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STATUS OF LASER COMPTON SCATTERED GAMMA-RAY SOURCE AT JAEA 150-MeV MICROTRON

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Abstract

We have developed a laser Compton scattered (LCS) gamma-ray source based on a 150-MeV racetrack microtron at Japan Atomic Energy Agency. The microtron equipped with a photocathode RF gun accelerates a single bunch of electrons to collide with a laser pulse from a Nd:YAG laser. Such gamma-ray source realizes industrial application of nuclear material detection in a ship cargo, which is one of the urgent requests of international nuclear security. Recent status of LCS gamma-ray source development is presented.

INTRODUCTION

Non-destructive detection of special nuclear materials (SNMs) at port-of-entries is of growing importance in view of the nuclear security. Fissile materials such as ^{235}U or ^{239}Pu with the weights of several kilograms may be hidden in a radiation-shield box and brought into a country using cargo containers for nuclear terrorism. However, some kind of nuclear material, ^{235}U for example, cannot be detected by self radiation. Therefore, we need to develop a method to detect nuclear materials with an active manner based on external radiation source to trigger nuclear reactions for detecting nuclides of interest. Neutrons and γ-rays are promising incident probes for the active inspection system because of their isotope-selectivity and their high penetration.

We have proposed a SNM inspection system, which is a hybrid system of two different probes, neutrons and γ-rays[1]. The system consists of a fast pre-screening system by using a D-D neutron source and subsequent precise screening by using quasi-monochromatic γ-rays generated from laser Compton scattering (LCS). If suspicious materials are detected during the fast pre-screening, the cargo is irradiated with LCS γ-rays to identify the isotope composition of the materials by using nuclear resonance fluorescence (NRF) [2].

As a compact and reliable LCS γ-ray source for the SNM inspection system, we are developing a LCS γ-ray source at the existing 150-MeV microtron of JAEA-KPSI (Kansai Photon Science Institute) [3]. The γ-ray energy available at the 150-MeV microtron is 0.4 MeV with a 1 μm laser and 0.8 MeV with a frequency-doubling of laser, which is lower than the γ-ray energy required for detecting nuclear material, 1.733 MeV for ^{235}U. A LCS source for a practical use can be designed and constructed, once generation of high-flux γ-ray is demonstrated at the 150-MeV microtron.

In the present paper, we describe the status of the LCS γ-ray source at JAEA 150-MeV microtron. A design study of 220-MeV microtron for a LCS γ-ray source of practical use in nuclear material detection is described in an accompanying paper [4].

LCS EXPERIMENT AT THE 150-MEV RACETRACK MICROTRON

LCS Source and Beam Line

We have developed a LCS γ-ray source at the 150-MeV RTM [2]. Figures 1 and 2 show the LCS source and beam line. A laser system for LCS γ-ray generation is a commercially available Nd:YAG laser followed by laser pulse compressor with stimulate Brillouin scattering (SBS). The SBS pulse compressor is a simple apparatus, two 1.5 m-long cells filled with Frolinate (3M, FC-40), to compress a laser pulse from the Nd:YAG laser ~8 ns to 0.2 ns with a good transmission efficiency ~80%. The laser system and SBS pulse compressor are installed on an optical table close to the e-beam pipe and laser pulses are introduced to the vacuum pipe at a mirror chamber to collide with an electron bunch at a LCS chamber. The collision is nearly head-on, 1.5 degree, so that we keep good spatial overlap between the laser and electron pulses. The generated LCS γ-ray beam is transported to the irradiation and detection area. The spent electron beam is deflected by a dipole magnet and goes to a beam dump.

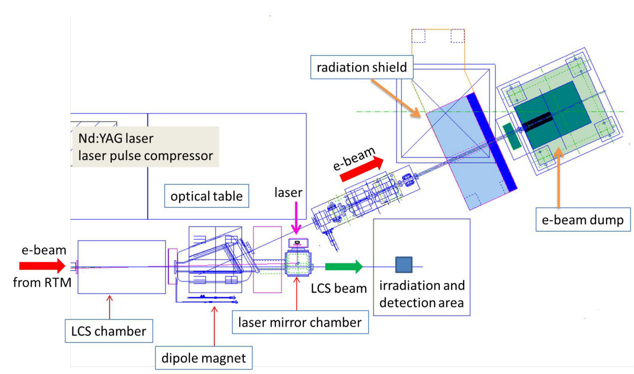

Figure 1: LCS beam line at the 150-MeV racetrack microtron.

Table 1 summarizes the parameters of LCS γ-ray source to generate 0.4-MeV photons at 5-10 Hz. In an experiment in 2012, we confirmed that the LCS source is

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able to generate LCS photons with a flux of 1.2x10^4 ph/shot (100%BW), which corresponds to a flux of 1.2 x 10^5 ph/s at a 10-Hz operation.

We have a plan to upgrade the LCS source by replacing the Nd:YAG laser of 0.8-J pulse by a new laser of 3-J pulse. After the upgrade, we can increase the γ-ray flux by factor of 3-4. We have already completed an off-line test of the new laser to confirm a stable operation of 3-J pulse energy at 10 Hz. The new laser is soon installed at the LCS source.

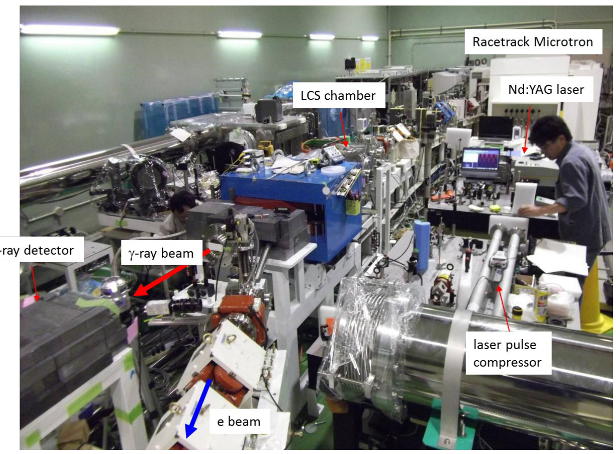

Figure 2: LCS beam line at the 150-MeV RTM.

Table 1: Parameters of LCS γ-ray Source

e beam		**laser**	
energy	150 MeV	wavelength	1064 nm
charge	60 pC	pulse energy	0.8 J
bunch length	10 ps (rms)	pulse length at the laser	8 ns (FWHM)
norm. emittance	35 π mm-mrad	pulse length after compression	0.2 ns (FWHM)
γ-ray			
max. energy	0.4 MeV	repetition	5 Hz or 10 Hz
flux at 10 Hz	1.2x10^5 /s (100%BW)		

Reduction of Background Radiations

After the successful demonstration of γ-ray generation from the LCS source, we irradiated a block of silver with the γ-ray beam to detect nuclear resonance fluorescence as a demonstration of non-destructive detection of nuclear material. The silver target was chosen as a substitute for nuclear material because the isotopes in natural silver, ^{107}Ag and ^{109}Ag, have nuclear excitation levels around 300 keV as shown in Fig. 3.

At the first irradiation experiment in June 2012, we found that the detection of NRF signal is difficult due to large background radiations. Experimental results with changing the geometry of detector shielding revealed that most of radiations comes from the electron beam dump and the radiations include both γ-ray and neutron. For the reduction of radiations from the beam dump, we installed additional radiation shield in front of the beam dump as shown in Fig. 1. From a Monte Carlo simulation of radiation transport, geometry of the radiation shield was determined to be 100-mm-thick iron and 500-mm-thick polyethylene including boron oxide. Figure 4 is a result of Geant4 simulation to confirm the effect of the additional shield, in which we can see that most of backward scattered radiations from the beam dump is stopped in the shield.

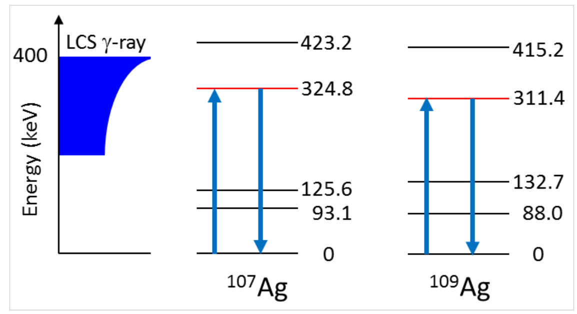

Figure 3: The spectrum of LCS γ-ray and excitation levels of ^{107}Ag and ^{109}Ag.

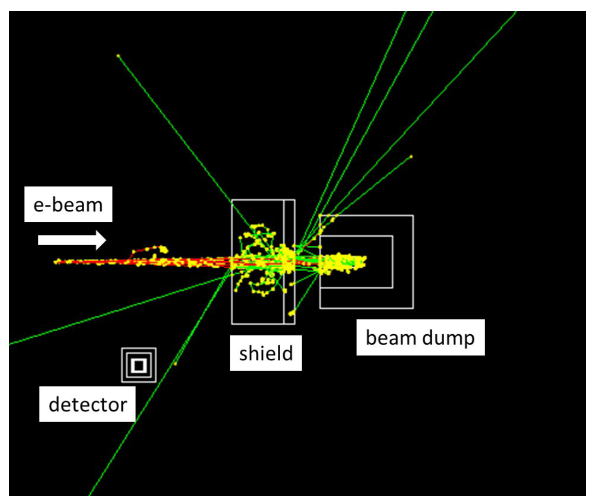

Figure 4: Radiation transport simulation by Geant4 to confirm the effect of the additional shield.

For the further reduction of background radiations, we put a collimator of 5 mm in diameter at the electron beam transport, upstream of the collision point, to remove beam halo, which may causes bremsstrahlung at a beam pipe at the dump line. After installation of the collimator, the electron beam spot at the collision point observed by LANEX screen is 520 µm x 420 µm in 1/e^2 radius fitted with a Gaussian shape. Beam halo previously observed have been removed by the collimator.

After installation of the shield and collimator, we measured background radiations by a GSO scintillation detector at the irradiation and detector area. Figure 5

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shows radiation spectra before and after the installation of shield and collimator, where the spectra were accumulated for 2965 shots and 3860 shots, respectively. From these experiments, we confirmed the background radiations have been greatly reduced.

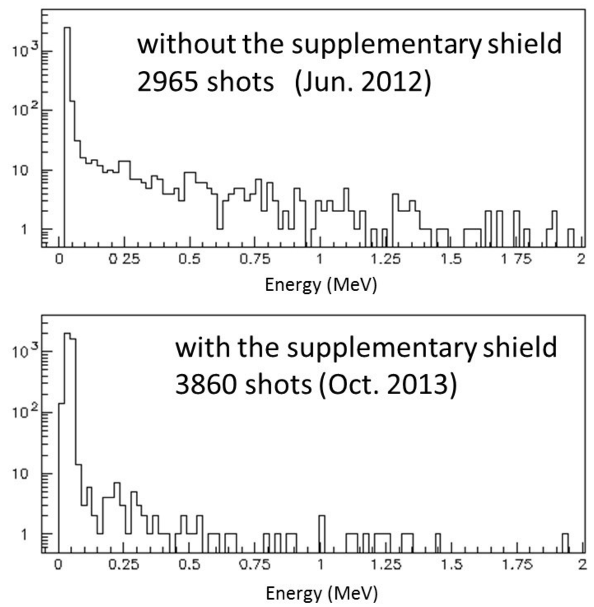

Figure 5: Background radiations measured with a GSO scintillation detector. (laser is turned off)

Detectors for γ-ray Measurements

For the evaluation of LCS γ-ray flux at the 150-MeV microtron, we conducted direct and indirect measurements of γ-ray photons. In these measurements, two types of scintillation detectors, LYSO (20 x 20 mm^2, 5 mm thickness) and GSO (20 x 20 x 50 mm^3) were used [5].

In a practical usage of LCS γ-ray sources for nuclear security applications, we consider to employ an array of $LaBr_3$:Ce scintillation detectors for measuring NRF signals [1]. The properties of $LaBr_3$:Ce in terms of energy resolution, light yield, decay time and material density are suited for LCS γ-ray measurements in an energy region of 2-3 MeV. The feasibility of $LaBr_3$:Ce in NRF measurements has been confirmed separately from experiments with standard γ-ray sources and LCS γ-ray facility, HIGS at Duke University [6]. In the experiment at HIGS, NRF excitations from ^{235}U around 1.7 MeV were successfully observed even with non-negligible internal radioactivity of $LaBr_3$:Ce originating from the metastable isotopes ^{138}La and ^{227}Ac decay chains.

For the detection of NRF signals from the silver target at the 150-MeV microtron, we use an array of $LaBr_3$:Ce scintillation detectors (3.81 cm in diameter and 7.62 cm in length) connected to a digital signal processor (Model AU8008, Techno AP). Applying a coincidence detection with a LCS-beam timing signal, we can greatly reduce the background from internal radioactivity as well as neutron signals from the beam dump. The gate width of timing signal is typically 150 ns. Background radiation due to bremsstrahlung from the 150-MeV electron beam, which cannot be rejected with the coincidence detection, is subtracted by measuring LCS laser-on and -off signals alternatively in a 10-Hz operation of microtron.

SUMMARY

We have developed a laser Compton scattered (LCS) γ-ray source for future application of non-destructive detection of nuclear materials hidden in a cargo at port-of-entries by using a 150-MeV racetrack microtron and a Nd:YAG laser. After successful demonstration of LCS photon generation at a flux of 1.2x10^4 ph/shot, we started an experiment of nuclear resonance fluorescence measurement using a block of silver as a substitute for nuclear material. Background radiations in the NRF measurement have been greatly reduced by installation of an additional radiation shield in front of the beam dump and a collimator in the electron beam transport to remove electron beam halo before the LCS interaction. A detector system for NRF measurement, an array of $LaBr_3$:Ce scintillation detectors connected to a digital signal processor is ready for measurement. We will continue the NRF measurement experiment with the silver target till the end of 2014 FY for the demonstration of non-destructive isotope detection using a LCS γ-ray beam from the 150-MeV micrtotron.

ACKNOWLEDGEMENT

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