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ARTICLE

Design Consideration on Position Sensitive Detectors Based on LuAG:Pr Scintillators for High Energy X-ray Cargo Inspection

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To prevent illegal trade of weapons, X-ray scanning systems are used for non-intrusive inspection of import containers and cargoes at every seaport and airport. Conventional X-ray scanning system for cargoes is based mainly on X-rays of several MeV energy generated by an electron Linac. For high quality X-ray imaging, an X-ray source with good directionality, narrow width of energy spectrum and tunable energy is ideal and a laser Compton scattering (LCS) X-ray source is much more promising one than those generated by the Linac. Thus we propose a cargo scanning system based on the LCS X-ray source. However, the small cross section of LCS sets a limit of the intensity of LCS X-rays, therefore high-density scintillators are suitable for the detector of this system. We adopted LuAG:Pr, which has high density, good energy resolution and high light-yield. The position sensitive detector was designed as stacked thin LuAG:Pr scintillators and their independent readouts. By Monte Carlo simulation, the thickness of the thin LuAG:Pr scintillator was optimized as 0.5 mm. In addition, we measured a response of a prototype detector to LCS X-rays generated with an 800 MeV storage ring "TERAS" at AIST-Tsukuba and experimental results agreed well with the simulation ones.

Keywords: nondestructive inspection, Pr:LuAG, one dimensional detector, laser compton scattering X-ray

I. INTRODUCTION

With development of globalism in world economy, illegal international trade of weapons such as guns and bombs is also increased. As the smuggling tricks tend to be complicated, it is important to establish security system to prevent ban things to flow into and out of the country. Thus, a lot of imported containers and cargoes must be inspected at every seaport and airport, short inspection time and high precision to distinguish contents are required. X-ray radiography systems are one of the most conventional inspection tools for cargo containers and suitcases in airports and seaports.[1)] For heavily loaded containers and cargoes, X-ray scanning system is based mainly on X-rays of several MeV energy generated by an electron Linac, because penetration of X-ray with energy below a few MeV is not enough for them.Thus we propose a cargo scanning system based on the laser Compton scattering (LCS) X-ray source and a high sensitive one dimensional position sensitive detector.[2)] The LCS X-ray source generated by interaction between electrons in a storage ring and an intense laser beam is much more promising one than those by the Linac with continuous energy spectrum and has advantages which are good directionality, narrow width of energy spectrum and tunable energy. Therefore, the LCS X-ray is suitable source for high quality X-ray imaging.[3)] However, the small cross section of LCS sets a limit of the intensity of the LCS X-ray. Thus, detector of high efficiency and high position resolution is necessary to derive full performance of the LCS X-ray inspection system.

Stuck of silicon semiconductor detector is used as a position sensitive detector in the conventional X-ray scanning system. However, the probability of interaction of high energy X-ray and the silicon detector is low because silicon has low density. High-density scintillators with high detection efficiency are suitable for the X-ray detector of our proposed system.

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II. MONTE CARLO SIMULATION

Fig. 1 shows properties of conventional and novel scintillator materials[4] Considering the short decay time, high light yield, non-hydroscopic and high specific gravity, we found LuAG:Pr[5-6] is the best for our purpose, which was a novel scintillation material developed by Yoshikawa et., al.

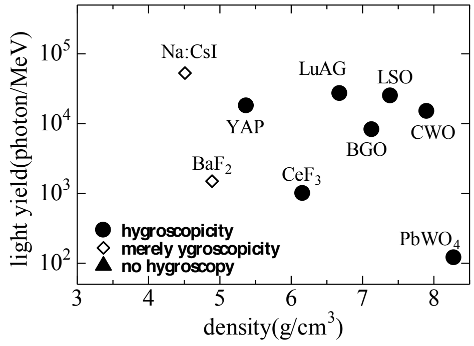

Fig. 1 scintillator materials

Fig. 2 shows the concept of one dimensional position sensitive detector for the LCS X-ray in the inspection system. When using one scintillator slab as the detector, it is difficult to get the position with high precision where the LCS X-ray entered. Thus, the detector is designed as stacked thin LuAG:Pr scintillators which light outputs were draw out with light guides individually. We calculated to evaluate the optimized thickness of the one piece of scintillator by a Monte Carlo simulation.

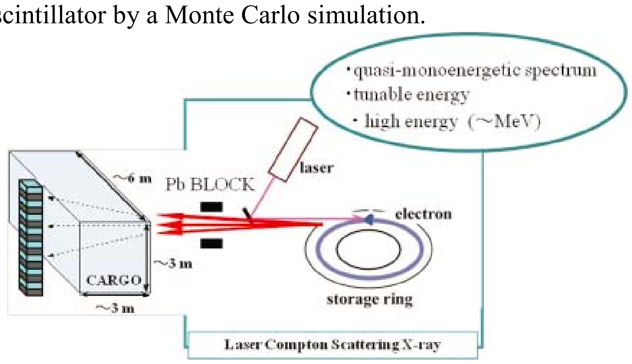

Fig. 2 Concept of the system

Fig. 3 shows simulation geometry. The detector was designed as stacked thin LuAG:Pr scintillators of L mm thickness and the LCS X-ray is incident on the center of stacked scintillators. We calculated the behavior of the electrons and photons accompanied by the incident of the LCS X-ray and evaluate the intrinsic position resolution with changing X-ray entering position. The LCS X-ray's energy is varied from 1 to 10 MeV and thickness of scintillators from 0.1 to 1 mm, respectively. The light output of the scintillator was assumed to be proportional to the integrated deposited energy in each scintillator. And the center of gravity of the light outputs was calculated as the estimated X-ray incident position. Taking a histogram of the assumed incident position, a position resolution of each condition was estimated as FWHM of the histogram peak.

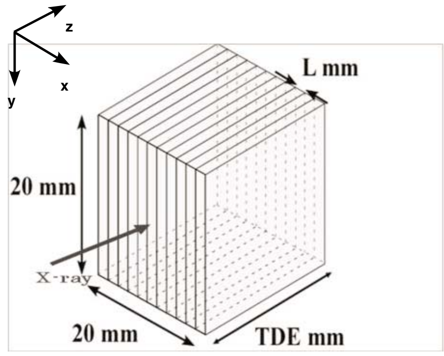

Fig. 3 simulation setup

Fig. 4 shows the results of these simulations. When thickness of scintillators is thinner, the position resolution becomes high. However, for over 5 MeV X-ray energy, position resolution becomes flat below scintillator thickness of 0.5mm, since high energy X-ray deposits its energy broadly more than 0.5mm. Therefore, the thickness of the thin LuAG:Pr scintillator was optimized to be 0.5 mm and the intrinsic position resolution was 1.8mm for 10MeV X-ray.

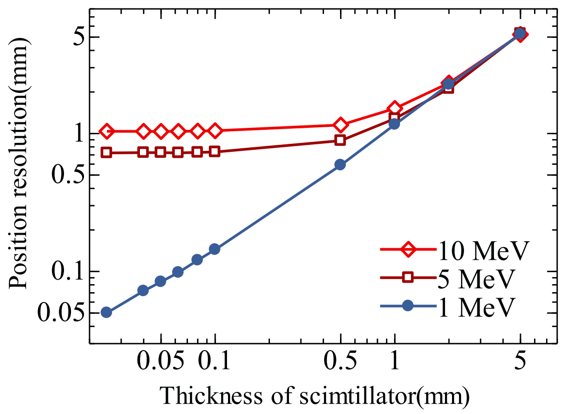

Fig. 4 Relation between position resolutions and thickness of scintillator

III. EXPERIMENT

We stacked five LuAG:Pr (0.5 mm in thickness) scintillators and four black acrylic resin plates (0.7 mm in thickness) as a prototype one-dimensional detector. Scintillating photons were collected through light guide which are made of styrene resin and read out by multi-anode photomultiplier tube (HAMAMATSU: H8600) independently. Then, we measured the response of this prototype detector by the LCS X-rays generated with an 800 MeV storage ring "TERAS" at AIST in Tsukuba. **Fig. 5** shows experimental setup. The LCS X-ray was collimated by Pb collimator (ϕ0.5mm, 20cm long) and its energies were selected to be 3 MeV and 10 MeV. The X-ray was incident in parallelism in z-axis direction and change position 0.1 mm in x-axis direction of the prototype detector.

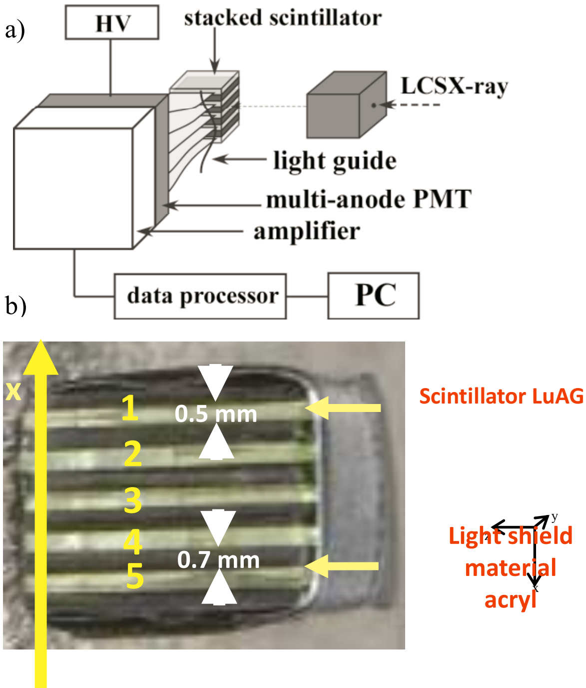

Fig. 5 (a)experimental setup

(b)stacked scintillator and black scintillator

Fig. 6 shows experimental result of the relation between the X-ray incident position and the outputs of center(No.3) scintillator compared with simulation results of the same system. The light output in experiment result is larger than that of simulation. This difference shows that there are some cross-talks between light guides when the emission of light of the scintillator travels to photomultiplier tube. In addition, coupling efficiency between scintillator and light guide are not constant every scintillator. Therefore, we evaluated the coupling efficiency and a ratio of the crosstalk to correct the light output or each scintillator. With these corrected data, we estimated the X-ray incident position with an assumption that the X-ray was detected at the center of the scintillator which emitted the largest light output.

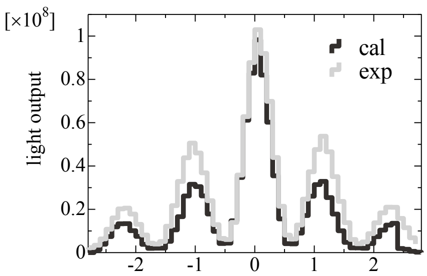

Fig. 6 Relation of between relation of light output and incident position

Fig. 7 shows the histogram of the assumed incident positions when the X-ray was entered at an end scintillator(No.5). From this result, the position resolution of the prototype detector was1.1 mm in HWHM (i.e. 2.2 mm in FWHM) for 10MeV LCS X-ray. This value was a little bit larger than that of simulation result reflecting the modeling difference between them. Optimization of light shielding material and size may approach the experimental position resolution to that of simulation.

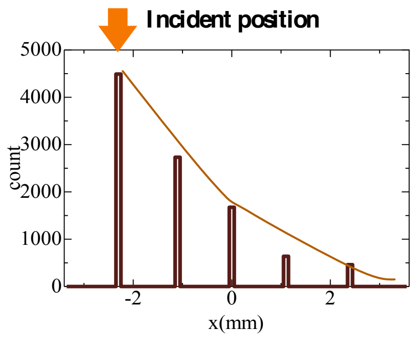

Fig. 7 The histogram of the assumed incident positions

IV. CONCLUSION

We proposed new position sensitive detector which stacked scintillators for X-ray cargo inspection using high energy Laser Compton Scattering X-ray. We adopted LuAG:Pr as the scintillator material and the thickness of the LuAG:Pr scintillator was optimized as 0.5 mm by Monte Carlo simulation.

In addition, we measured a response of a prototype detector to LCS X-rays generated with an 800 MeV storage ring "TERAS" at AIST-Tsukuba. Therefore, we evaluated coupling efficiency and a ratio of the crosstalk to correct the light output of each scintillators. And, with an assumption that the incident position was the scintillator's position which emitted largest light, the prototype detector showed the position resolution of 2.2 mm in FWHM for 10MeV LCS X-ray. This detector is expected to be applicable for high energy X-ray cargo inspection.

References

1) K.kanda et al., Radioisotopes, 42, 413, (1993) [in Japanese]
2) R.H.Milburn, Phys.Rev.Lett., 10, 75, (1963)
3) H.Toyokawa, Isotope News, 2002-7, 5, (2002) [in Japanese]
4) Glenn F. Knoll "Radiation Detection and Measurement", 265, (2001)
5) M.Nikl et al., Phys.Stat.Sol.,202, R4-R6, (2005)
6) H.Ogino et al., J.Cryst.Growth, 292, 239, (2006)