DEPENDENCE OF LuAG:Ce^{3+} SCINTILLATION EFFICIENCY ON ENERGY

T.A. Mamyrbayev[1], A. Cecilia[2], Yu.Yu. Kryuchkov[1], T.G. Petrasheva[1]
E-mail: talgat.mamyrbayev@yandex.ru

Tomsk Polytechnic University

ABSTRACT – The experiment described in this work was performed at the synchrotron light source ANKA (Angstroemquelle, Karlsruhe). The dependence of the scintillation efficiency of LuAG:Ce^{3+} scintillating crystal on the energy was studied in the range of 10 to 40 keV. In this work calculations of photon flux and scintillation efficiency are presented. The photon flux decreases with increase in energy. On the contrary, the scintillation efficiency was found to increase with energy. Scintillator non-proportionality was observed.

INTRODUCTION

New scintillator materials require high energy resolution for X-ray detection. High energy resolution is defined by two important parameters that are Poisson statistics and non-proportionality (nPR) of the scintillator. In this work the LuAG:Ce scintillator yield non-proportionality is studied. Scintillator non-proportionality denotes that the scintillator yield is not proportional to the energy deposited in a scintillator. Non -proportionality is being studied for 50 years, but it has been not yet fully clarified. It was first researched in 1950's [1-2]. At that time, the main question was the dependence of the scintillation efficiency on the particle energy. It means that electrons and alpha particles at 1 MeV produce a different number of scintillation photons. The main works were focused on NaI:Tl and CsI:Tl investigations. In 1960's, studies showed that the scintillation efficiency depends on the particle type and its energy through the ionization density (dE/dx). In 1967, Aitken et. al analyzed the fluorescent response of NaI:Tl, CsI:Tl, CsI:Na and CaF$_2$:Eu to X-ray and low energy gamma rays. The three scintillating iodides exhibit qualitatively similar photon-nPRs down to a photon energy of about 20 keV. The CaF$_2$:Eu curve differs from them heavily. There was a dip in the photon-nPR near K-shell and L-shell absorption edges of calcium and iodine. In 1991 were discovered new scintillator materials with high density, high atomic number, short decay time, and high light output. One of them is LSO. In 1995 Dorenboset. al. investigated LSO:Ce scintillator. They concluded that the photon- nPR of LSO:Ce is independent of physical properties (defects, impurities, self-absorption, concentration of vacancies, etc.) Later, Rooney and Valentine suggested that the energy resolution depends on scintillator non-proportionality. Since that time many investigations have done in this field [3].

EXPERIMENT

The synchrotron light source ANKA (Angstroemquelle, Karlsruhe) is located at the Karlsruhe Institute of Technology (K.I.T.) and is operated with ring electron energy of 2.5 GeV and beam currents of 180-200 mA. The dipole bending magnets are working with 1.5 T magnetic field and the resulting critical energy is E_c=6.2 keV . The synchrotron light produced by ANKA is used for a wide range of analytical methods as well as for micro-fabrication techniques. At present 13 beamlines are operative and offering competences which include the areas X-ray spectroscopy, x-ray diffraction and imaging, infrared spectroscopy and x-ray lithography.

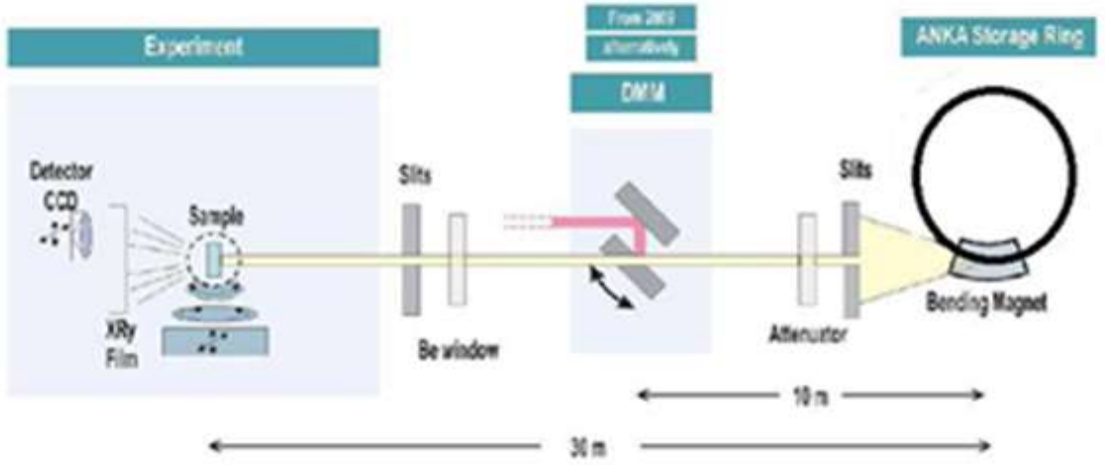

Figure 1.TopoTomobeamline

The relative yield measurements described in this work were performed at the TopoTomobeamline, whose characteristic features are the first slit system in the front end (6 m distance to the source), no optical component inside the 30 m long beam path and a second in-vacuum slit system followed by a Be windows directly in front of the experiment (Figure 1).The available energy spectrum ranges between 8 up to 40 keV and the total flux at sample position is in the order of 10^{16}ph/s (5 mm x 10mm)[4]. To tune the X-ray flux, it is possible to use a set of filters (Be, Al and Cu) that are positioned before the Double Multilayer Monochromator. In this work, the flux impinging on the scintillator was measured by using a PIN diode and the flux converted by the scintillator into visible photons was measured by using the setup represented in figure 2.

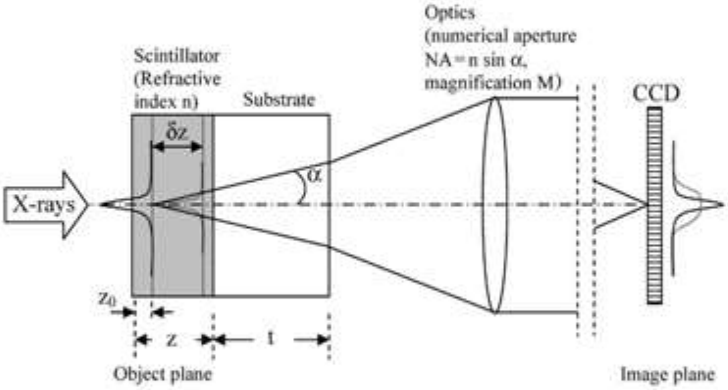

Figure 2. Setup used for measuring the X-ray flux converted in the scintillator [6]

EXPERIMENTAL RESULTS

The LuAG:Ce scintillation crystal was excited with a monochromatic X-ray beam in the energy range of 10-40 keV. For each measurement, the impinging photon flux was measured with a PIN diode. The beam line filters (Be, Al) were combined and interchanged at different energies to protect CCD from radiation damage. At the energies equal to 23 keV, 28 keV and 33 keV, external Si filters were added in front of the detector. To calculate the photon flux, photon counts were converted into responsivity. Next, the flux (Φ) was determined by using the following conversion formula:

$$\Phi = R_1 \cdot I_{out} = R_1 \cdot \frac{cts \cdot 10^{gain}}{10^5} \tag{1}$$

Where R_1 is responsivity, I_{out} is a current, cts are counts. The results of photon flux are shown in table 1.

Table 1.The photon flux calculations

E, keV	gain	Counts	Exposure time, s	Filters, mm	Beam size	Responsivity, 10^{15}
10	5	59377	1	Be 0,2; Al 0,2	2*2	2.34564
12	5	79430	1	Be 0,2; Al 0,2	2*2	2.16169
14	5	47959	1	Al 0,5;Al 0,2	2*2	2.21626
16	5	27075	1	Al 0,5;Al 1	2*2	2.42809
18	5	48883	1	Al 0,5;Al 1	2*2	2.74067
23	6	67322	1	Al 0,5;Al 1; Si 3	1*2	3.76311
28	6	151410	1	Al 0,5;Al 1; Si 3	2*2	5.02037
33	6	20854	1	Al 0,5;Al 1; Si 3	2*2	6.58949
36	6	30125	1	Al 0,5;Al 1	2*2	7.71
40	7	53552	1	Al 0,5;Al 1	Vertical gap 1.5	9.289

The scintillation efficiency (SE), which describes the number of the emitted photons per unit of absorbed energy, was calculated by using the following formula:

$$SE = \frac{N}{\frac{\Phi}{(pixel)^2} \cdot \eta_{abs} \cdot E \cdot \frac{1}{2}\left(\frac{NA}{n}\right)^2 \cdot QE \cdot ADU} \tag{2}$$

Where η_{abs} is absorption of X-ray photons in the scintillator, $E \cdot SE$ – number of visible photons emitted from the scintillator, $\frac{1}{2}(NA/n)^2$ – collection efficiency of emitted visible photons from the optics, QE – Conversion of collected visible photons into electrons, ADU – Analog to digital Unit conversion of electrons, Φ – the number of X-ray photons "converted" in the pixel in 1 second, N is mean value divided by 4. The results of the calculations are shown in table 2.

Table 2. Scintillation efficiency calculation

E, keV	Mean value	Flux, 10^{10}	Counts	η_{abs}	½(NA/n)^2	N	(pixel)^2	$\frac{\Phi}{(pixel)^2}$	SE
10	18326	1.393	59377	1	0.02376	4581	107438	129635	0.148742
12	27296	1.717	79430	0.99993	0.02376	6824	107438	159816	0.14977
14	20823	1.063	47959	0.9998	0.02376	5206	107438	98931	0.158222
16	15662	0.657	27075	0.99554	0.02376	3915	107438	61189	0.169078
18	37611	1.340	48883	0.98712	0.02376	9403	107438	124697	0.178611
23	19315	0.253	67322	0.90269	0.02376	4829	53719	47160	0.207563
28	31447	0.760	151410	0.776	0.02376	7862	107438	70751	0.215246
33	5833	0.137	20854	0.64193	0.02376	1458	107438	12790	0.22653
36	9268	0.232	30125	0.55853	0.02376	2317	107438	21618	0.224329
40	1730	0.050	53552	0.44733	0.02376	433	107438	4630	0.219739

According to the table 2 the results of Light Yield are depicted in the figure 3.

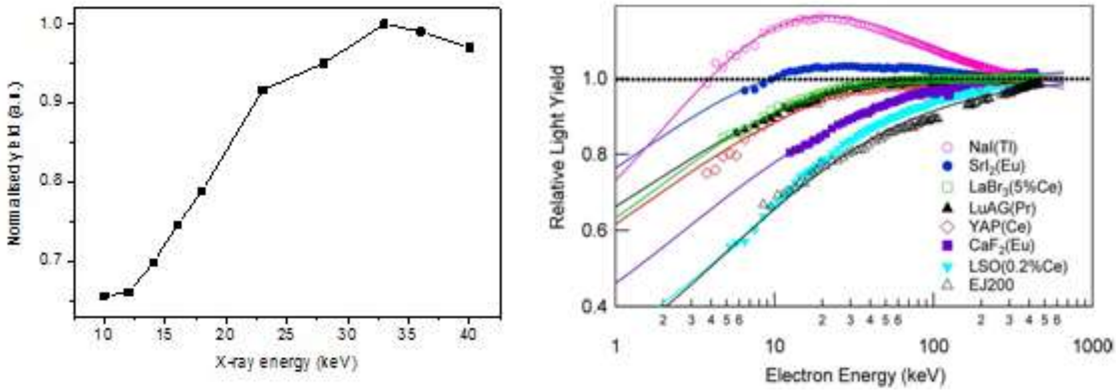

Figure 3. Scintillation efficiency of LuAG:Ce (left side) and results of W. Moses studies (right side) [1].

SUMMARY

In this work the scintillation efficiency of LuAG:Ce was calculated between 8 keV and 40 keV. Despite the experimental approach was right, the measured values of the scintillation efficiency were extremely low (< 1 photon/keV). The reason is almost certainly the observed radiation damage of the optics induced during a previous experiment in which the high flux and high intensity synchrotron white beam X-ray was used. The measured photon flux decreases with increase in energy. The non-proportionality of scintillation efficiency in LuAG:Ce scintillator crystal was observed in this experiment. The obtained results are qualitatively very similar to the results discussed in the study of W. Moses et al in [1]. Non-proportionality can be explained by three models: minimalist approach, kinetic model and diffusion model. These approaches imply that the non-proportionality depends on the following parameters: ionization density, particle energy and type, electron, hole, exciton interactions, exciton formation and other. Unfortunately, at this time, which of this approaches dominate is not known. Therefore, the investigations in this field are needed [1-3, 6].

REFERENCES

1. W. W. Moses et. al. The Origins of Scintillator Non-Proportionality// IEEE transactions on nuclear science, v. 59, N. 5, p.2038-2044, (2012).
2. W. W. Moses et.al. Scintillator Non-Proportionality: Present Understanding and Future Challenges.// IEEE transactions on nuclear science, v. 55 , №3 , p. 1049 - 1053,(2008).

3. I. V. Khodyuk and P. Dorenbos. Trends and patterns of scintillator nonproportionality. // IEEE transactions on nuclearscience. , v.59,№ 6, p. 3320 – 3331,(2013).

4. Rack A. et al. The microimaging station of the Topotomobeamline at the ANKA synchrotron light source// NIMB, v. 267, p. 1978-1988, (2009).

5. T. Martin, A. Koch, Recent developments in X-ray imaging with micrometer spatial resolution// Journal of Synchrotron Radiation, p. 15, (2006)

6. I. V. Khodyuk, P. A. Rodny, and P. Dorenbos. Energy Dependence of the Relative Light Output of YAlO$_3$:Ce,Y$_2$SiO$_5$:Ce, and YPO4:Ce Scintillators.//InstrumentsandExperimentalTechniques, v. 55, No. 2, p. 187–197, (2012).

ПРОСТРАНСТВЕННОЕ РАСПРЕДЕЛЕНИЕ ТЕМПЕРАТУРЫ ПРИ ОБЛУЧЕНИИ ПУЧКОМ ЭЛЕКТРОНОВ

Панова Л.С., Пермякова К.А., Постников Д.В.
lilihka_94@inbox.ru

Омский государственный технический университет

Введение.

Разработка радиационных технологий в настоящее время является актуальной задачей. Данный вид обработки позволяет существенно улучшить поверхностные свойства материалов, увеличить твердость, износостойкость, коррозионную стойкость и др. свойства. Существенно ускорить отработку режимов радиационной обработки позволяет численное моделирование процессов происходящих в поверхностном слое материала. Одним из основных процессов происходящих при данном виде облучения является неравномерный нагрев образца. В данной работе на основе литературных данных изложена модель расчета температурного поля при облучении пучком электронов и приведено распределение температуры по глубине образца при облучении пучками электронов.

Модель расчета поглощенной дозы.

Для расчета поглощенной дозы воспользуемся следующим методом заимствованным из литературы [1].

Пробег электрона в веществе:

$$\xi = 2\pi N_A e^4 Zgb^2 l/(AI^2) = Kl. \tag{1}$$

Уравнение Бете позволяет найти тормозную способность вещества:

$$d\varepsilon / d\xi = -\ln(\varepsilon)/\varepsilon, \tag{2}$$

где N_A - число Авогадро; I - средняя энергия возбуждения атома; l - путь; b -множитель, равный 1,166.

Уравнение Бете действительно только для $E >> \hat{I}$ в остальных случаях формула лишена физического смысла. Согласно Ф. Блоху I =13,5эВ, но ее экспериментальное значение оказалось действительным только для тяжелых элементов.

Преобразуем закон Бете через траекторный пробег:

$$d\varepsilon / d\xi = 1/(\kappa n \varepsilon^{n-1}) \tag{3}$$

Выразим из формулы (3) энергию первичного электрона после заданного прохождения пути в веществе:

$$\varepsilon^n(\xi) = \varepsilon_1 - (\xi/\kappa), \tag{4}$$

где ε_1 - начальная энергия.

Для дальнейшего описания проникновения электронов в твердое тело будем считать торможение и угловое рассеяние независимыми друг от друга.

Угловое рассеяние – это процесс изменение направления электронов, которые происходят в результате упругих и неупругих соударений. Для описания этого движения используется функция, которая называется амплитудой рассеяния:

$$f(\theta) = -\frac{2\pi m}{h}\int V(r) e^{-2\pi/\Delta S r} dr \quad . \tag{5}$$

1)Однократное рассеяние. Однократное рассеяние характеризуется сечением рассеяние:

$$\sigma_n = 4{,}792 * 10^{-18} Z^{1/3}(Z+1)/E_1 \tag{6}$$