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Paper

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Comparison of cell casted and 3D-printed plastic scintillators for dosimetry applications

D. Kulig[1,*], Ł. Kapłon[1,2,3], G. Moskal[1,3,4], S. Beddar[5], T. Fiutowski[6], W. Górska[1], J. Hajduga[1], P. Jurgielewicz[6], D. Kabat[1], K. Kalecińska[6], M. Kopeć[6], S. Koperny[6], B. Mindur[6], J. Moroń[6], S. Niedźwiecki[2,3], M. Silarski[2,3], F. Sobczuk[7], T. Szumlak[6] and A. Ruciński[1,8]

[1]Department of Medical Physics, Maria Sklodowska-Curie National Research Institute of Oncology Krakow Branch, Garncarska 11, 31-115 Krakow, Poland
[2]Department of Experimental Particle Physics and Applications, Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University in Krakow, Lojasiewicza 11, 30-348 Krakow, Poland
[3]Total-Body Jagiellonian-PET Laboratory, Jagiellonian University, Lojasiewicza 11, 30-348 Krakow, Poland
[4]Department of Chemical Technology, Faculty of Chemistry of the Jagiellonian University, Gronostajowa 2, 30-387 Krakow, Poland
[5]Department of Radiation Physics, The University of Texas MD Anderson Cancer Centre, Houston, TX 77030, USA
[6]Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Mickiewicza 30, 30-059 Krakow, Poland
[7]Department of Photonics, Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University in Krakow, Lojasiewicza 11, 30-348 Krakow, Poland
[8]Institute of Nuclear Physics, Polish Academy of Sciences, Radzikowskiego 152, 31-342 Krakow, Poland

*Corresponding author: dkulig@agh.edu.pl

Abstract

Currently, the most used methods of plastic scintillator (PS) manufacturing are cell casting and bulk polymerisation, extrusion, injection molding, whereas digital light processing (DLP) 3D printing technique has been recently introduced. For our research, we measured blue-emitting EJ-200, EJ-208, green-emitting EJ-260, EJ-262 cell cast and two types of blue-emitting DLP-printed PSs. The light output of the samples, with the same dimension of 10 mm × 10 mm × 10 mm, was compared. The light output of the samples, relative to the reference EJ-200 cell-cast scintillator, equals about 40–49 and 70–73% for two types of 3D-printed, and two green-emitting cell-casted PSs, respectively. Performance of the investigated scintillators is sufficient to use them in a plastic scintillation dosemeter operating in high fluence gamma radiation fields.

Introduction

Dosimetry methods are widely used to maintain the accuracy and safety of radiotherapy treatments. Despite many advances in radiotherapy, the ionisation chambers or thermoluminescent detectors are still used as the main dosimetry equipment. These detectors have many advantages, however, the rapid development of beam delivery techniques in radiotherapy requires the development of adequate dosimetry methods[1, 2]. Therefore, one of the promising candidates for novel dosimetry approaches are plastic scintillators (PSs). PSs are characterised by high sensitivity to electrons and protons and also allow the detection of single ions[3, 4]. PSs are water-equivalent (density of about 1 g/cm^3), their elemental composition is similar to that of human tissues (mainly carbon, hydrogen, and traces of oxygen and nitrogen), as well as can be easy manufactured in small geometries offering a high spatial resolution[5].

PSs offered commercially are based on cell casting and bulk polymerisation fabrication technology[6]. The cell casting is a process where the solution of fluorescent dyes in styrene or vinyltoluene monomer is poured in mold and is polymerised in an electric furnace[7]. In turn, digital light processing (DLP), a type of additive manufacturing technology, can be used for obtaining PSs. DLP is a vat 3D printing technique based on layer-by-layer polymerisation of fluorescent substances and photoinitiator solution in liquid resin

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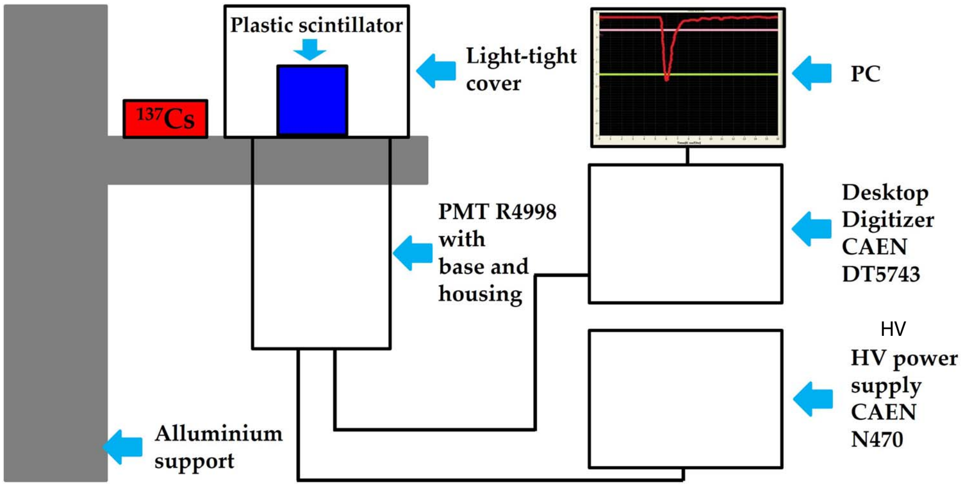

Figure 1. Schematic illustration of the experimental setup used for measurements of the relative light output of PS samples exposed to a ^{137}Cs radiation source. Measurements were performed with a photomultiplier tube connected to high-voltage supply and personal computer.

upon ultraviolet light irradiation from a digital light projector(8).

Comparing these two methods of manufacturing of PSs, we can distinguish several advantages characterising the cell casting and the DPL printing methods. The cell casting is characterised by high transparency of produced scintillators(9), high light output(10) and long-term stability, whereas the DLP is characterised by low cost, fast printing and finished surface of printed scintillators, which may require additional polishing(11).

These two methods of producing PSs are characterised by several differences, including different types of monomers and presence of a co-solvent in DLP(12). Polymerisation reaction is initiated by heat in cell casting and by UV light and photoinitiator in DLP. The cell casted scintillators are made in one piece during the whole process, whereas the DLP scintillators are printed layer-by-layer. The 3D-printing process takes several hours(13), whereas cell casting of scintillators may take several days(14).

Purpose of this research was to measure performance of blue- and green-emitting PSs connected to the photomultiplier tube (PMT) with light detection efficiency centered at the blue part of the visible spectrum.

Materials and methods

Experimental setup

A schematic illustration of the experimental setup used in our research is shown in Figure 1. The measurement was performed using a PMT R4998 from Hamamatsu. To connect the surface of scintillators with the PMT window, we use an optical-grade silicone grease BC-630 from Saint-Gobain Crystals. The PMT, the electric base and the mu-metal shielding were enclosed in light-tight aluminum housing. CAEN N470 power supply was used to power up the PMT.

For the readout of signals desktop digitizer CAEN DT5743 was used. Scintillators were exposed to the 882 kBq ^{137}Cs source positioned 50 mm from the scintillator. The PMT window with the sample attached in the center of the active area was covered by a light-tight plastic cap. Emission spectra were measured using the USB4000 fiber optic spectrometer from Ocean Optics. Samples were excited by laser diode with the maximum emission at 405 nm.

Scintillator samples

In the experiment, blue-emitting EJ-200, EJ-208, green-emitting E-260, EJ-262 cast scintillators purchased from Eljen Technology, and two types of blue-emitting DLP 3D-printed in Hanyang University scintillators were investigated. Scintillators had the wavelength of the maximum emission ranging from 425 to 490 nm. Properties of the samples are listed in Table 1, and illustrated in Figure 2.

All samples had the same dimensions of 10 mm × 10 mm × 10 mm, all surfaces were polished and five surfaces were wrapped with three layers of PTFE tape.

Measurements and data analysis

The measurements of the light output were triplicated for each sample to ensure the stability of the experimental setup; the average and standard deviation were calculated. The samples were exposed to the ^{137}Cs

Table 1. Properties of the PSs obtained from the literature. The two types of 3D-printed scintillators (3DPS)[11–13], and the four types of cell-casted polyvinyltoluene-based PSs (EJ-2XX product code)[15] were listed.

Sample	Wavelength of max. Emission (nm)	Light output (ph/MeV)	Decay time (ns)	Density (g/cm^3)
3D-printed plastic scintillators				
3DPS violet	429	3370	2.5	1.175
3DPS blue	470	6700	1.9	1.188
Cell casted plastic scintillators				
EJ-200	425	10 000	2.1	1.023
EJ-208	435	9200	3.3	
EJ-262	481	8700	2.1	
EJ-260	490	9200	9.2	

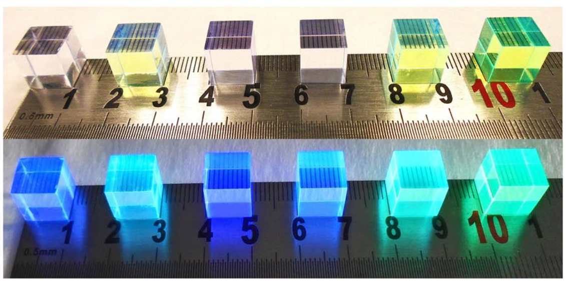

Figure 2. PS samples used in this study under ambient light (top) and 365 nm UV light (bottom). From the left to right: 3DPS violet, 3DPS blue, EJ-200, EJ-208, EJ-262 and EJ-260.

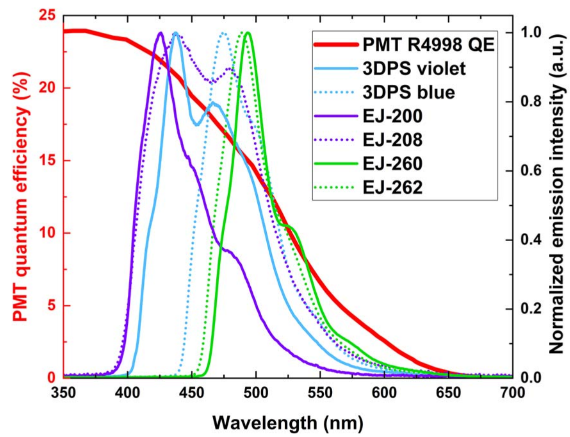

Figure 3. Emission spectra of PS samples measured in this study and superimposed on the quantum efficiency curve of the PMT R4998.

radiation source. The light output of the scintillator was calculated based on the charge spectra collected by the PMT and the digitizer (see Figure 4), and it was determined for the energy corresponding to the maximal value deposited by the 662-keV gamma quanta in the Compton scattering processes (so-called Compton edge). The middle of the Compton edge was determined by fitting part of the Gaussian function to the right edge of the charge spectrum in the OriginLab software. The EJ-200 scintillator was used as reference, due to its maximum emission centered at 425 nm, which is close to the maximum quantum efficiency of the R4998 PMT located at 420 nm; see Figure 3. We compared positions of the Compton edge for the investigated samples with the position of the Compton edge for the EJ-200 scintillator with corresponding light output 10 000 photons/MeV given by the manufacturer.

Results and discussion

The measured emission spectra are presented in Figure 3 and wavelengths of maximum emission are listed in Table 2.

Positions of wavelength of maximum emission vary up to 9 nm in comparison with the data sheet for commercial scintillators[15] and previous research papers[12, 13]. Those differences are expected due to the use of different spectrometers, excitation sources and experimental setup geometry used in cited works and our research.

Table 2. Wavelengths of maximum emission and light output of the 3D-printed and cell casted PSs measured in this study. Uncertainty of the light output value was calculated as standard deviation from three measurements of the same sample.

Sample	Wavelength of maximum emission (nm)	Light output (photons/MeV)
3D-printed plastic scintillators		
3DPS violet	438	4931 ± 15
3DPS blue	475	4050 ± 24
Cell-casted plastic scintillators		
EJ-200	426	10 000 ± 73
EJ-208	436	9426 ± 62
EJ-262	489	7322 ± 28
EJ-260	494	6975 ± 19

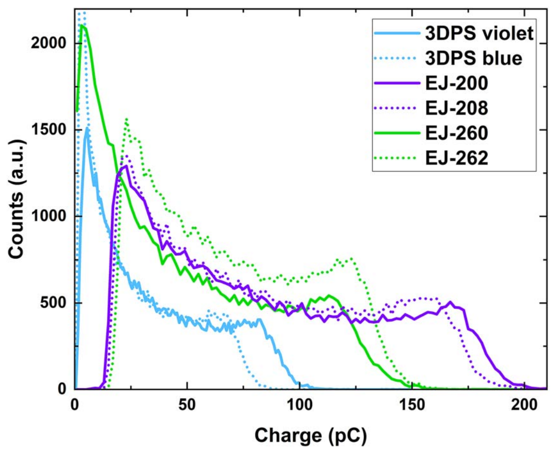

Figure 4. Cs-137 charge spectra of PS samples acquired during light output measurements in this study. The right edge of the spectrum corresponds to the Compton edge. The higher the Compton edge position, the higher is the light output of the scintillator.

Charge spectra measured with Cs-137 irradiation are presented in Figure 4. Light output of the samples calculated by comparison of position of the Compton edge with reference scintillator EJ-200 is given in Table 2. The best performing are EJ-200 and EJ-208 blue-emitting cast scintillators with light output close to 10 000 photons per MeV. The pair of EJ-260 and EJ-262 green-emitting cast PSs have mean performance about 7000 photons/MeV. The smallest light output of about 4900 and 4000 photons/MeV was measured for violet and blue DLP-printed PSs, respectively. The light output results for DLP-printed scintillators are consistent with our previous work[16]. Lower performance of DLP-printed PSs is associated with the type of resin and different technical processes used for 3D-printing with comparison to standard cast polymerisation.

In the group of cast polyvinyltoluene-based scintillators, light output decreases with the increasing wavelength of its emission spectra. Increasing differences between the emission spectrum of the scintillator and the peak of quantum efficiency of the PMT result in smaller conversion of light into electrical signals by the PMT and lower performance of green-emitting scintillators.

Conclusions

The maximum emission wavelength of the measured PSs ranges from 425 nm to 490 nm. The light output of investigated scintillators decreases in the following order: commercial, blue-emitting EJ-200, EJ-208 and green-emitting EJ-262, EJ-260 cell cast scintillators, and 3DPS violet, 3DPS blue DLP 3D-printed scintillators. Blue-emitting polyvinyltoluene cast scintillators had the best performance. DLP-printed scintillators had the worst performance. However, the performance of printed PSs is good enough for application in dosimetry.

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Data availability

Data will be made available on request.

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