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DOPED PLASTIC SCINTILLATORS WITH IMPROVED LIGHT OUTPUT AND RADIATION HARDNESS

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Abstract

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Small samples of polystyrene scintillators prepared with improved technology and containing scintillating 2%pTP + 0.05% POPOP and low concentrations of about 0.05% of two antiradiation dopants have shown increased levels of the light output and radiation hardness.

Аннотация

Васильченко В.Г., Соловьёв А.С. Допированные пластмассовые сцинтилляторы с улучшенными световыходом и радиационной стойкостью: Препринт ИФВЭ 97-53. – Протвино, 1997. – 5 с., 2 рис., 1 табл., библиогр.: 18.

Небольшие образцы полистирольного сцинтиллятора, изготовленные по улучшенной технологии и содержащие низкие концентрации около 0.05% двух антирадиационных добавок, а в качестве сцинтиллирующих добавок 2%pTP + 0.05% POPOP, показали улучшенные световыход и радиационную стойкость.

In some cases now used plastic scintillators based on the polystyrene (PS) have not shown enough radiation resistance for their wide application in experimental setups in high energy physics. Searches for new radiation resistant plastic scintillators are being carried out in many scientific centers [1-5]. Such scintillators are needed to improve the radiation hardness of morden electromagnetic (EM) calorimeters [6,7]. During $\sim$ 10 yr of their lifetime radiation doses up to 10 Mrad and even more [8] are expected. The most promising trend in such research is the investigation of different dopants influence on plastic scintillators radiation properties [1,4,5].

On the other hand, other scintillating media with high light outputs, for example, organic crystals may also be used in morden EM-calorimeters as well as for neutrons monitoring against high fluxes of γ-quanta and other secondary particles.

This work is a continuation of our previous investigations of the radiation hardness of different scintillating media [4,5] with the aim of their widescale application in high energy physics.

It is well known that the main processes which lead to colour centers formation under irradiation are the appearance of highly excited radicals [9,10,11] and self-trapped electrons [11], crosslinks in the the scintillators base [12], oxidation of surface layers under irradiation in air [13], etc. Note that these first two types of colouration centers appear practically in equal numbers. For quenching the highly excited states of radicals (the first of these processes), different antiradiation dopants have been widely used for a very long time and for preventing oxidation — antioxidation ones. Some noticeable results in the radiation hardness improvement of scintillating media have been achieved by this approach [1,4,5,9,10].

Clearly that all the processes which lead to the creation of colourtion centers should be quenched. That is why we investigated here a possibility to improve radiation properties of PS scintillators by quenching two channels of the colouration centers appearance under irradiation with the use of two dopants: PO (petroleum oil) and Ac (a derivative of acralate). Here PO should quench the highly excited radicals and Ac should prevent surfaces oxidation.

Due to our technology of PS scintillators production [4.5], the monomer was deinhibitied through a column and distilled [14] in vacuum. Then, the monomer ($\sim$100 cm^3)

was placed in cylindrical glass ampoules and doped with dopants. The glass ampoules with solutions were sealed off air and polymerized at a temperature of about 170^{o}C for 24 h in a polysilicone bath. So, our standard sample of PS scintillator (sample 1 in Table) was prepared.

It is well known that the technology of PS scintillators production plays an important role both on their light outputs and radiation properties [9,10,15]. It is very interesting to compare scintillation and radiation properties of PS scintillators manufactured by our technology [4,5] and those presented in [9,10]. So, we also prepared PS scintillators containing the antiradiation dopants (PO and Ac at different concentration levels) with our standard set of scintillation dopants like pTP (paraterphenyl with λ_{em}=340 nm, where λ_{em} — the maximum of the emission spectrum) and POPOP (1,4-bis-[2- (5-phenyloxazolyl)]-benzene with λ_{em}=420 nm) according to a technology close to [9,10].

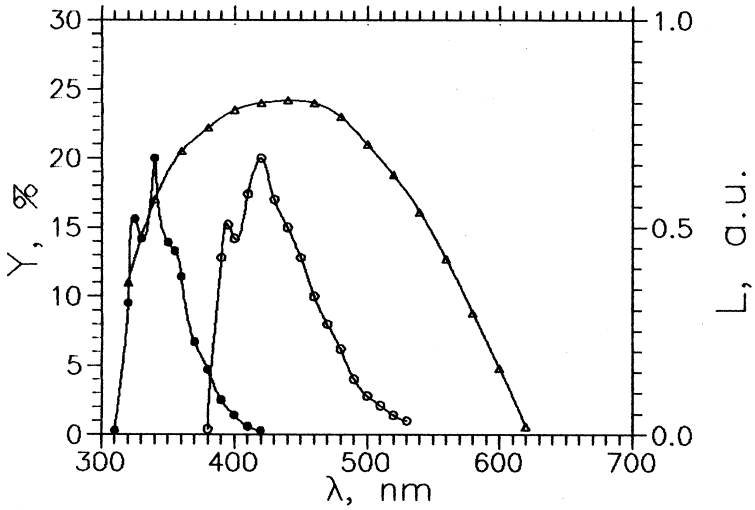

Fig. 1. Quantum efficiency Y of our PM FEU-84-3 (Δ) and normalized luminescent spectra L of pTP ($\bullet$) and POPOP ($\circ$).

The 5 mm thick disks with the diameter of about 30 mm were cut from the polymerized blocks of scintillators. To measure the light output of the samples, the scintillation was excited with a ^{90}Sr β-radioactive source having an intensity of about 10^7 Bq. The source and samples were placed on the entrance window of a photomultiplier (PM) FEU-84-3 having a multialkaline photocathode. The PM quantum efficiency Y is presented in Fig. 1. The samples photocurrent I_o was measured in comparison with that from our standard PS scintillator (sample 1 in Table) containing only 2% pTP + 0.05% POPOP. The light output of our standard scintillator was set equal to 100%. The luminescent spectra L of pTP and POPOP are also presented in Fig. 1.

We measured light outputs I_o of our samples. The experimental accuracy was determined on the base of repeated measurements and was about $\pm$2% with a possible systematic error of about $\pm$5%. Some results of I_o measurements without taking into account the PM quantum efficiency are summarized in Table.

For comparison, radiation and scintillation properties of our standard PS 1 prepared with the use of technology close to [4,5] and crystal scintillators 2-3 are given at the beginning of Table. As is clear from Table the light outputs of samples 1 and 3 are in good agreement with the data presented in [16]. Sample 4 prepared with the use of technology close to [9,10] has shown an enhanced level of the light output. Increased levels of the dopants (PO and Ac) concentration above an optimum ($\sim$0.05% by weight) lead

to a reduction of the light output. Note that samples of PS scintillators with enhanced levels of the light output were presented yearly in [17].

Table 1. Scintillation and radiation properties of our new PS scintillators containing 2% pTP + 0.05% POPOP.

N	Scintillators	I_o, %	I/I_o, 3.4 Mrad	I/I_o, 10 Mrad	I/I_o, after 23 days
1	PS	100	0.51	0.24	0.53
2	crystal pTP	141	0.16	0.07	0.10
3	crystal St	113	0.16	0.07	0.08
4	PS*	116	0.43	0.25	0.66
5	PS* + 0.05% PO	107	0.44	0.24	0.62
6	PS* + 0.05% Ac	103	0.45	0.23	0.65
7	PS* + 0.05% PO + 0.05% Ac	113	0.56	0.33	0.79
8	PS* + 0.1% PO + 0.1% Ac	108	0.50	0.28	0.71
9	PS* + 0.2% PO + 0.2% Ac	106	0.49	0.27	0.66
10	PS* + 0.5% PO + 0.5% Ac	106	0.48	0.26	0.64
11	PS* + 0.5% PO + 0.05% Ac	108	0.52	0.28	0.71
12	PS* + 0.05% PO + 0.5% Ac	106	0.40	0.31	0.68

* — these PS scintillators were prepared by a technology close to [9,10]. Samples of crystal pTP and St (stilbene with λ_{em}=410 nm), were manufactured in NPO Monocrystal, Khar'kov, the Ukraine.

Fig. 2 shows transmission properties T of PS bases prepared by our technology [4,5] and a similar technology close to that presented in [9,10] as functions of the wavelength λ. The accuracy of T measurements was about $\pm 1\%$. As is clear from Fig. 2, the technology close to [9,10] provide some improvements of the PS base transmission in the short wavelength region. It explains the observed improvement of the light outputs for samples 4-12 in comparison with sample 1.

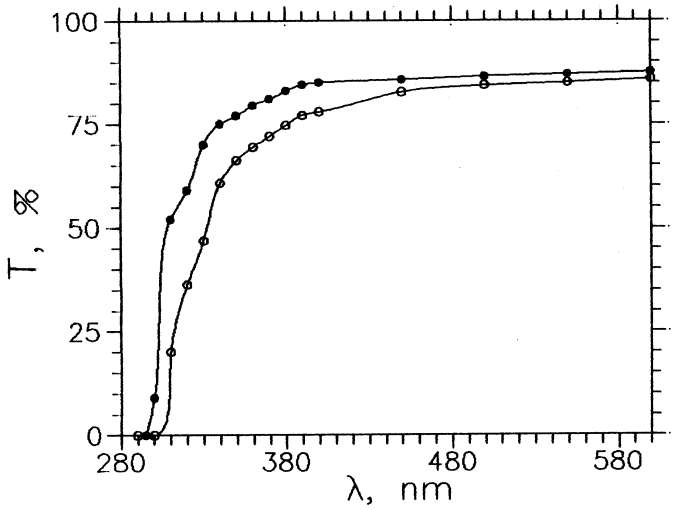

Fig. 2. Transmission properties T of pure polystyrene samples of 0.5 cm thick. (○) — prepared by technology presented in [4,5] and (•) — prepared by technology close to [9,10].

The radiation hardness of our samples was measured in a flux of γ-quanta from ^{137}Cs radioactive sources with a dose rate of about 5.2 rad/s (150 Mrad/yr) at 20^{o}C in air. Note that such dose rate will be tens times higher in comparison with what is expected at future experimental setups. Taking into account a prolonged time of scintillators irradiation in EM-calorimeters, the study of recovery processes in plastic scintillators is an essential part

of any radiation properties investigation. Because of that we measured the relative light output I/I_o both soon (10-20 min) after having received doses 3.4 and 10 Mrad and in 23 days of recovery at 20^{o}C in air after having received the maximum dose. This investigation of our scintillators samples radiation properties began 2 days after their polymerization. Some results of this investigation are presented in Table.

As is clear from Table, the organic crystals showed very low levels of the radiation hardness. It is well known that pTP solution in toluene showed a radiation hardness >100 Mrad [18]. It means that the recombination processes in crystal pTP are more hampered in comparison with plastics, to say nothing of liquids, and explains such low level of pTP radiation hardness in the observed time interval.

The introduction of two antiradiation dopants in PS scintillators brought a decrease of their relative light outputs I/I_o soon after the irradiation in comparison with sample 1. However, the degree of their light outputs recovery was higher and for some samples practically reached a level of $I/I_o \cong 0.79$. Note that the above data are comparative with the data presented in [1,4,5,9,10] where the improved levels of the radiation hardness were reached with the use of single antiradiation dopant at high concentration levels $\geq$10-20%. The long term stability of such materials needs further investigation and, in many cases, improvement.

The acquired results have shown higher efficiency of the multicomponent doping with the aim of improvement of the radiation properies. The improved polymerization technology close to one presented in [9,10] has provided encreased levels of the light outputs for PS scintillators.

It is well known that levels of the radiation hardness for prolonged samples are usually lower in comparison with small samples [5]. Note that in particle detectors, prolonged scintillators are commonly used. Because of that there is a need for a more detailed optimization of the dopants concentrations and the radiation hardness determination for prolonged samples.

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