PRODUCTION OF MEV PHOTONS BY THE LASER COMPTON SCATTERING USING A FAR INFRARED LASER AT SPRING-8*

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Abstract

In order to produce MeV photons (γ-ray) by the laser Compton scattering (LCS), a high power optically pumped far infrared (FIR) laser has been developed at SPring-8. We obtained about 1.6 W of maximum output power of FIR laser at CH_3OH 119 μm lasing line pumped by 9P(36) branch line of CO_2 laser. In case of the SPring-8 storage ring, the momentum acceptance is so large (± 200 MeV) that the Compton scattered electron is re-accelerated. Therefore, the stored beam is not lost by the LCS process. The beam diagnostics beamline I (BL38B2) is used to inject a FIR laser beam against 8 GeV stored electron beam and to extract MeV photons produced by LCS. The FIR laser system, MeV photons production system, and measured MeV photons spectrum will be presented. Production rate of MeV photons by LCS was estimated to be the order of 10^3 photons/sec with 890 mW output power of FIR laser. Future plans will also be introduced. In order to produce higher intense MeV photons, we are constructing a new MeV photons production system at another beam diagnostics beamline (BL05SS).

INTRODUCTION

SPring-8 is the third generation synchrotron radiation facility providing a highly brilliant X-ray photon beam having an energy range from 0.2 to several hundreds keV by bending magnets and insertion devices. Synchrotron radiation is obtained according to the motion of stored electrons in a bending magnet or an insertion device. There is another way to generate photons in a different mechanism. High energy photons generated by the inverse Compton scattering of laser photons with relativistic electrons have an energy range from MeV to GeV and narrow angular divergence. The divergence of the produced γ-ray is approximately proportional to the inverse of the Lorentz factor (= $E_e/m_ec^2 = \gamma$). In case of SPring-8, γ-ray is well collimated in a small solid angle (≈ 0.06 mrad) because of the large Lorentz factor, γ= 15650.

The γ-ray in MeV region was produced by LCS using a storage ring and a laser of infrared or visible region at some facilities, such as Frascatti, AIST, etc [1]. In these cases, however, the momentum acceptance of the ring are so small because of low beam energy that the stored electrons in storage ring are lost due to the LCS process. On the other hand, in case of SPring-8 storage ring, the momentum acceptance is so large (±200 MeV) that the scattered electron is re-accelerated. Therefore the stored beam is not lost by the LCS process. Experiments with MeV photons can be performed parasitically, independent of synchrotron radiation users. Furthermore, since the photon energy of the FIR laser light is extremely low, the laser beam contains a huge number of the quantum photons compared with the case of the visible laser (more than a factor of 1000). These mean that we can irradiate the 8 GeV beam with a higher intensity laser light. There is a possibility for us to obtain the extremely high production rate of MeV photons.

To generate 10 MeV LCS photons with the 8 GeV electrons, a laser of far infrared region is necessary. An optically pumped FIR laser has been developed for the application of spectroscopy, plasma diagnosis, frequency standards, astronomy, etc. For example, for the heterodyne method at the Large Helical Device, a stable laser oscillation was achieved for a long time [2],[3]. As various laser oscillation lines are possible by an optically pumped FIR laser, the maximum energy of LCS γ-ray can be changed in a wide range.

For the sake of some merits as mentioned above, the LCS γ-ray can be used for scientific developments in various fields. Particularly, the photons in 10 MeV regions have many applications to study of the extensive fields such as nuclear physics, astrophysics, medical science, nuclear engineering, etc.

FIR LASER SYSTEM

FIR laser system consists of a CW CO_2 laser and a waveguide-type FIR resonator as shown in Fig. 1. The CO_2 laser cavity consists of a water-cooled 10.8 mm-I.D. Pyrex glass tube, an internal resonator which is formed by a diffraction grating (150 lines/mm) and a 20 m concave ZnSe output coupler (R=55 % for 10.6 μm). The cavity

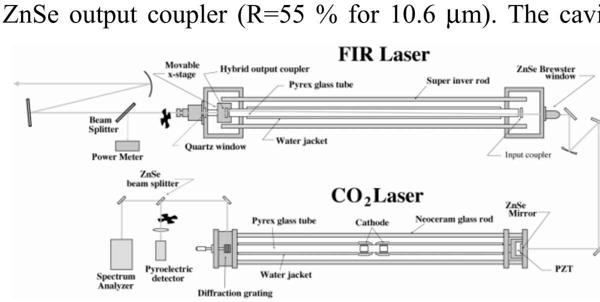

Figure 1: Schematic view of FIR laser system.

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length is fixed at 3.0 m using four Neoceram glass rods which have a low thermal expansion coefficient of -1×10^{-7}°C^{-1}. 234.5W-output power of the pumping CO_2 laser was achieved at 9P(36) lasing line, which was used for pumping CH_3OH for 119 μm lasing. The absorption line center of FIR lasing molecules is located on the slope of the detuning curve of the CO_2 pump laser and the width of the absorption line is quite narrow relative to the free spectral range of the pump laser. FIR laser power is highly sensitive to the frequency of the pump laser. So stabilization of CO_2 laser is important. The long-term drift of the CO_2 laser output is less than ±0.6 % for 24 hours in free running operation.

The FIR laser cavity consists of a 35.2 mm-I.D., 3m-long Pyrex hollow circular waveguide with an input and an output coupler. The waveguide is cooled by a coaxial water jacket. Both the input and output couplers are also water-cooled. The laser optical elements are mounted in the inside of vacuum chambers at both ends in order to be free from atmospheric pressure changes. The vacuum chambers are supported by two Super-Invar rods. The vacuum chambers equip with a ZnSe Brewster window at the input and a 1.57 mm-thickness Z-cut quartz window at the output. CO_2 laser light is transported to FIR laser cavity by four water-cooled Cu mirrors. Third mirror is a 1000 mm focal length spherical mirror and focuses CO_2 laser light at the inside of FIR cavity through the tiny coupling hole of input coupler. The input coupler is 50 mm-diameter high reflector Cu mirror with an off-center 3 mm-hole of which inner surface is coated by gold. The output coupler (40 mm in diameter and 2 mm thick) is hybrid type and consists of a quartz window coated with a dielectric to reflect (>99 % for 9.7 μm) the CO_2 laser light. The window is masked to produce a coupling hole with a required diameter (11 mm) and then over-coated with a thin gold layer. The FIR output passes through the hole in the gold film. The output coupler is attached on movable x-stage for detuning the cavity length. The FIR laser power depends on a gas pressure, so the gas flow rate is controlled by a piezo-bulb controller. Helium gas is added to lasing medium of CH_3OH as a buffer gas. The 1.6 W output power was obtained at an optimized condition, and ±1 % stability with about an output power of about 1W was achieved for a long-term operation of 24 hours [3]. By optimization and improvements of FIR laser system, we plan to increase an FIR output power more than 2 W.

FIR LASER TRANSPORTATION

The FIR laser system is set up in the laser clean room at the experiment hall of the storage ring. FIR laser light is transported to a collision point in the storage ring. The hollow circular dielectric waveguides which are made form acrylic resin are used for long distance optical transportation of FIR laser light. Figure 2 shows the laser transportation system. The laser light is transported about 20 m to reach an incident mirror system by waveguides and corner mirrors. It is air tight, and dry air of -40°C

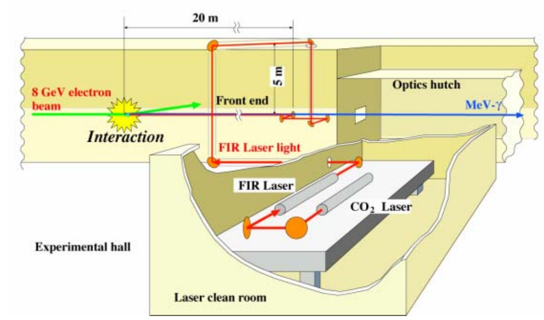

Figure 2: Laser transportation system with hollow dielectric waveguides and corner mirrors.

dew-point temperature is flowed into waveguides in order to minimize attenuation of the FIR laser light owing to water vapor absorption. A 70% transmission efficiency by waveguide system was achieved. A beam profile of FIR laser light from exit-end of the waveguide is adjusted by the incident mirror system. FIR laser light passes through the Z-cut quartz transparent window which is equipped on the vacuum chamber. The vacuum chamber is installed at the front-end of the beamline at the 20 m downstream from a collision point. Final reflection mirror which is also equipped in the vacuum chamber transfers FIR laser light to the collision point against the electron beam of the storage ring. A beam profile monitor using a pyro-electric sensor was developed and installed at 2m-upstream from the chamber. By using this monitor, the laser optical axis was tuned for finding the interaction point to electron beam.

By considering the diffraction effect by many aperture limits in the duct of front-end, a production rate of MeV photons was estimated to be $N_\gamma = 3.8 \times 10^3$ photons/sec with 1.6 W FIR laser of 119 μm. Figure 3 shows the expected MeV photons spectrum and angular distribution calculated by a Monte-Carlo simulation with the 1.6 W of the FIR laser power and 0.66 of the transmission efficiency of the laser transportation system [4].

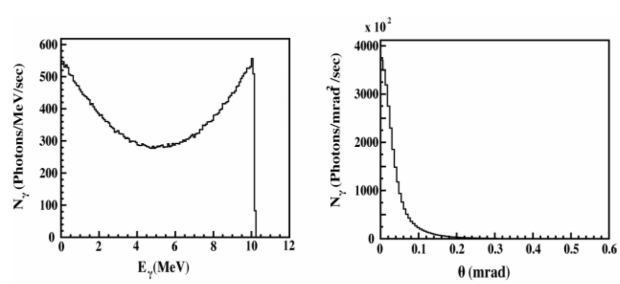

Figure 3: Calculated energy and angular distributions of LCS MeV photons by Monte-Carlo simulation.

MEASURMENT OF PRODUCED MEV PHOTONS

Figure 4 shows the schematic drawing of detection system. LYSO:Ce sincillator (ϕ50 × 90mm) and PMT were used for a detector of produced MeV photons. In case of BL38B2, synchrotron radiation from the bending magnet is emitted to the same direction of LCS MeV photons. In order to reduce pileup of detector by synchrotron radiation photons of several hundred keV to a few MeV region and Bremsstrahlung, a 20mm-thickness lead and a 200mm-thickness carbon absorbers were installed in front of the detector. LCS MeV photons was collimated by two 50 mm long lead collimators with the hole of 10 mmϕ (0.15 mrad) and 12 mmϕ (0.17 mrad). To reduce a background, LYSO:Ce scintillator was installed in a lead-box with a wall thickness of 10 mm. Fine tuning of the laser beam axis was accomplished by maximizing the count rate in the detector. Energy calibration was done by using radioactivity source of ^{88}Y.

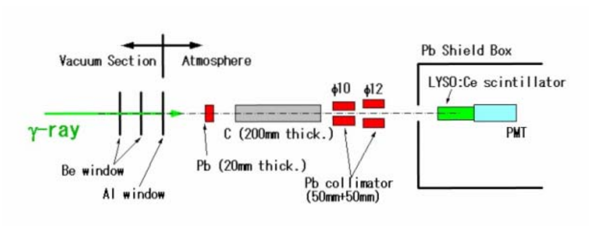

Figure 4: Schematic drawing of measurement system.

Figure 5 shows measured spectra with the conditions of “FIR laser on” and “FIR laser off”. The γ-ray spectrum from the LCS process has been deduced after the subtraction of the “FIR laser off” spectrum from the “FIR laser on” spectrum as shown in Fig. 5. Since the discriminator of detection circuits was set at about 2MeV, MeV photons by LCS and synchrotron radiation less than 2 MeV were not observed in these spectra. During the experiments, FIR laser output power was 890 mW which was measured near the exit window of FIR laser by a power meter. We confirmed that stored electrons were not lost during the experiment with LCS process. From measured result, we estimate that the MeV photons production rate is $2{\times}10^3$ photons/sec per FIR laser output power of 1W. This is in agreement with the calculated prediction.

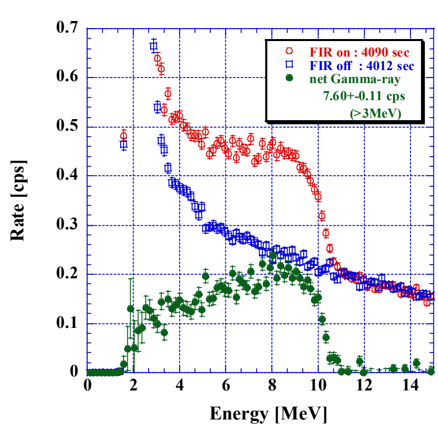

Figure 5: Measured energy spectrum of LCS MeV photons.

FUTURE PLAN

We proceed with MeV photons production study at BL38B2. The MeV photons intensity which was obtained in this beamline is not sufficient because an interaction region for the head-on collision between laser photons and electrons is very short as this beamline is designed and constructed as a bending magnet light source. To produce high intense MeV photons, an advanced plan is in progress at the beam diagnostics beamline II (BL05SS) which has a 16m-long interaction region, because this beamline has a straight section for installation of an insertion device as a light source. Furthermore, we plan to transport laser beam to near the interaction region by waveguides to recover a reduction of effective cross-section of Compton scattering due to a large divergence of laser beam. For that purpose the vacuum chamber equipped with the final mirror was manufactured and installed in the storage ring tunnel. The distance from the final mirror to an interaction region is about 3 m, which is very short compared with the case of BL38B2. The construction of the laser clean room and the waveguide system were completed. In this beamline MeV photons production rate will be expected more than 10^5 photons/sec. Figure 6 shows a comparison the calculated production rate of LCS MeV photons at BL05SS with that at BL38B2 per FIR laser output power of 1W.

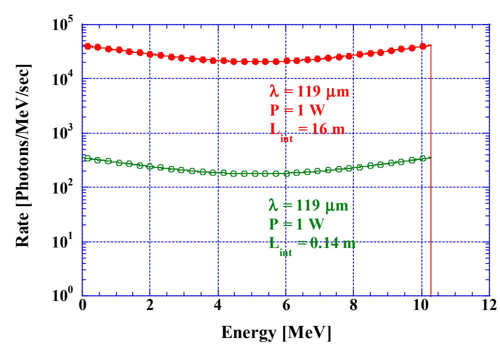

Figure 6: Comparison BL05SS with BL38B2 by calculated LCS MeV photons spectra.

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