2 laser beam was sent to the straight section "LS8" used for beam injection, where the laser photons collide head-on with the electron beam. The transmission of the laser beam through the interaction region was monitored by a power meter located behind the exit viewport. The LCS gamma-rays were extracted from the water-cooled flange to the detector space, which is 6.1 m downstream from the center of the interaction region, and they were detected without using a collimator.

We used focusing optics for the laser beam to enhance the LCS event rate. The maximum LCS event rate was designed to be 1.4×10^8 s^{-1} when the beam current is 300 mA and the laser power is 10 W. The effective gamma-ray flux at the detector was estimated to be 3.2×10^7 photons/s for gamma-rays with energies of over 0.5 MeV by accounting for the gamma-ray transmission through the mirror and flange. The gamma-ray transmission was calculated using the EGS5 Monte Carlo code [8].

We used a scintillation detector equipped with a 2 inch BGO crystal to measure the gamma-ray spectrum and to evaluate the gamma-ray flux at a low beam current. We employed a measurement method based on a dosimetry to measure the gamma-ray fluxes up to about 10^7 photons/s. The effective dose rate in the irradiated area was evalu-

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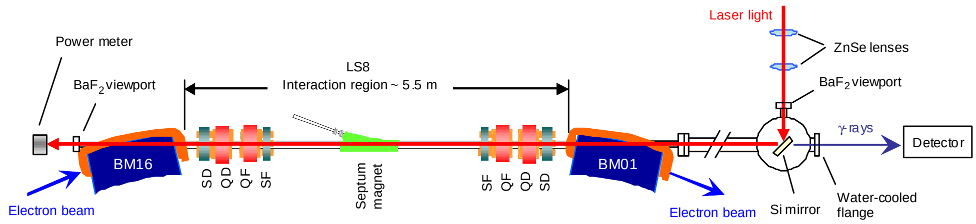

Figure 1: Experimental setup for LCS gamma-ray generation at the SAGA-LS storage ring.

ated to be 3.4 Gy/h at the maximum event rate using the EGS5 code. The irradiated area was defined by a circle with a radius of 2.2 mm, corresponding to L/γ, where L is the length between the center of the interaction region and the detector and γ is the Lorentz factor. We used a glass dosimeter (Chiyoda Technol, SC-1) and an ion-chamber survey meter (Aloka, ICS-321) to measure the dose rate. The effective gamma-ray flux was estimated from the dose rate using a coefficient calculated by the EGS5 code.

RESULTS AND DISCUSSION

Spatial Distribution

To confirm the size of the irradiated area, we measured the spatial distribution of the LCS gamma-rays by using an imaging plate (Fujifilm, BAS-SR). Figure 2(a) shows the spatial distribution of the LCS gamma-rays generated at a beam current of 5.7 mA and a laser power of 10 W. The horizontal and vertical rms beamsizes of the gamma-rays were measured to be 2.1 and 1.1 mm, respectively. Most of the gamma-rays were detected inside the irradiated area, which is defined by a circle with a radius of 2.2 mm.

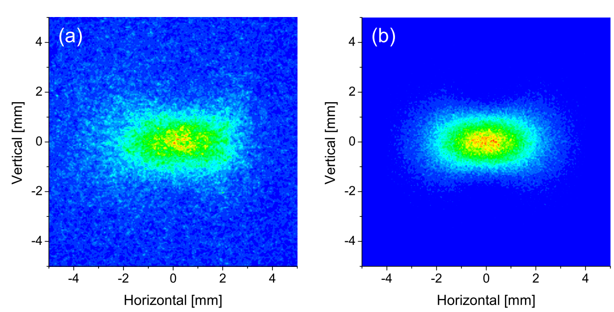

Figure 2: (a) Measured and (b) simulated spatial distributions of LCS gamma-rays.

The gamma-ray beam profile extends in the horizontal direction due to the anisotropy of the scattering cross section with respect to the laser polarization axis [9]. To confirm the origin of the spatial distribution, we simulated the gamma-ray beam profile using the EGS5 code. To simplify the simulation, we assume that the electron and laser beams collide at the center of the LS8. The simulation accounted for the transverse sizes of the electron beam and the differential cross section of the Compton scattering. The simulation results well reproduce the overall features of the spatial distribution as shown in Fig. 2(b). The simulated spatial distribution varies drastically with the polarization state of the laser light. We thus conclude that the spatial distribution of the LCS gamma-rays is characterized by the anisotropy of the Compton scattering with respect to the laser polarization axis.

Gamma-ray Flux

Figure 3 shows the dose rate in the irradiated area measured using a glass dosimeter and a survey meter. Gamma-rays were generated using beam currents of 100, 200, and 300 mA. The dose rates are plotted as a function of the product of the beam current and the laser power. An exposure time of 30 min was used for the glass dosimeter, whereas the survey meter could perform real-time measurements. The measured dose rates were reasonably linear over a wide range of beam currents and laser powers and the two sets of measurements are in approximate agreement with each other. However, a slight discrepancy was observed between the glass dosimeter and the survey meter measurements at a high beam current and a high laser power. One possible cause for this discrepancy is the misalignment of the glass dosimeter. Since the glass dosimeter is much smaller than the survey meter, a small misalignment of the dosimeter position will probably reduce the dose rate. Therefore, we estimated the gamma-ray flux based on the dose rate measured by the survey meter.

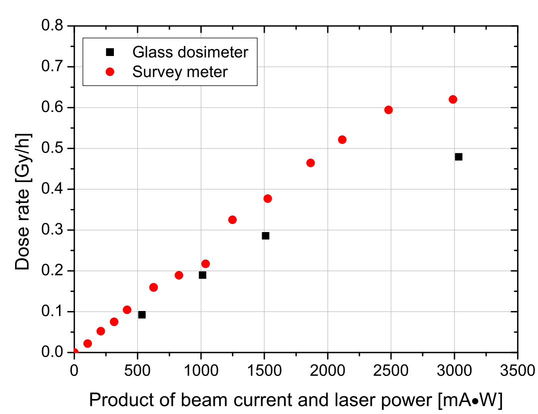

Figure 3: Effective dose rate of LCS gamma-rays in the irradiated area. The dose rates were measured using a glass dosimeter and a survey meter.

The gamma-ray dose rate is about 0.6 Gy/h at 3000 mA·W, which is about 20% of the designed value. Thus, the effective flux is estimated to be 6×10^6 photons/s for gamma-rays with energies of over 0.5 MeV. This result agrees approximately with that estimated by the detector counting rate at a low current. Prior to the dose measurement, we examined the gamma-ray flux at a low beam current using the BGO detector and found that the counting rate was about 25% of the designed value.

A gamma-ray flux of the order of 10^6 photons/s was successfully evaluated using the dosimetry-based method. This method can be used to measure higher fluxes of the order of 10^7 photons/s. Although the observed flux was limited to 15–30% of the designed value in the beam tests, we expect that a further increase in the gamma-ray flux can be achieved by carefully adjusting the laser optics to improve the overlap between the electron and laser beams. Furthermore, we expect to achieve a high-flux of the order of 10^{10} photons/s when we use a high-power CO_2 laser with an output power of the order of several kW.

Effect on the Beam

To examine the influence of the LCS on the stored beam up to the maximum event rate of 3000 mA·W, we measured the beam parameters of the storage ring (i.e., the beam current, lifetime, and transverse beam sizes) during gamma-ray generation. In this experiment, the dose rate was measured by the survey meter, while the beam sizes were obtained using a synchrotron radiation interferometer [10]. Figure 4 shows a typical observation of the beam parameters during the generation of LCS gamma-rays. No sudden drops in the beam lifetime or variations in the transverse beam sizes were observed, which confirms that LCS gamma-rays of the order of 10^6 photons/s flux were successfully generated without affecting the light source performance of the storage ring.

SUMMARY

We performed experiments on LCS gamma-ray generation up to the maximum event rate. The gamma-ray flux was evaluated based on dosimetry. The observed dose rate was 0.6 Gy/h at 3000 mA·W, which corresponds to a gamma-ray flux of 6×10^6 photons/s. The dosimetry-based method enabled us to measure gamma-ray fluxes of the order of 10^6 photons/s. We investigated the effect of the LCS on the stored beam and confirmed that LCS gamma-rays generation did not affect the light source performance. By adjusting the laser optics, it should be possible to use the present LCS setup to generate gamma-rays with high fluxes of the order of 10^7 photons/s. Higher gamma-ray fluxes of up to order of 10^{10} photons/s are expected by employing a high-power laser with an output power of the order of several kW.

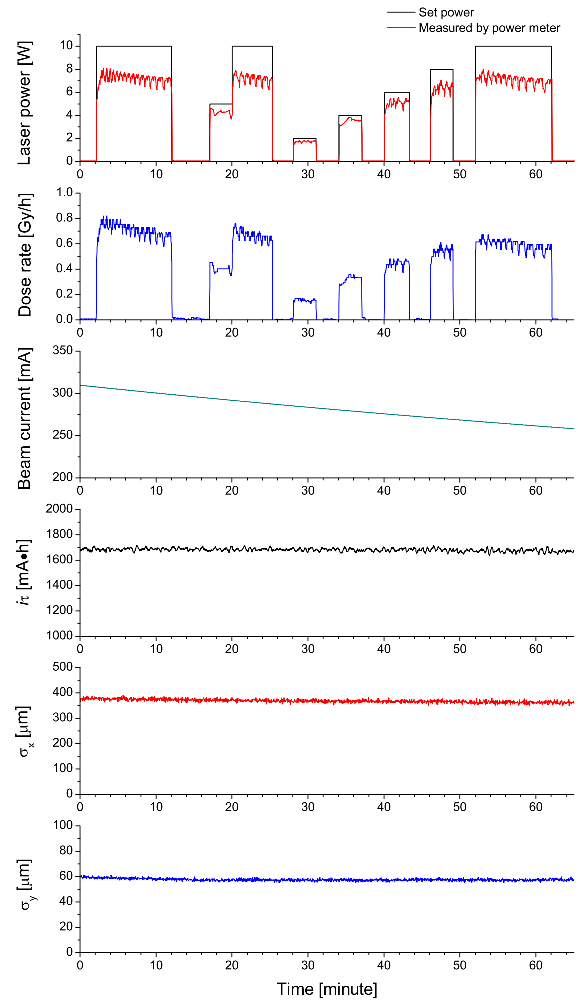

Figure 4: Laser power, dose rate, and beam parameters (i.e., beam current, product of the beam current and lifetime, and transverse beam sizes) recorded during LCS gamma-ray generation.

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