Developing plastic scintillators for novel positron emission tomograph

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The aim of this project is to obtain plastic scintillators based on polystyrene or polyvinyltoluene which can be used in positron emission tomography (PET) scanner being developed by the J-PET collaboration [1]. Nowadays, all commercial PET devices use inorganic scintillator materials as radiation detectors, therefore a usage of plastic scintillators requires a novel approach to the issue. The research aims at development of scintillator characterized by high light output, short decay time and chemical stability. The main advantage of plastic scintillators is a low price within a range from $0,1 to $3 per 1 cm^3 while price for 1 cm^3 of crystals reach up to $500 [2]. Plastic scintillators are not only cheaper but can be easily formed to different shapes. In addition they are chemically stable and they have high degree of optical homogeneity. However, the production is time consuming and highly intensive labour process.

Energy transfer in plastic scintillators

The mechanism of energy transfer in plastic scintillator with exemplary substances widely used as scintillating additives after interaction with high energy radiation like gamma rays is shown in Fig. 1.

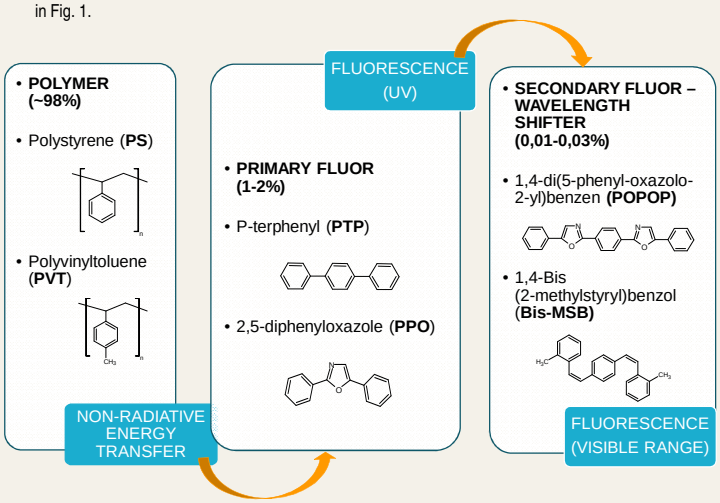

Fig. 1. Energy transfer scheme in a plastic scintillator.

Synthesis of plastic scintillators

Because of the requirement of high optical properties, e.g. homogeneous dopant distribution, scintillators have to be synthesized from pure monomer, therefore purification process is needed. Appropriate amounts of both additives have to be dissolved in monomer and then plastic scintillators are obtained in the way of bulk polymerization in glass containers which have to be prepared before the polymerization by silanization treatment. Time and temperature of the process were optimized accordingly (Fig. 2).

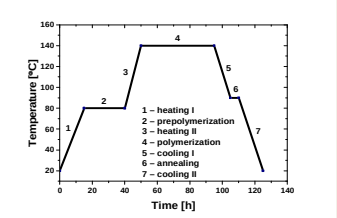

Fig. 2. Temperature cycle steps during plastic scintillators synthesis.

Light output

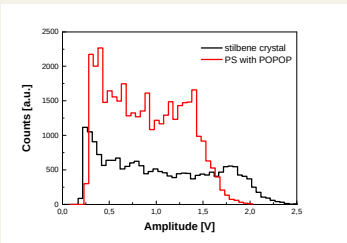

Fig. 3. Cs-137 energetic spectra of plastic and organic crystal scintillator.

Scintilation efficiency is measured and compared to the stilbene crystal as standard sample by analyzing their energetic spectra. 511 keV gamma quanta interact with plastic scintillator predominantly by Compton effect. The position of the Compton edge is measured and compared with the value of the standard sample. One of the spectra is shown in Fig.3. Light output measurements of about 50 synthesized scintillators have been done using Cs-137 source. Their values range from 60 to 80% comparing to stilbene. They are slightly lower than values reached by commercial scintillators BC-420 used in the experiment which light output equals 91% [3]. It is a result of a compromise between properties and the price of scintillator base. The composition of a scintillator with the highest light output out of all synthesized in our collaboration is shown in Tab.1.

Tab.1. Composition of the scintillator with the highest light output.

Base	Primary additive	Wavelength shifter	Light output
Polystyrene PS	2% PPO	0,03% bis-MSB 0,03% POPOP	80% comparing to stilbene

Decay time

Fluorescence decay time was measured by time-correlated single photon counting technique. Data were acquired with spectrofluorometer FluoroLog-3 (Horiba Jobin-Yvon) using NanoLED exitation diode with 340 nm emission maximum and 1,3 ns pulse FWHM. Typical decay time obtained from scintillator with PPO and POPOP is 2,4 ns – see Fig. 4. Decay time values for commercial plastic scintillators are in the.1,4 to 4,0 ns range [3].

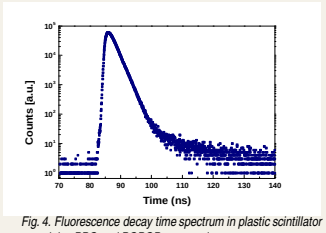

Fig. 4. Fluorescence decay time spectrum in plastic scintillator containing PPO and POPOP compunds.

Emission spectra

Photo-induced emission spectra of synthesized scintillators were measured with spectrofluorometer FluoroLog-3 (Horiba Jobin-Yvon). Measurements were done in reflecting mode using PMT R928P and continuous wave xenon source. Maximum intensity is observed at blue light about 423 nm. Fig. 5 shows exemplary scintillator with POPOP compound as wavelength shifter.

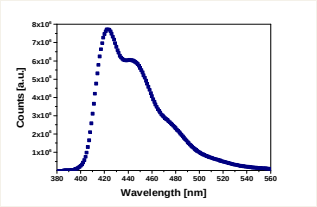

Fig. 5. Emission spectrum of the scintillator with POPOP wavelength shifter.

Thermal characteristic of plastic scintillators

Differential Scanning Calorimetry (DSC) and Thermal Gravimetric Analysis (TG, DTG) of scintillator samples were carried out. Corresponding curves are presented in Fig. 6 and Fig. 7. Both curves show decomposition process of a polymer occurring with maximal rate in about 400 °C. Maximum close to 100 °C visible in Fig. 7. is interpreted as temperature of glass transition temperature (Tg), connected with vitrification process when polymer changes its mechanical properties. Therefore Tg is the highest temperature in which scintillator can be used.

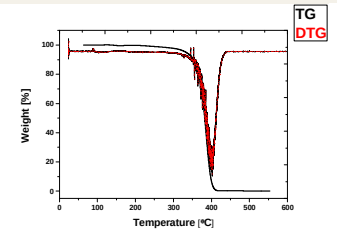

Fig. 6. TG and DTG curves of a scintillator sample.

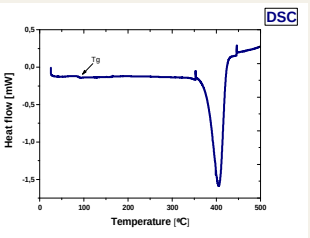

Fig. 7. DSC curve of a scintillator sample.

Analysis of volatile decomposition products using infrared spectroscopy (IR) enables to confirm high rate of conversion of monomer to polymer. Studying TG-IR spectrum which is shown in Fig. 8. we ascertain no significant differences in styrene boiling point (146 °C) and slightly above it.

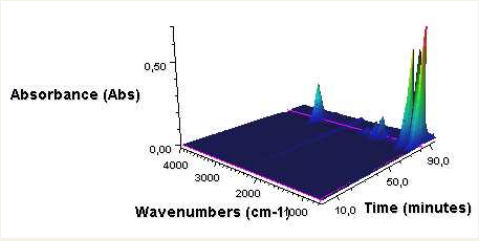

Fig. 8. TG-IR spectrum of a scintillator sample

Conclusions

Plastic scintillators with common additives were developed and their most important properties were determined. Obtained values of scintillation efficiences are satisfactory for usage in J-PET scanner and are independent on molecular masses of the scintillator rods due to their high values.

References

[1] P.Moskal et. al., Radiotheraphy and Oncology 110 (2014) S69
[2] Buvat I, Grupen C, editors. Handbook of particle detection and imaging. Berlin: Springer, 2012
[3] Saint-Gobain Plastic Scintillation Products, website:
http://www.crystals.saint-gobain.com/Plastic_Scintillation.aspx