AIDA-2020-CONF-2017-004

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Conference/Workshop Paper

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30 August 2017

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **14: Infrastructure for advanced calorimeters**.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site `<http://aida2020.web.cern.ch>` or on the CERN Document Server at the following URL: `<http://cds.cern.ch/search?p=AIDA-2020-CONF-2017-004>`

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PEN as self-vetoing structural Material

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Abstract. Polyethylene Naphtalate (PEN) is a mechanically very favorable polymer. Earlier it was found that thin foils made from PEN can have very high radio-purity compared to other commercially available foils. In fact, PEN is already in use for low background signal transmission applications (cables). Recently it has been realized that PEN also has favorable scintillating properties. In combination, this makes PEN a very promising candidate as a self-vetoing structural material in low background experiments. Components instrumented with light detectors could be built from PEN. This includes detector holders, detector containments, signal transmission links, etc. The current R&D towards qualification of PEN as a self-vetoing low background structural material is be presented.

Experiments for the search of extremely rare events such as neutrinoless double beta-decay or dark matter interactions require extremely good control of the radio-purity of the materials they are made of. Additionally, experiments can also strongly benefit from instrumenting the detector surroundings with materials that are scintillating and transparent for light, as recently demonstrated by the GERDA experiment [1].

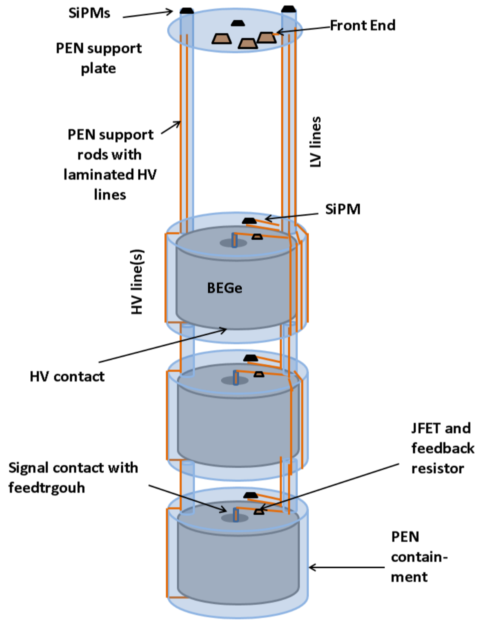

FIGURE 1. Sketch of a possible configuration of a germanium detector string in a future experiment.

Usually the infrastructural parts, such as holders and containments are made of low background copper or other materials known to be radio-pure. These parts are, however, usually not transparent for light, hence inactive from the viewpoint of background radiation detection.

Recently it has been reported that transparent Polyethylene Naphtalate (PEN), commonly used in industry, is efficiently scintillating with a peak emission at 425nm [2]. PEN has been recognized earlier to be radio-pure and has already been used in low background experiments as a cable substrate for signal transmision cables [3] and as a material for low background HV capacitors [4].

The mechanical properties of PEN at cryogenic temperatures (77 K) have been reported to be rather favorable. The yield strength has been shown to be > 300 MPa, even for a degree of crystallinity of 44% [5]. This is a factor of ≈ 3 higher than for copper. The Youngs modulus at 77 K has been measured to be 13 GPa, significantly higher than for other commonly used polymers, such as polyethylene-teraphtalate. While this is considerably less than for metals, it is still high enough to allow for many standard mechanical applications.

The combination of its radio-purity, its favorable mechanical properties and the fact that it is scintillating makes PEN a very interesting material for applications

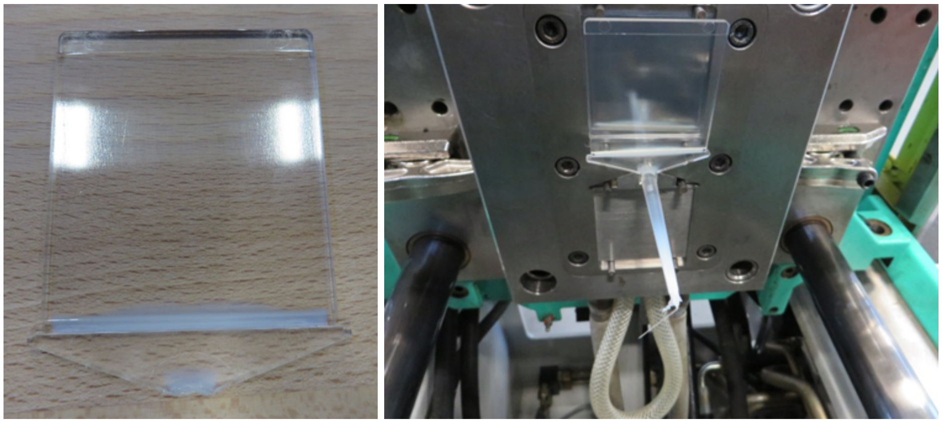

FIGURE 2: Tiles molded at Fraunhofer Institute ICT. Left: 170x170 mm^2 tile. Right: 55x50 mm^2 tile still inside the mold.

in low background experiments. Generally, PEN could be used as a structural material for detector holders or containments. These components could be arranged with clever geometries, allowing to guide the scintillation light with high efficiency to attached light detectors, for example SiPMs. Like this the surrounding of the detector could be practically fully self-vetoing. Additionally, the structural components could also be used to detect radiation from the surrounding and act as an additional veto system.

Ideally, PEN structural components could additionally serve as the substrate for signal transmission lines and HV leads. This could remove the usual challenge of having to find custom made low background cables and largely reduce the complexity of proper cable routing and reduce microphonics due to lose cable strands.

A simplistic sketch of a possible configuration of a string containing three germanium detectors, encapsulated in PEN instrumented with SiPMs is shown in Fig. 1.

PEN pellets of types TN-8050SC and TN-8065S and a 1 mm thick sample of PEN in the form of Scintirex^{TM} were procured from Tejin DuPont [6]. A fraction of the pellets was sent for screening measurements to the GeMPI HPGe screening facility at LNGS [7]. The results of these measurements are shown in the table below.

It is apparent that the samples are clean in terms of the uranium and thorium decay chains, while there seems to be a contamination with ^{40}K. This might be due to the catalyst used during PEN synthesis.

The PEN pellets from Tejin Dupont were used to perform first test moldings at Fraunhofer Institute für Chemische Technologie (ICT) [8]. In a first run, tiles with a size of 170x170x4 mm^3 were molded in a molding machine of type Ferromatic Milacron K110. There was no surface treatment of the mold, resulting in an undefined surface roughness. Prior to molding, the pellets have been dried at 160^{o}C for 6 hours. The mold temperature was kept at 30^{o}C, the temperature at the nozzle was between 280$\,^o$C and 300$\,^o$C. Once the machine parameters were optimized, air enclosure free and transparent tiles were produced.

In another trial, tiles with size 50x55x3 mm^3 were molded using a machine of type Arburg Allrounder 320C 600-250 using similar parameters as before. Again, air enclosure free and transparent tiles were produced. Both, pellets of types TN-8065S and TN-8050SC were used. Fig. 2 shows one tile of each geometry.

TABLE 1. Results of radio purity measurements obtained with a low background HPGe detector for two PEN samples. Uncertainties are given with approx. 68% CL)

	TN-8065S	TN-8050SC
	[mBq/kg]	
Ra-228	< 0.15	< 0.15
Th-228	(0.23 ± 0.05)	< 0.13
Ra-226	(0.25 ± 0.05)	< 0.11
Th-234	< 11	< 15
Pa-234m	< 3.4	<3.0
U-235	< 0.066	< 0.054
K-40:	1600 ± 400	1000 ± 400
Cs-137	< 0.057	< 0.064

Independent molding tests have been performed at TU Dortmund [9]. Transparent samples with geometry 30x30x3 mm^3 could be molded succesfully.

For qualification of usage at cryogenic operational temperatures the 170x170x4 mm^3 tiles produced at Fraunhofer ICT were immersed into liquid nitrogen > 10 times. Optical microscopy was used to determine differences in the

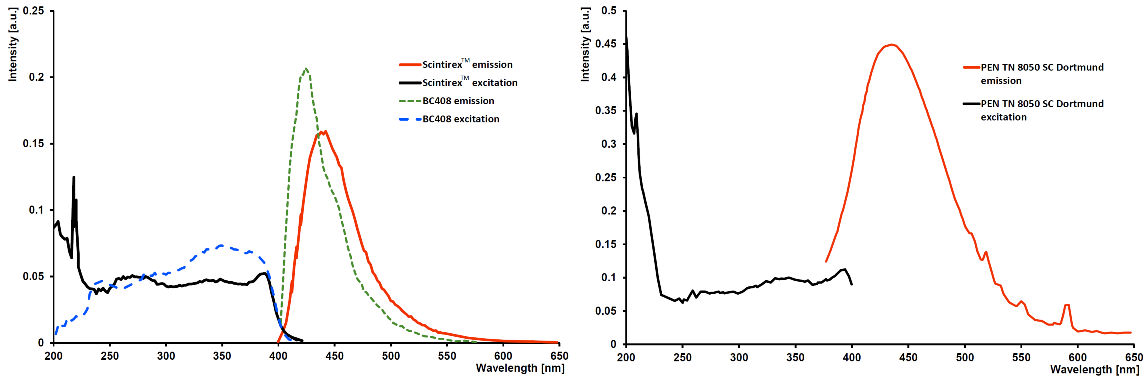

FIGURE 3: Excitation and emission spectra of Scintirex^{TM} (left) and TN-8050SC PEN molded at TU Dortmund (right). For comparison also the spectra for a BC408 sample are shown (left).

surface quality before and after thermal cycling. Comparing pictures before and after cryogenic treatment no hints for material deterioration could be found.

For the characterization of scintillation properties, tiles with standard geometry were produced from all samples. These have 30x30 mm^2 surface and a dimple with 10 mm diameter and 1 mm depth in the center on one side for light collection with silicon photomultipliers (SiPMs), using the tile geometry developed for the CALICE analog hadron calorimeter [10],[11].

Samples molded at TU Dortmund were characterized at Lancaster University using a Agilent Cary Eclipse spectrograph [12]. For emission measurements, the PEN samples were illuminated with a (360±2.5) nm light source, the excitation light output was measured at 450 nm.

The Scintirex^{TM} sample was investigated using photo-luminescence at CERN. For comparison, also a sample of standard scintillator from Saint Gobain BC408 [13] with 3 mm thickness was measured. For emission measurements the Scintirex^{TM} was illuminated with a (350±2.5) nm light source. The excitation light output was measured at 420 nm. The obtained spectra are displayed in Fig. 3. It is clearly visible that all samples have an emission peak at wave lengths compatible with the detection peak efficiency of SiPMs. The maximum light output was measured at 442 nm and 435 nm for the PEN TN-8050SC and the Scintirex^{TM} samples, respectively. This is both reasonably close to to the maximum emission wavelength of 425 nm reported in [2]. Remarkably, the overlap between excitation and emission spectra is as small as for BC408, showing that PEN by itself acts as a wavelength shifter. Also it is very interesting to note that the emission spectrum for both PEN samples (Scintirex^{TM} and TN-8050SC) is increasing singnificantly below 230 nm.

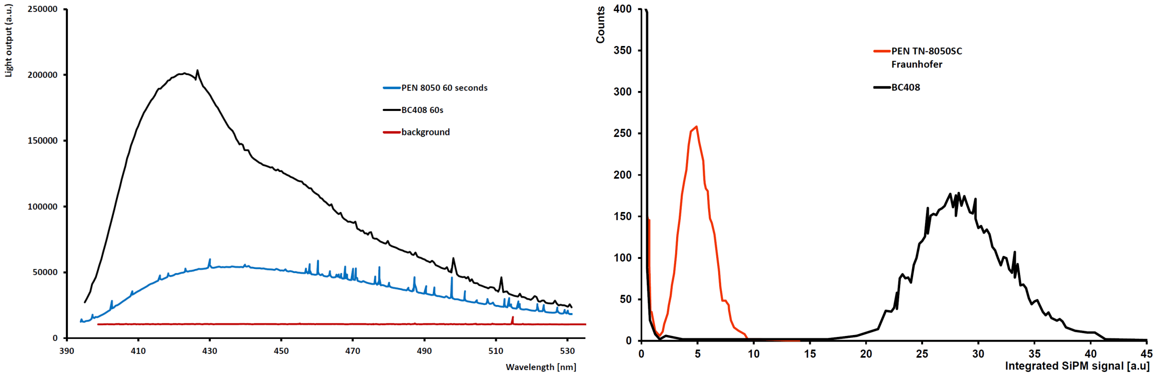

FIGURE 4: Left: Comparison of scintillation light output as a function of frequency for two tiles made from BC408 standard scintillator and PEN TN-8050SC. Scintillation light was induced using a ^{106}Ru source. A background measurement is also shown. Right: Light output measurment of a PEN TN-8050SC tile and a BC 408 tile taken with SiPMs. A ^{90}Sr source was used.

To prove that PEN can be used as an active detector component, a tile molded at Fraunhofer ICT from PEN type TN-8050SC with geometry 30x30x3 mm^3 with a dimple was exposed to a ^{106}Ru β-source. Scintillation light produced inside the PEN tile was measured using an Andor Shamrock 303i spectrograph in connection with an Andor iDus 420 spectroscopy CCD [14]. For comparison, the same measurement was repeated using a tile of same geometry made from BC408. Also a blank measurement without tile and light source was performed. Fig. 4 (left) shows the resulting spectra. It is apparent that PEN emitts a significant amount of scintillation light induced by β-particles, however, the light output of the sample was significantly less ($\approx$ 6 times) than for the BC408 tile.

Additionally a PEN tile molded at Fraunhofer ICT was exposed to a collimated ^{90}Sr β source in a dedicated scintillator test stand [10]. The scintillation light was read out with a 3x3 mm^2 SiPM mounted inside the dimple on on the bottom of the 30x30x3 mm^3 tile. Only events that were triggered in a 5x5x5 mm^3 BC420 cube placed in the line of the ^{90}Sr source below the PEN tile were recorded. The same measurement was repeated with a tile of same geometry made from BC408. The result of the measurement is displayed in Fig. 4.

In conclusion we state that first proof of principle tests seem to confirm the potential of PEN as a self-vetoing structural material for low background applications: It could be shown that large enough forms can relatively easily be molded from commercially available low background PEN pellets. It was also confirmed that the samples molded from these pellets are scintillating with a maximum emission around 430 nm. Further investigations will need to be performed to qualify PEN as a material to be used in future low background experiments.

ACKNOWLEDGMENTS

We would like to thank M. Stommel and M. Pohl from Technische Universität Dortmund as well as B. Beck and C. Anselment from Fraunhofer ICT for the work on molding the PEN tiles. Additionally we thank M. Laubenstein from Laboratorio Nazionale del Gran Sasso of the INFN for performing the PEN screening measurements. We thank E. Auffray from CERN for help with the photo-luminescence measurements and H. O'Keeffe for help with measurements at Lancaster University. This project was supported by the H2020 project AIDA-2020, GA no. 654168.

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