FEASIBILITY STUDY OF GAMMA-INDUCED POSITRON ANNIHILATION LIFETIME SPECTROSCOPY IN AN ELECTRON STORAGE RING*

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Abstract

New techniques for gamma-induced positron annihilation lifetime spectroscopy (GiPALS) are developed by using laser Compton scattered gamma rays. Highly penetrating and ultra-short pulse gamma rays are used to create positrons throughout the entire sample volume via pair production. Due to the ultra-short pulses with pulse width of 5 ps (FWHM), laser Compton scattered gamma rays are suitable for GiPALS. For a proof-of-principle, ultra-short gamma ray pulses are incident upon a lead target with 5 cm in thickness. Annihilation gamma rays of energy 0.511 MeV are measured by the positron annihilation lifetime spectrometer based on BaF_2 scintillator, PMT and digital oscilloscope. A preliminary result of data analysis is shown in this paper.

INTRODUCTION

Positron annihilation lifetime spectroscopy (PALS) is very sensitive tool to characterize materials and study crystal lattice defects like vacancies, dislocations and cluster at the nanometer scale. However, PALS has been restricted to thin samples because of the limited range of positrons in materials. In many cases, determination of types of defects for the entire sample volume is of interest. PALS for thick samples is possible by using high energy gamma rays to create positrons inside the sample via pair production. The method of gamma-induced positron annihilation lifetime spectroscopy (GiPALS) has been demonstrated in the several facilities by using ultra-short bremsstrahlung gamma rays and coincident gamma rays through $^{27}Al(p, \gamma)^{28}Si$ reaction [1 - 4].

We have developed new techniques for GiPALS using laser Compton scattered (LCS [5]) gamma rays. Ultra-short gamma ray pulses with pulse width of 5 ps (FWHM) can be generated by 90-degree collision between the electron beam and the femtosecond laser [6 - 7]. GiPALS is realizable because of the ultra-short pulses that are negligible compared to positron annihilation lifetimes (100 ps to ns range). The feasibility study was carried out at the UVSOR-II electron storage ring, a 750 MeV synchrotron light source.

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EXPERIMENT

A schematic representation of the experiment is shown in Fig. 1. The electron beam and the laser collided in a vacuum chamber along the straight section. The storage ring was operated with beam energy of 750 MeV and a beam current of 50 mA (single bunch). The horizontal and vertical beam sizes (rms) at the collision point were 0.60 and 0.03 mm, respectively. The pulse width of the electron bunch was 400 ps (FWHM).

Laser pulses having a power of 2.5 W were provided by a Ti:Sa laser system (Coherent, Legend-HE) synchronized with the RF frequency of the storage ring, 90.1 MHz. The wavelength, repetition rate, and pulse width of the laser were 800 nm, 1 kHz, and 1.0 ps (FWHM), respectively. The laser light was transmitted to the collision point through air by high-reflection mirrors because the laser system was located ~20 m from the collision point. The laser was injected into the electron beam from the horizontal 90-degree direction (the direction in the orbital plane) through a magnesium fluoride window. The spot-size of the laser was focused at the collision point through a convex lens having a focal length of 125 mm, and was estimated to be 0.01 mm or less. The laser power in front of the window was measured to be 2.2 W by a power meter and estimated to be 2.0 W at the collision point, considering the absorption of the window.

The timing between the electron beam and the laser pulses was adjusted by using a pick-up electrode and a

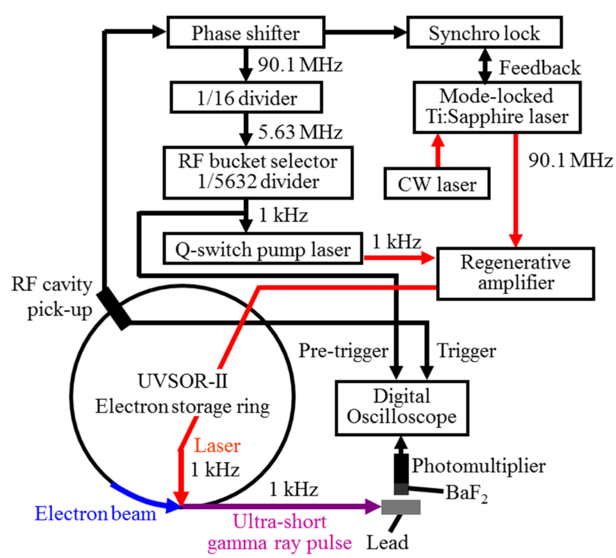

Figure 1: Schematic representation of the experiment.

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photodiode near the collision point. The spatial alignment was adjusted by changing the position of the laser.

LCS gamma rays were scattered along the axis of the electron beam. The maximum energy, intensity at the collision point, and pulse width of the gamma rays were calculated as 6.6 MeV, 10^6 photons s^{-1}, and 5 ps (FWHM), respectively.

Ultra-short gamma ray pulses were incident upon a lead target with 5 cm in thickness. About 60 % of the incident ultra-short gamma ray pulses created electrons and positrons inside a lead target via pair production, and the positrons annihilated with valence electrons. Annihilation gamma rays of 0.511 MeV were detected by BaF_2 scintillators coupled to a photomultiplier tube (PMT). The output signals from the PMT were measured by a digital oscilloscope (LeCroy, WaveRunner 104MXi), which has

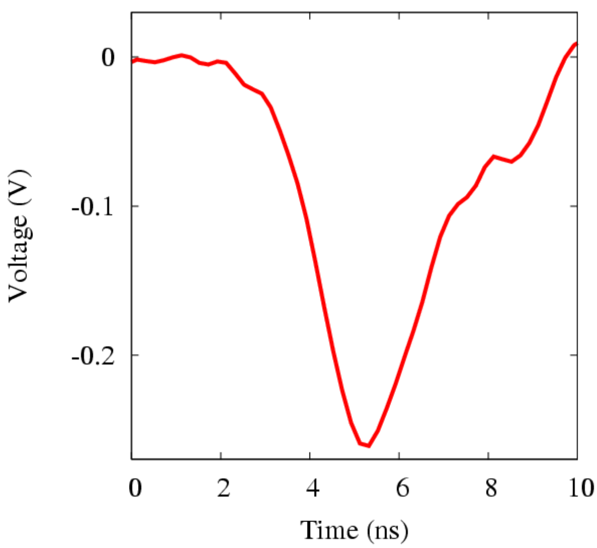

Figure 2: Anode output signal of a PMT recorded by a digital oscilloscope.

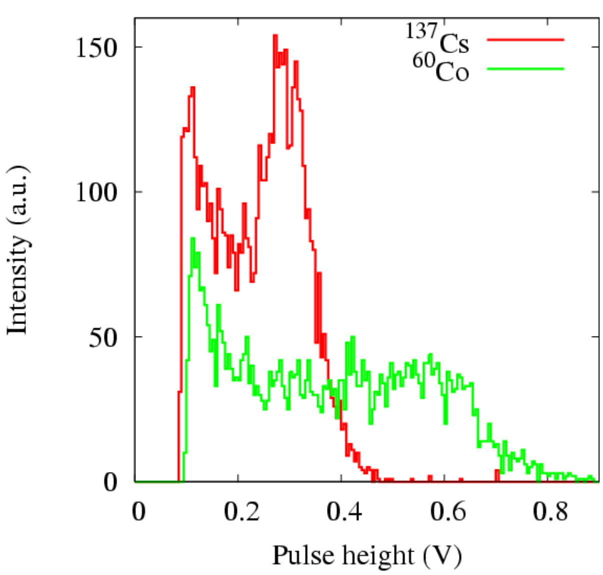

Figure 3: Pulse height distribution for ^{137}Cs and ^{60}Co gamma ray sources.

4ch inputs, a sampling rate of 10GS/s, and a bandwidth of 1GHz. A divided signal from the RF cavity pick-up supplied a pre-trigger signal. RF cavity pick-up supplied the trigger signal. We saved 1,677 waveforms and conducted data analysis in off line.

Figure 2 shows a typical waveform of an anode output signal of a PMT recorded by a digital oscilloscope. The rise time is about 2 ns. For energy calibration of BaF_2 scintillator, ^{137}Cs and ^{60}Co gamma ray sources were used. Pulse height distribution for ^{137}Cs and ^{60}Co is shown in fig. 3. Although an energy resolution of BaF_2 scintillator is low, a pulse height of annihilation gamma ray of 0.5 MeV was estimated to 0.25 V by setting a pulse height 0.32 V to 0.66 MeV and 0.65 V to 1.33 MeV.

RESULT

Figure 4 shows preliminary result of correlation between time and energy of saved waveforms. We have successfully measured annihilation gamma rays of energy 0.511 MeV. We will conduct analysis of a positron annihilation lifetime spectrum in a lead target.

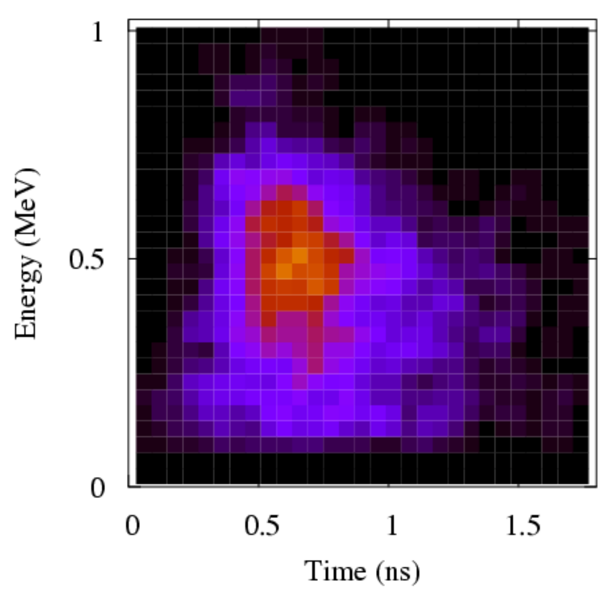

Figure 4: Correlation between time and energy of saved waveforms.

CONCLUSION

We have carried out the feasibility study of GiPALS using laser Compton scattered gamma rays. The primary advantage of this technique is that high penetrability of ultra-short gamma ray pulses allows measurements of crystal lattice defects for thick targets. For a proof-of-principle, ultra-short gamma ray pulses with pulse width of 5 ps were incident upon a lead target with 5 cm in thickness. Annihilation gamma rays of energy 0.511 MeV were successfully measured by the positron annihilation lifetime spectrometer based on BaF_2 scintillator, PMT and digital oscilloscope. Detailed analysis for the positron annihilation lifetime spectrum is being processing.

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