Functional Materials 11, No.4 (2004)

Dependence of light yield of scintillation strips on the reflective coating material kind

S.V.Melnichuk

STC "Institute for Single Crystals", Institute for Scintillation Materials,
National Academy of Sciences of Ukraine, 60 Lenin Ave., 61001 Kharkiv,
Ukraine

Received May 13, 2003

Effect of the coating material on the reflection factor and light yield of scintillation strips has been studied. The light yield dependences on the pigment type, its concentration, and the coating material preparation techniques have been investigated. A novel method has been developed and realized to introduce a powdered pigment into polymer matrix at high pigment concentrations. This technique has been shown to provide co-extruded scintillation strips with the light yield up to 9 ph.el. (exceeding about by 40 % the foreign analogs).

Проведено изучение влияния вида покрытия на коэффициент отражения и световой выход сцинтилляционных стрипов. Исследованы зависимости светового выхода от типа пигмента, его концентрации и способа получения материала покрытия. Разработан и реализован новый метод введения порошкового пигмента в полимерную матрицу в больших концентрациях. Показано, что это позволило получать соэкструзионные стрипы, которые имеют световой выход до 9 ф.э. (на 40 % больше, чем аналоги мировых производителей).

The long-length profiled plastic scintillators (strips) are used widely now in nuclear physics and high-energy physics experiments. For example, in detectors used in MINOS, D0, and OPERA experiments, about 7 m long scintillation strips are used as sensors [1–3]. The scintillation strips are provided by a groove for a light guide and a reflective coating. Such scintillators should provide a maximum light yield. For example, the OPERA detector strips should provide the minimum light yield of 5 ph.el. while a 8 or 9 ph.el. one is desirable [4].

The purpose of this work was to search for the reflective materials to coat the long strips that would provide the maximum light yield in the specific geometry at a high performance level and industry-favorable production technique.

The strip light yield as a function of the reflective material type was studied using samples of the OPREA detector strips having 10.6×26.3 mm^2 cross-section and f=50 cm length (*L*). $\mathrm{A}^{90}{}_{\mathrm{Sr}}$ source and a Kuraray Y11 light guide of 1.2 mm diameter and 1 m length were used. The strips were manufactured by extruding the specially prepared polystyrene (PS) blocks. A FEU-115M PMT was used as the light receiver showing the average quantum efficiency of 14 % in the maximum emission region of the fiber. The coating reflection factor was measured using a FMSh-56 instrument at 400 nm wavelength that answers approximately to the emission maximum of the secondary admixture in the scintillating composition used in the strip matrix.

As the light reflecting materials, aluminized Mylar, synthetic paper TYVEK, metals, and white paints and plastics are in wide use in physical experiments [5]. It is just the TYVEK that is used most often as a reflector because it has a sufficient reflection factor and provides a high light yield

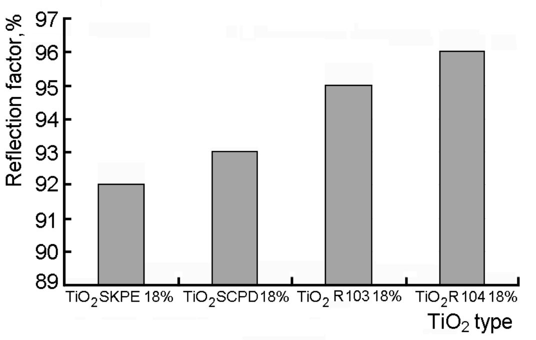

Fig. 1. Reflection factors of coatings containing various TiO_2 kinds.

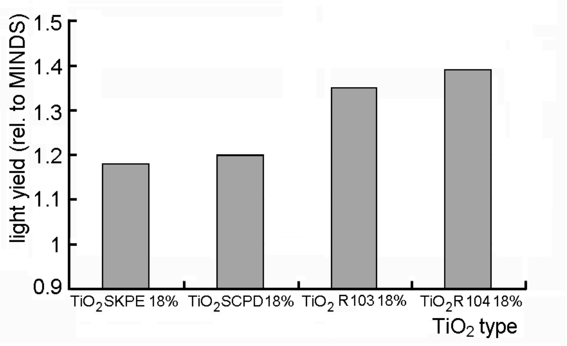

Fig. 2. Dependence of the strip light yield on the TiO_2 kind in the coating material.

of the scintillator. It is to note, however, that such a reflector is inconvenient to use in long-length counters. A novel coating obtained by chemical modification of the surface is described in [5]. It is just the polymer-based coatings applied by co-extrusion technique immediately in the strip manufacturing process that are believed the most practically feasible. This method provides a reduced laboriousness and a favorable production cost.

The light collection calculations in scintillation strips [6] have shown that the light yield is influenced to the greatest extent by the scintillator material transparency and the coating reflection factor (R). The latter dependence is exponential, and a considerable light yield increase is attained at $R > 90$ %. In this work, the following factors influencing the coating reflection factor were studied: (I) the pigment type (TiO_2, MgO, ZnO, $BaSO_4$, Al_2O_3); (II) the pigment concentration; (III) the coating thickness; and (IV) the coating obtaining technique.

In contrast to colored pigments that provide the light-tightness due to the visible light absorption, titania and other white pigments provide the light-tightness due to the light scattering. Table 1 presents the refractive indices for the most widely used white pigments and polymers. It is seen from the Table that it is just TiO_2, in particular, its rutile form, that shows the highest refractive index and, therefore, offers an advantage in the reflection.

In this connection, the rutile TiO_2 was selected as the pigment. The commercial TiO_2 is produced as powders of different purity and dispersity grades as well as concentrates based on various polymers. The following titania products were used in the studies:

(I) TiO_2 powder of R103 and R104 brands produced by DuPont,

(II) TiO_2 powder of A20 brand from Sumy Chemical Works,

(III) TiO_2 super concentrate on polystyrene basis from DuPont, SCPD brand (TiO_2 content in the granules 60 %),

(IV) TiO_2 super concentrate on polyethylene basis from Schulmann, SCPE brand (TiO_2 content in the granules 60 %).

The coating material was prepared on the PS basis by adding titania and blending in a worm extruder. The coating was applied in

Table 1. Refractive indices of white pigments and polymers

White pigment	Refractive index	Polymer	Refractive index
TiO_2 (rutile)	2.73	Polystyrene	1.6
TiO_2 (anatase)	2.55		
Antimony oxide	2.09–2.29	Polycarbonates	1.59
Zinc oxide	2.02		
White lead	1.94–2.09	Polyethylene	1.5–1.54
Lithopone	1.84	Acrylates	1.49
Magnesium silicate	1.65		
Barium sulfate	1.65	Polyvinyl chloride	1.48
Calcium carbonate	1.63		

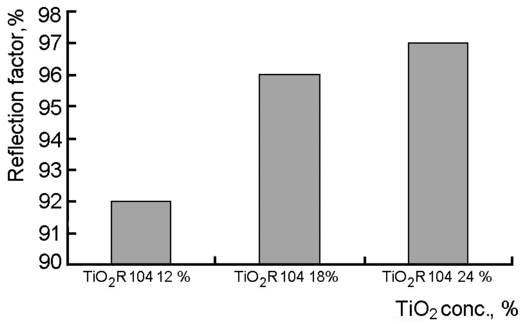

Fig. 3. Dependence of the coating reflection factor on titania concentration.

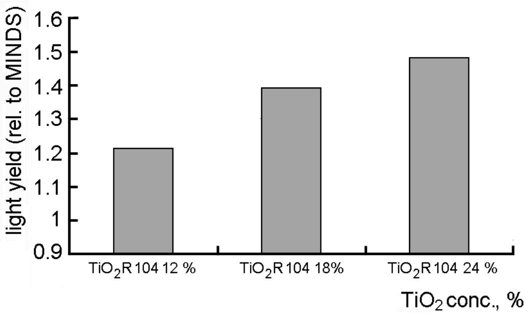

Fig. 4. Dependence of the strip light yield on the TiO_2 concentration in the coating material.

the course of manufacturing by co-extrusion. The reflective coating thickness was 300 μm as defined by the detector specifications. To increase the coating thickness is undesirable because this results in an increased dead zone of the detector.

At the first step, the dependences of reflection factor and light yield on the TiO_2 kind. To that end, strips were made with coatings containing the same concentration (18 %) of different titania kinds. The strip light yield and the coating reflection factor values are shown in Figs. 1, 2. It is seen that it is just the strips with a coating containing TiO_2 powder of R104 brand produced by DuPont that show the highest reflection factor and light yield, while R103 brand provides very similar results. The advantage of those two types is due, first of all, to the material high purity (96–97 %) as well as to the high dispersity (particle size about 0.2 μm). In Figs. 3 and 4, presented are measured the reflection factor and light yield values for the strips containing 12 %, 18 %, and 24 % of R104 TiO_2 as the best reflective material found in preliminary experiments. The reflection factor and light yield are seen to increase as the TiO_2 concentration rises.

The reflection factor (and thus the light yield) is known to be affected by the reflective material dispersity in the polymer matrix. This instance becomes especially important at high pigment concentrations when the agglomeration of the pigment particles is favored. The introduction of TiO_2 in high concentrations by using the superconcentrates is a rather easy solution, however, as it is seen from Figs. 1 and 2, such coating are not the best ones. We have developed and realized the TiO_2 introduction technique into the initial monomer followed by the polymerization. That technique provides the use of a powder at high concentrations and the maximum dispersity of the material.

All experimental results are summarized in Table 2. It is to note that the advantages of Samples Nos.6 and 9 are due to a superhigh titania concentration in the coating (24 %). In this case, some problems with co-extrusion arise connected with the increased viscosity of the coating resulting in the non-uniform application. That is why the Sample No.8 is more preferable. It contains 18 % of TiO_2 and shows a little difference only from the Samples Nos.6 and 9 in light yield, while causing no problems with uniform application on the scintillator.

Thus, in the work, presented are the measurement data of the coating reflection factor and the scintillating strip light yield for various reflective materials. The light collection in the strips is realized using the fibrous spectrum shifters. The light yield dependence on the pigment type and its concentration in the coating has been studied. A novel technique has been proposed and realized using the pigment introduction not into polymer but into monomer followed by the polymerization. This provided the scintillating strips coated by co-extrusion, the coating having high light reflection properties and providing a high light yield. The samples obtained exhibit a light yield attaining 8.9 ph.el., i.e. higher by 40 % as compared to the strips with TYVEK reflectors and not less than those with chemically modified surface. The co-extruded coating seems to be the most feasible practically in the mass production.

References

1. A.Pla-Dalmau, A.D.Bross, K.L Mellot, Extruded Plastic Scintillation Detectors, in: DPF Proc., January 1999 (Fermilab-Conf-99/095).
2. The MINOS Detectors, Technical Design Report, NuMI-L-337 (1998).

Table 2. Effect of the reflective coating type on the reflection factor (R) and light yield* of the strips

Manufacturer	Sample No.	Reflective material	Coating technique	R, %	Light yield	
					To MINOS	to ph.el.
ISMA	1	TiO_2 SKPE 12 %	Co-extrusion	91	1.10	–
	2	TiO_2 SKPE 18 %	Co-extrusion	92	1.18	7.6
	3	TiO_2 SKPE 24 %	Co-extrusion	94	1.20	–
	4	TiO_2 SKPD 12 %	Co-extrusion	90	1.09	–
	5	TiO_2 SKPD 18 %	Co-extrusion	93	1.20	–
	6	TiO_2 SKPD 24 %	Co-extrusion	95	1.42	8.35
	7	TiO_2 R104 12 %	Co-extrusion	92	1.21	–
	8	TiO_2 R104 18 %	Co-extrusion	96	1.39	8.20
	9	TiO_2 R104 24 %	Co-extrusion	97	1.48	8.90
	10	TYVEK	Enveloping	93	0.98	–
	11	Modified surface	Chemical modification	96	1.43	–
MINOS	12	TiO_2 12 %	Co-extrusion	92	1.00	5.60
Chemo Technique	13	TiO_2 R104 15 %	Co-extrusion	94	0.91	5.00
Pol.Hi.Tech	14	TYVEK	Rreversal	93	0.85	4.76
	15	TiO_2 R104 2.5 %	Co-extrusion	80	0.58	2.50
	16	VL-548 paint	Painting	85	0.67	–

* The light yield in photoelectron numbers has been measured at IReS (Strasbourg) using a mono-energy electron beam

3. A.Pla-Dalmau,Extruded Plastic Scintillator for the MINOS Calorimeters, *Frascati Physics Series*.-2000.-V.n.-P.00-00. (2000).
4. OPERA Proposal, An Appearance Experiment to Search for nm Oscillations in the CNGS Beam, CERN/SPSC 2000-028, SPSC/P318, LNGS P25/2000 (2000).
5. A.A.Durum, V.I.Kochetkov et al., Study of Light Reflecting Coatings of Scintillation Counters with Spectrum Shifting Fibers, IFVE Publ. 99-6, Protvino, (1999) [in Russian].
6. V.G.Senchishin, A.F.Adadurov, S.V.Melnichuk, *Functional Materials*, **11**, 305, (2004).

Залежність світлового виходу сцинтиляційних стрипів від типу світловідбиваючого покриття

Мельничук С.В.

Проведено вивчення впливу типу покриття на коефіцієнт відбиття та світловий вихід сцинтиляційних стрипів. Досліджено залежність світловиходу стрипів від типу пігмента, його концентрації та способу отримання матеріалу покриття. Розроблено та реалізовано новий спосіб введення порошкового пігменту у покриття у великих концентраціях. Показано, що це дозволило отримувати коекструзійні стрипи, що мають світловий вихід до 9 ф.е. (на ~40 % більше, ніж світові аналоги).