HIGH FLUX LASER-COMPTON SCATTERED GAMMA-RAY SOURCE BY COMPRESSED ND:YAG LASER PULSE

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Abstract

A non-destructive inspection system of nuclear material hidden in cargo containers is under development in Japan Atomic Energy Agency and Kyoto University. The system is able to detect and identify the nuclide in the container by employing Nuclear Resonance Fluorescence triggered by mono-energetic Laser Compton Scattered Gamma-ray tuned at the energy of the nuclear resonance. The most important technology of the system is generation of high-flux gamma-ray, required flux of 3×10^5 photon/s is estimated. In order to achieve the flux without increasing the laser pulse energy, the pulse compression system for Nd:YAG laser by using Stimulated Brillouin Scattering is developed. The laser pulse which duration of 10 ns in FWHM is compressed down to a few hundreds ps. As a feasibility study to achieve the high flux, 400 keV gamma-ray generation is performed at Kansai Photon Science Institute by using 150 MeV electron beams from a microtron accelerator and compressed Nd:YAG laser.

INTRODUCTION

After the September 11 attacks in 2001, development of non-destructive inspection for Special Nuclear Material (SNM) at port-of-entries becomes a pressing subject in a view of the counter-terrorism and nuclear proliferation. Detection of γ-rays from nuclear resonance fluorescence (NRF) excited by using quasi mono-energetic γ-rays generated laser Compton scattering (LCS) is one of the most promising methods to identify nuclides of interest hidden in cargo container since its energy selectivity of LCS γ-ray for nuclear resonance and high penetrability for radiation shield and container wall [1].

A collaboration of Kyoto University and Japan Atomic Energy Agency (JAEA) have proposed a two stage SNM inspection system; detection of delayed neutron via resonance of SNM by using D-D fusion neutron source as a fast screening and of NRF γ-ray by LCS for a precise inspection [2]. In this paper, we describe the current status of the development of high flux LCS γ-ray generation. We make a feasibility study of 400 keV LCS γ-ray generation by using 150 MeV electron beam from racetrack Microtron (RTM) accelerator [3] in JAEA-Kansai Photon Science Institute (KPSI) to achieve a flux of 3×10^5 γ-ray /s which flux is required to detect several kilograms of SNM within 10 minutes [4].

LASER PULSE COMPRESSION

In a previous experiment performed in 2009 [5], γ-ray flux of 220 photon/shot was achieved with a commercial product Nd:YAG laser (PowerLite 90 product of Continuum) colliding to 150 MeV electron beams from RTM. The laser pulse energy is 1.6 J and the pulse duration is 8 ns in FWHM. The flux obtained is more than 2 orders smaller than our requirement. In the experiment, the pulse width, 8 ns is quite long compare with the Rayleigh length of laser and the betatron function of the electron beam. Therefore, most part of photons containing in the laser pulse does not over-lapped with the electron bunch at the beam waist. In order to avoid an increase of cost by installation of a larger pulse energy laser system or a gain of unnecessary radiation by the higher current electron beam, we employ a pulse compression technique with stimulated Brillouin scattering (SBS) for efficient use of laser photons. A layout of SBS pulse compressor is shown in Figure 1. An SBS cell is quite simple device. In a glass tube inserted into a stainless steel pipe, SBS

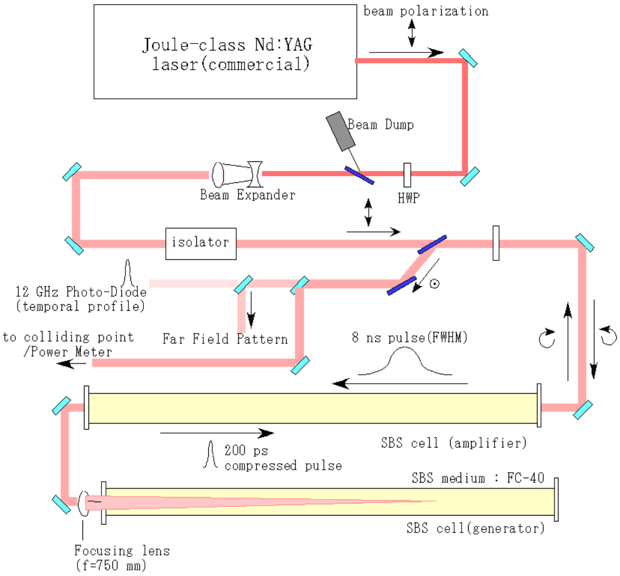

Figure 1: Schematic drawing of laser pulse compressor. The linear polarized laser pulse from Nd:YAG becomes circular polarized by Quarter Wave Plate (QWP) and focused in the SBS medium of second SBS cell by the focusing lens which is located between first- and second-SBS cell. Backward scattered compressed SBS pulse is separated by two thin film polarizer (TFP) from the incident pulse. The temporal structure is measured with a 12 GHz photo-diode and a 8 GHz oscilloscope.

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medium is filled. Both ends of the pipe are sealed by anti-reflection-coated glass windows. According to a literature [6], to achieve 200 ps pulse duration, we select a liquid fluorocarbon (Fluorinert FC-40, product of 3M) as a SBS medium. To exceed a threshold of the fluence, a focusing lens (f = 750 mm) is located between first- and second SBS cell. A linearly polarized incident laser pulse is converted to be circularly polarized by a quarter wave plate (QWP) which is located at the upstream of the first call. Backward scattered SBS pulses generated at the wave front of incident pulse in the second cell are amplified by overlapping with the incident pulse and extract from the end of upstream of the first cell. The SBS pulse is linearly polarized perpendicular to the direction of polarization of incident pulse with a QWP to separate by two thin film polarizer (TFP). The SBS pulse is monitored its temporal shape by 12 GHz photo diode connecting to 6 GHz oscilloscope, reflectivity by power meter and far field profile by CCD with f=200 mm focusing lens.

Reflectivity above pulse energy of 70 mJ is ~80 % and pulse duration of 200 ps are achieved (shown in Figure 2). A far field pattern of the SBS pulse is slightly degrade (M^2 = 2.1 → 2.3). A temporal jitter of 300 ps to a trigger synchronized to RF of RTM is due to the instability of oscillator cavity length of laser by an instability of temperature, is not caused by SBS compression. A spatial jitter at the focal point is smaller than the focal spot size of electron beam.

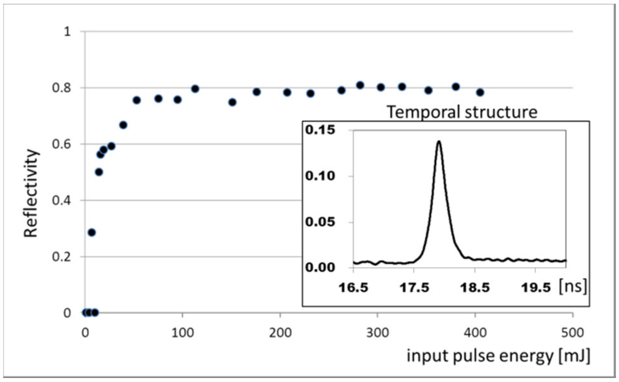

Figure 2: Input pulse enegy dependence of SBS reflectivity and temporal profile of a compressed pulse (superimposed). Above 60 mJ of pulse energy, reflectivity achieves ~80 % and becomes constant. A compressed pulse width of 200 ps is obtained at 300 mJ pulse energy.

LASER COMPTON SCATTERING GAMMA-RAY GENERATION

Experiment of LCS γ-ray generation is performed at KPSI-JAEA with 150 MeV electron beam from RTM accelerator. In Figure 3, a schematic drawing of experimental set up is shown. The electron beam current is typically 60 pC/ bunch, the temporal width of pulse is 10 ps in FWHM and the repetition rate of the beam is 10 Hz. The electron beam is focused at interacting point in vacuum and the size of the focal spot is 177 µm (H) × 321 µm (V). The pulse-compressed laser is introduced into the vacuum chamber at the downstream of a bending magnet which is installed to separate γ-rays from the electrons and focused onto the spot of the electron beam by a f = 2000 mm plano-convex lens. A colliding angle of the beam and the laser is 1.5 degree. The yield of γ-ray estimated by a Monte Carlo simulation code "CAIN" [7] is shown in Figure 4. Parameters which are used in the simulation are listed in Table 1. In the estimation, the pulse energy of 1 J is assumed. In the Figure 4, red circles indicate the yields obtained by uncompressed (8 ns) and compressed (200 ps) laser pulse. The yield of γ-ray by compressed laser pulse is clearly exceeded the target value of 3×10^5 photons/second (horizontal line shown in the figure). The first trial in January 2012, we successfully observed LCS γ-rays by the compressed laser pulse. An experimental demonstration of γ-ray generation and inspection of a dummy material in a metallic box will be performed in 2012.

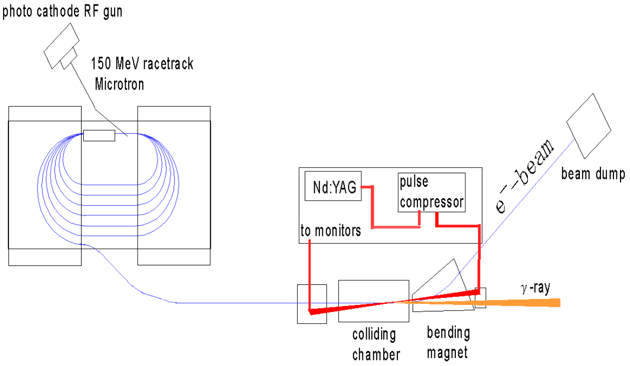

Figure 3: Schematic view of LCS gamma-ray source. The laser pulse from 10 Hz-Joule class Nd:YAG laser is compressed down to 200 ps and focused on the focal point of the 150 MeV electron beam from a racetrack microtron accelerator. The colliding angle is 1.5 degree.

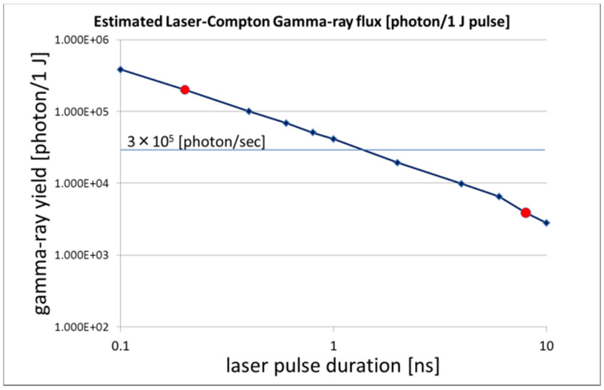

Figure 4: Estimated laser pulse duration dependence of LCS gamma-ray yield. The estimation have been made by the monte-calro code CAIN. Red circles are corresponding to the original pulse dutration (8 ns) and compressed pulse length (200 ps). The repetition rate of laser and RTM is 10 Hz.

Table 1: Specification of Microtron and Nd:YAG Laser

Microtron	
Extraction energy	150 MeV
Pulse duration	10 ps (FWHM)
Bunch charge	60 pC
Repetition rate	10 Hz
electron source	Laser photo-cathode RF gun
Normalized emittance	30.5 πmm mrad (H) × 36.4 πmm mrad (V)
Focal spot size	177 µm (H) × 321 µm (V)
Nd:YAG laser	
Maximum pulse energy	1.6 J
Wave length	1064 nm
Pulse duration	8 ns (FWHM)
Repetition rate	10 Hz
M^2 at focal point	2.3

SUMMARY

High flux LCS γ-ray source is under construction by JAEA and Kyoto University for non-destructive inspection system of SNM hidden in containers. In order to achieve a flux of 3 × 10^5 photon/sec., a SBS pulse compression is employed. The pulse duration of 200 ps in FWHM is achieved by employing FC-40 as SBS medium. In a calculation, γ-ray flux is possible to excess our requirement in 10 Hz operation. The first trial of γ-ray generation is performed at KPSI-JAEA by colliding a compressed Nd:YAG laser pulse to a 150 MeV electron beam accelerated by MTR and successfully observed LCS γ-ray. A demonstration of γ-ray generation and detection of dummy material hidden in a metallic box will be performed in 2012.

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REFERENCES

[1] R. Hajima et al., J. Nucl. Sci. Tech. 45 (2008) 441.

[2] H. Ohgaki et al., Proc. 2010 IEEE Int. Conf. on Technologies for Homeland Security, 525(2010).

[3] M. Kando et al., Proc. PAC1999, p. 3702 (1999).

[4] R. Hajima et al., “Compact Gamma-Ray Source for Non-Destructive Detection of Nuclear Material in Cargo” THPS098, Proc. of IPAC2011.

[5] K. Kawase et al., Nucl. Instr. Meth A 637 (2011) S141.

[6] H. Yoshida et al., Opt. Exp. 17 (2009) 13655.

[7] P. Chen et al., Nucl. Instr. Meth. A 335 (1995) 107.