LASER COMPTON BACK-SCATTERING GAMMA-RAY SOURCE ON NewSUBARU

Shuji Miyamoto, Yoshihiko Shoji, Sho Amano, Ken Horikawa, Yoshiki Hidaka, Ainosuke Ando, Takayasu Mochizuki, Laboratory of Advanced Science and Technology for Industry, University of Hyogo, 678-1205, JAPAN
Dazhi Li, Kazuo Imasaki, Institute for Laser Technology, Osaka, 550-0004, JAPAN
Kazuhiko Aoki, Graduate School of Engineering, University of Hyogo, 671-2201, JAPAN
Yoshihiro Asano, Tetsuya Takagi, SPring-8, Hyogo, 679-5198, JAPAN

Abstract

The laser-Compton scattering gamma ray generation was tested on a synchrotron radiation facility, "NewSUBARU". Cw laser (wavelength: 1.064 μm, maximum power: 5 W) was used in the experiments. Maximum energies of scattered gamma ray are 17.6MeV and 39.1 MeV at the operating electron energy of 1GeV and 1.5GeV, respectively. A scintillation detector (NaI) and Ge detector was used to measure the gamma-ray spectrum and the yield. A measured gamma-ray yield was 5×10^3 photons/sec/mA/W. Preliminary experiments of gamma-ray application were performed on a nuclear transmutation and on a gamma-ray radiography. Radiation shield of new gamma-ray beam line (BL01) was designed and the construction has been completed.

1 INTRODUCTION

Scattering of laser beam by high-energy electrons (backward Compton scattering) is unique gamma-ray source for various applications. Several laboratories are using the gamma-rays generated by this method[1-3]. The schematic of the laser-Compton scattering gamma-ray generation is shown in Fig.1. In the case of head on collision between relativistic electrons and photons, the scattered photon energy E_γ is written by

$$E_\gamma = \frac{4E_L\gamma^2/(1+R)}{1+\gamma^2\theta^2/(1+R)}、\quad R = \frac{4E_L\gamma}{mc^2} \tag{1}$$

where γ is the electron energy, E_e, in units of rest energy ($\gamma = E_e/mc^2$), m is the rest mass of electron, c is the speed of light in vacuum, θ is angle of photon scattering

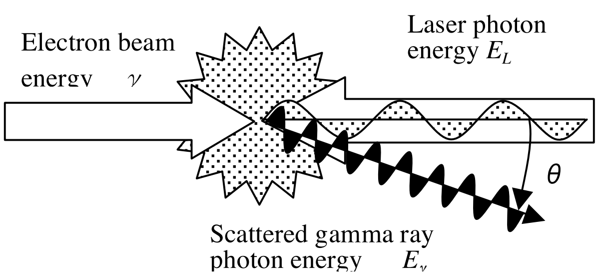

Fig.1 Laser Compton scattering gamma-ray generation.

measured from electron beam axis and E_L is the laser photon energy. The dependence of the gamma-ray energy on the scattered angle gives attractive possibility to produce nearly mono energetic gamma-ray beam by using an axial collimator.

Generation and applications of gamma-ray are studied on NewSUBARU, 1 to 1.5GeV electron storage ring[4,5]. One of the applications is a basic study of transmutation for disposal of radioactive waste[6]. In this process, (γ, n) photo nuclear reaction will be used to change the long life radioactive isotopes to the short life or the stable isotopes.

2 LASER COMPTON GAMMA-RAY GENERATION

Figure 2(a) shows calculated relationship between laser-Compton gamma-ray energy and scattering angle on NewSUBARU. An Nd:YVO laser (wavelength of 1064nm) is assumed as an injection photon. The maximum gamma-ray energies at axis are 17.6 MeV and 39.1 MeV for 1GeV and 1.5GeV electron energy, respectively. Figure 2(b) shows gamma-ray spectrum calculated from the Klein-Nishina formula. The curve notated as "giant resonance" in this figure, is a conceptual example of spectral cross section of photo nuclear reaction. Peak energy of giant resonance weekly depends on the atomic mass of the target nuclei. These resonance energies distribute around 15 MeV to 25 MeV.

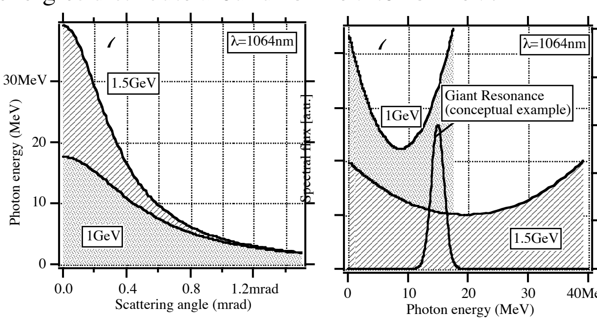

Fig.2 Spectral characteristics of Laser Compton scattering gamma ray on NewSUBARU (1 to 1.5 GeV) with a laser of 1064 nm wavelength. (a) Angular distribution of gamma ray. (b) Spectral distribution of gamma ray compare with spectral cross-section of giant resonance of photo nuclear reaction.

NewSUBARU is a racetrack shape electron storage ring synchrotron radiation facility. The circumference of the ring is about 118.7 m. Electron beam is injected from 1GeV linac at Spring-8 facility. The laser-Compton scattering experiments were performed at one of the long straight section.

2.1 Experimental setup and gamma-ray yield

Figure 3 shows the layout of BL01, gamma-ray beam line. Laser was installed at the outside of the wall and was injected into the vacuum ducts. The gamma-ray detector was located about 16 m from the electron-photon collision point. A high-purity Germanium coaxial detector was used with the detection efficiency of 45%.

The measurements of gamma-rays were carried out at a lower current of several mA, to avoid saturations at the detector. An example of measured spectrum are shown in Fig 4, for laser ON and laser OFF, with a collimator of 24 mm in diameter in front of the detector. The background signal is due to the bremsstrahlung by the residual gases in the vacuum duct of the straight section. The maximum energy appears around 17 MeV, which is in agreement with the theoretical prediction. We simulated the process of generated gamma-ray transport from the source to the detector including photons passing through the reflected mirror, output window, collimator, and being detected by the detector, by employing the EGS4 code[7]. After processing the experimental data with 10 mm in diameter collimator, we achieved the actual gamma-ray generation rate of 5×10^3 photons/mA/W/s. This yield is contributed by the gamma-ray energy of 12.4-17.6MeV. The maximum gamma-ray photons' yield of more than 10^7 photon/s is expected by NewSUBARU under the condition of storage current I_e= 500mA and laser power P=5 W.

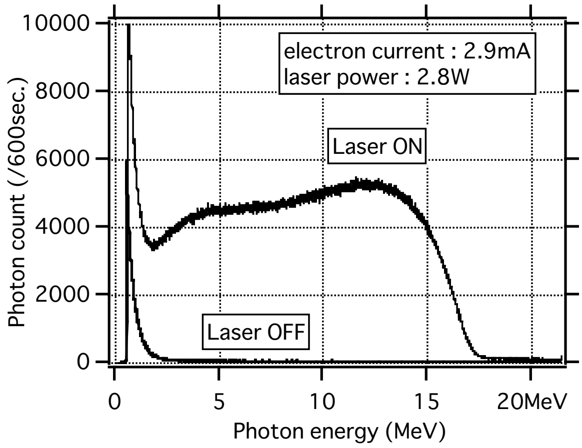

Fig.4 Examples of the laser Compton gamma ray signal. Pb collimator of 24mm in diameter was used.

3 APPLICATION OF LASER COMPTON GAMMA-RAY SOURCE

3.1 Nuclear transmutation

In order to dispose nuclear waste composed of long-lived fission products, a concept of shortening their long radioactive life by transmuting their nuclei to an unstable isotope through irradiation by laser Compton scattering gamma-ray, which is based on a storage ring, was proposed in recent years[8,9]. The concept points out the conversion efficiency of nuclear transmutation, induced by the gamma-ray photons coupling to nuclear giant resonance of a certain material[10]. Experiments are being conducted to investigate the fundamental issues concerning nuclear transmutation on NewSUBARU.

Gold rods of 5 cm long with radii of 0.25 cm and 0.5 cm were adopted as the test nuclear targets in the present experiment and irradiated for duration of 8 h on an axis. The transmutation process of this target is ^{197}Au (γ, n) ^{196}Au (EC) ^{196}Pt (92.5%), (β-) ^{196}Hg (7.5%). After irradiation by gamma-ray, the activated Au sample was measured by a NaI(Tl) detector. Through data processing, we concluded that the number of transmuted nuclei was 3.2×10^6 and the absorbed laser Compton gamma-ray photons by the target during the irradiation was determined as 3.0×10^8. The coupling efficiency of gamma ray to nuclear giant resonance was derived as 1.1%.

3.2 γ -ray radiography

Another application is radiography for nondestructive testing thick objects. In the energy range of MeV photon, absorption coefficient is almost proportional to the density of the transmitting material, then the image of the radiography indicates the density distribution of the testing material. Laser Compton scattering gamma-ray beam source is adapted for this purpose because of a low divergence and quasi-mono

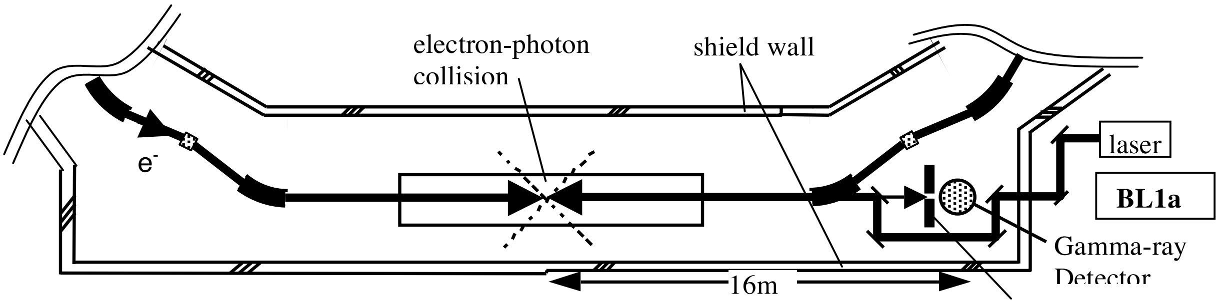

Fig.3 BL1, laser-Compton gamma ray experimental area. Laser was injected from the outside of the wall.

energetic property [11].

Gamma-ray images were taken by imaging plates (IP) located after a sample. The sample consisted of metal rods bundled by Lucite holder. Aluminum and gold rods of 2mm in diameter and 50 mm long were used. Figure 5 shows typical gamma-ray image of the target. These images were taken by 6 hours irradiation with 5×10^5 γ/s flux of gamma-ray (3W laser and electron current of 30 mA). The radiography images show, that the divergences of laser Compton gamma-ray are sufficiently low to indicate the spatial resolution better than 200μm.

4 SHIELDING DESIGN OF GAMMA-RAY BEAMLINE

A shield of new beam-line hutch was designed for extracting the gamma-ray outside the storage ring tunnel. Schematic of the design is shown in Fig.6. Beam shutter consists of 300mm thick lead and 300mm thick polyethlene that shield the gamma-ray and secondary generated neutrons. Gamma-ray is extracted through a hole of the beam shutter of 50mm in diameter. Extracted gamma-ray beams are used and measured in the shield hutch covered by 2cm thick lead and 45 cm thick concrete. End of the beam axis was shielded by 300mm thick lead inside the beam hutch.

Shielding of the beam line was estimated using radiation calculation codes[12]. In photon estimations, maximum gamma-ray yield of 5.4×10^7 photon/sec was used with spectrum having 39.1 MeV peak photon energy (see Fig.2). In neutron dose estimations, electron energy of 1GeV was used, because of the neutron yield is higher at 1GeV electron mode.

Gas bremsstrahlung and associated photo neutrons are calculated by EGS4 and EGS4+MCPHOTO combination. Compton scattered gamma-ray and photo neutron were calculated using EGS4, EGS4+MCPHOTO and MCNPX. Calculations show 2cm thick lead is sufficient to shield the photon to be less than 3μSv/h.

The hole at position "C" will be used for time of flight measurements for photo neutron, and this direction is shielded only by 2cm thick lead. Even with this condition, the estimated dose of 410 μSv/w is still lower than the criterion value indicated in the law.

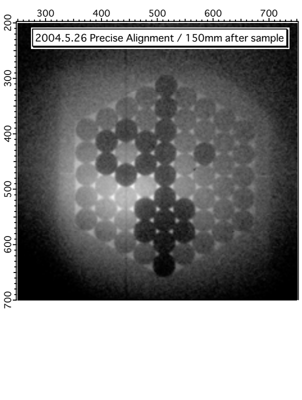

Fig.5 Gamma-ray radiography image. Sample targets are bundle rods of Al and Au with 2mm in diameter and 50mm in length.

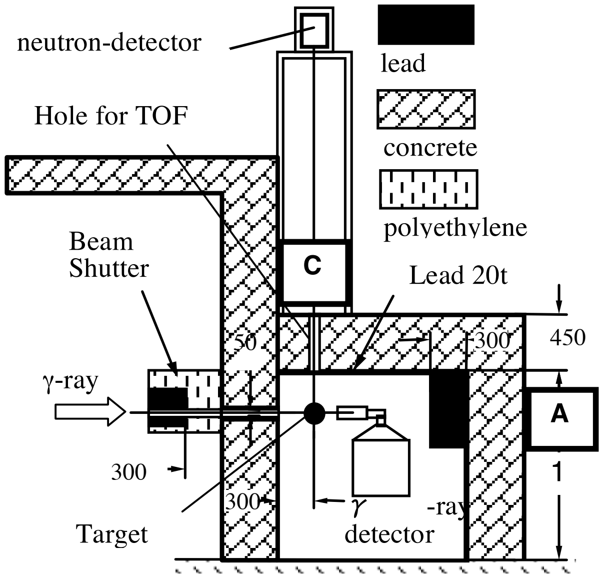

Fig.6 Shielding design of the laser Compton gamma-ray beam-line (BL1)

4 SUMMARY

A laser-Compton scattering system on "NewSUBARU" was used to generate 5×10^5 γ/s of flux at maximum energy of 17.6MeV. The energy and flux are possible to extrapolate to higher vale by using 1.5GeV electron and higher electron current with new gamma-ray shielding beam line. Preliminary experiments of application were performed on a nuclear transmutation for disposal of the radioactive nuclear waste and a gamma-ray radiographic imaging.

REFERENCES

[1] M.Hosaka et al., Nucl. Instr. Methods in Physics Research A, Vol. 393, pp. 525-529(1997).

[2] V.N.Litvinenko, et al., Phys. Rev. Lett. 78, 24, pp.4569-4572 (1997).

[3] V.Nelyubin et al., Nucl. Instr. Methods in Physics Research A, 425, (1999) pp.65-74.

[4] A.Ando, et al., J.Synchrotron Radiation, Vol.5, Part 3, pp.342-344(1998).

[5] S.Miyamoto et al., Proceedings of the 3rd Asian Pacific Laser Symposium, FrSA5, Osaka, Japan, Sep.17-20 (2002).

[6] D. Li, et al., Rev. Laser Engineering, Vol.32, no.3, pp.211-213(2004).

[7] NW.R.elson et al., The EGS4 code system, SLAC-Report, 1985, p. 265.

[8] K.Imasaki , Moon A., SPIE 3886 (2000)721.

[9] M.Aoki et al., WePB25, Osaka, Japan, Sep.17-20 (2002).

[10] D.Li, et al., J. Nucl. Sci. Tech. 39(2002) 1247.

[11] H.Toyokawa, Ohgaki H., Mikado T., Yamada K., Rev. Sci. Instrum. 73(9), pp.3358-3362 (2002).

[12] Y.Asano et al., J.Nuclear Science and Tech., Supplement 1, pp.217-221(2000).