Performance of the Laser Compton Scattering Gamma-Ray Source at SAGA-LS

T. Kaneyasu, Y. Takabayashi, Y. Iwasaki, S. Koda
SAGA Light Source, 8-7 Yayoigaoka, Tosu, Saga 841-0005, Japan
E-mail: kaneyasu@saga-ls.jp

Abstract. A laser Compton scattering gamma-ray source was constructed at the SAGA light source facility. To produce high-flux gamma rays in the few MeV region, we used a CO$_2$ laser with a 10.6 $\mu$m wavelength. Head-on collisions between the laser photons and the 1.4 GeV electron beam in the storage ring can produce gamma rays up to a maximum energy of 3.5 MeV without affecting the light source performance. The performance of the LCS source with respect to the stability of gamma-ray flux during continuous operation is reported.

1. Introduction
The availability of intense gamma rays in the few MeV region enables a wide variety of applications in basic science, technology, and industry [1]. To provide high-flux gamma rays in the MeV region, we constructed a laser Compton scattering (LCS) gamma-ray source in the SAGA light source (SAGA-LS) facility. Owing to the useful characteristics of the LCS source, such as tunable energy, polarization control, and low divergence, LCS facilities providing the gamma rays in the MeV region have been developed [2, 3, 4].

SAGA-LS is a synchrotron radiation facility consisting of a 255 MeV injector linac and a 1.4 GeV storage ring [5, 6]. The LCS source at SAGA-LS is based on a 1.4 GeV storage ring equipped with a CO$_2$ laser with a wavelength of 10.6 $\mu$m. LCS gamma rays up to a maximum energy of 3.5 MeV are produced by colliding the laser photons with the 1.4 GeV stored electron beam. The maximum gamma-ray flux at the detector position is expected to be on the order of $10^7$ photons/s at a 300 mA beam current and 10 W of laser power. In the present configuration, the energy acceptance of the storage ring is well above the gamma-ray energy, enabling LCS without a reduction in beam lifetime. It is therefore possible to conduct experiments using LCS gamma rays in conjunction with normal user time (10 hours per day with a 300 mA initial current) for synchrotron radiation research.

We previously investigated the basic characteristics of the LCS gamma rays and the effect of LCS on the stored beam [7, 8]. In this paper, we will concentrate on a feasibility study of continuous gamma-ray generation during the one-day user time. In addition, future plans for improving the availability of the gamma rays and for studying the performance of the storage ring using LCS are presented.

2. LCS gamma-ray source
A schematic drawing of the LCS gamma-ray source constructed in SAGA-LS is shown in Fig. 1. Currently, the laser and detector systems are placed in the experimental area inside the storage
ring tunnel. To expand the experimental area for use of the LCS gamma rays, the construction of experimental and laser hutches is planned, as discussed in a later section.

The detailed LCS setup and the scheme used to evaluate the gamma-ray flux were described in previous papers [7, 8]. Briefly, the 10.6 μm wavelength photons from the CO₂ laser having a 10 W maximum power were scattered by the 1.4 GeV electron beam in head-on collision conditions in the straight section used for beam injection. The laser light was focused around the center of the straight section to enhance the LCS event rate. The LCS gamma rays were detected without a collimator in the present setup. Hence, the spectral character of the gamma ray was a continuous distribution up to the highest energy edge around 3.5 MeV. We evaluated the gamma-ray flux up to the order of 1×10⁷ photons/s by dosimetry using an ion-chamber survey meter. The effective dose rate inside an irradiated area defined by a circle of 2.2 mm radius was measured, and this was converted to gamma-ray flux with energies over 0.5 MeV.

To examine the feasibility of continuous gamma-ray generation during user time, we performed beam tests in which LCS gamma rays were produced for 10 hours at the maximum laser power of 10 W with an initial beam current of 300 mA. To investigate the stability of the gamma-ray intensity and the influence of the LCS on the stored beam, we recorded the gamma-ray flux and various beam parameters (beam current, lifetime, and transverse beam sizes). Along with the data collection for the feasibility study, the gamma rays generated were used to study exposure effects on sample materials.

3. Performance of the LCS source; flux and stability
A typical observation of gamma-ray flux for 10 hours of operation is presented in Fig. 2. In the beginning of the measurement, the gamma-ray flux was about 1×10⁷ photons/s at 300 mA of beam current. As the measurements continued, the flux gradually decreased in accordance with the beam current decay. In this measurement, a laser mirror within the mirror chamber (see Fig. 1) was adjusted every hour to compensate for thermal deformation of the mirror. Several intensity drops observed in the gamma-ray flux can be attributed to these adjustments. Except during the mirror adjustments, the gamma-ray flux was almost proportional to the beam current decay. Moreover, no sudden drops or changes in the beam lifetime and transverse beam sizes due to LCS were observed in the beam tests. These results imply that the LCS source can continuously provide stable gamma rays in conjunction with the user time.

To investigate the stability of the gamma-ray source in one-day operation, we compared flux data obtained in different measurements. Figure 3 shows the gamma-ray flux over 10 hours of operation, plotted as a function of the product of transmitted laser power and beam current. Run #2 corresponds to the flux data shown in Fig. 2. The initial current and beam current decay in Runs #1 and #3 were almost the same as those obtained in Run #2. The gamma-ray

Figure 1. The LCS setup in SAGA-LS for gamma-ray generation.
flux in Run #3 was lower than the others. This was caused by a poor adjustment of the laser optics during Run #3. The observed flux was limited to 15-30% of the designed value in the measurements, but we expect that the flux could be increased by more precise adjustment of the laser optics.

The linearity of the gamma-ray flux against the product was somewhat worse in Run #1. While the laser mirror was adjusted every one to three hours in Runs #2 and #3, Run #1 was performed without adjustment. In addition, the orbit drift of the electron beam was much smaller than the transverse size of the laser light. Therefore, the intensity decrease observed in Run #1 resulted from thermal deformation of the laser mirror under synchrotron radiation. The laser mirror should be adjusted several times during a one-day experiment to keep the gamma-ray flux proportional to the beam current.

![Figure 2](image1.png)

**Figure 2.** Beam current and gamma-ray flux in one-day operation of the LCS source.

![Figure 3](image2.png)

**Figure 3.** Gamma-ray flux during 10 hours of operation. The flux is plotted as a function of the product of transmitted laser power and beam current.

4. Future plan

At present, the laser and detector systems are inside the storage ring tunnel. Therefore, the LCS experiment is strongly limited in space, which allows only a simple setup for use of the gamma rays. Another problem of the limited space lies in the difficulty of adjusting the laser optics to enhance the LCS gamma-ray flux. In order to optimize the focusing and alignment conditions of the laser light, it is preferable to handle the optical components during machine operation. However, we could adjust only one mirror among the optical components during the LCS gamma-ray generation in the present setup. To overcome such difficulties, we plan to construct experimental and laser hutches in the experimental hall. The layout of the construction plan is shown in Fig. 1. The LCS gamma rays can be extracted to the experimental hutch through the transport line in the shielding wall. The laser system and focusing optics are placed in the laser hutch, and the laser light is transported into the storage ring tunnel. Construction of the hutches will begin in fiscal year 2012.

In addition to development of the LCS source using a CO\textsubscript{2} laser, we began an experimental study to evaluate the momentum acceptance of the storage ring by means of coincidence detection between beam loss induced by LCS and gamma-ray energy. For that study, we introduced a fiber laser with a 1064 nm wavelength. LCS gamma rays up to 34 MeV were generated by colliding the 1064 nm wavelength photons with the 1.4 GeV beam, causing a loss of the stored beam. As a first step in the experiment, we tested the LCS using the fiber laser.
and successfully observed the resulting gamma rays. Figure 4 shows the gamma-ray spectra measured by a scintillation detector equipped with a 5 inch NaI crystal. High energy gamma rays up to around 34 MeV were observed when the laser power was on, indicating the production of LCS gamma rays.

5. Summary
We constructed an LCS source based on the 1.4 GeV storage ring equipped with a CO$_2$ laser in the SAGA-LS facility, and investigated the stability of the gamma-ray flux during one-day operation. The maximum gamma-ray flux was about $1 \times 10^7$ photons/s at 300 mA current. Although thermal deformation of the laser mirror caused an intensity decrease of the LCS gamma rays, mirror adjustment assured a gamma-ray flux proportional to the beam current decay. We conclude that the LCS source can continuously generate stable gamma rays in the several MeV region in conjunction with normal user time for synchrotron radiation experiments. To improve the availability of the LCS gamma rays, construction of experimental and laser hutches is planned.

Acknowledgments
This work was in part supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (no. 23760071).

References
[1] Tain J L 2009 Synchrotron Radiation News 22 3
[2] Ohgaki H, Toyokawa H, Kudo K, Takeda N and Yamazaki T 2000 Nucl. Instrum. Methods A 455 54
[3] Miyamoto S, Asano Y, Amano S, Li D, Imasaki K, Kinugasa H, Shoji Y, Takagi T and Mochizuki T 2007 Radiation Measurements 41 S179
[4] Wu Y K, Busch M, Emamian M, Faircloth J, Hartman S, Howell C, Li J, Mikhailov S, Popov V, Swift G, Wallace P and Wang P 2009 Proc. 23rd Particle Accelerator Conf. (Vancouver) p 3181
[5] Tomimasu T, Koda S, Iwasaki Y, Ohgaki H, Toyokama H, Yasumoto M, Yamatsu Y, Kitsuka T, Hashiguchi Y and Ochiai Y 2003 Proc. 20th Particle Accelerator Conf. (Portland) p 902
[6] Koda S, Iwasaki Y, Takabayashi Y and Kaneyasu T 2010 Proc. 1st Int. Particle Accelerator Conf. (Kyoto) p 2579
[7] Kaneyasu T, Takabayashi Y, Iwasaki Y and Koda S 2011 Nucl. Instrum. Methods A 659 30
[8] Kaneyasu T, Takabayashi Y, Iwasaki Y and Koda S 2011 Proc. 2nd Int. Particle Accelerator Conf. (San Sebastián) p 1476