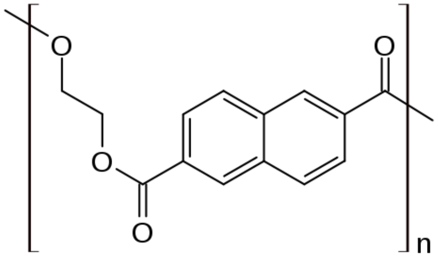
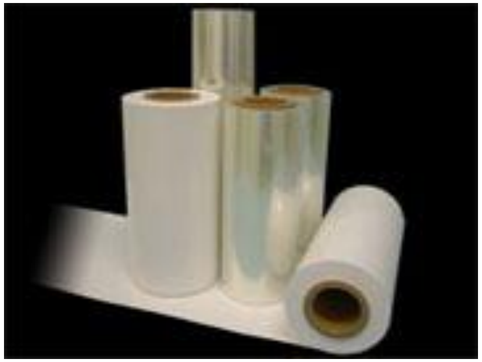


PEN: The material of choice?

Béla Majorovits, MPI für Physik

- Mechanical properties
- Applications and commercial availability
- Radiopurity
- R&D ond lamination
- Scintillation properties
- How could PEN help us?



22.Oct.2015, Ringberg, Castle

Mechanical properties of PEN

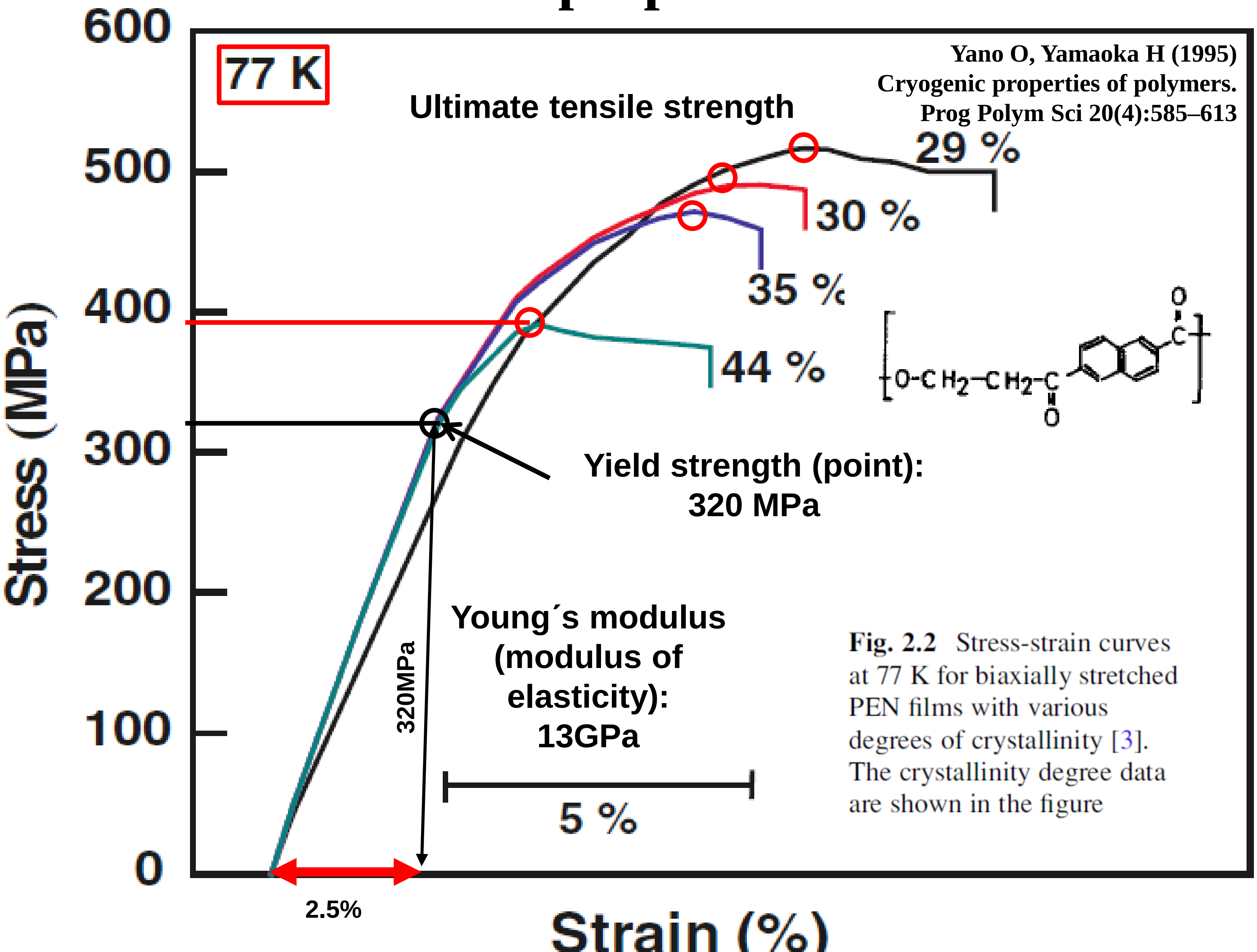


Fig. 2.2 Stress-strain curves at 77 K for biaxially stretched PEN films with various degrees of crystallinity [3]. The crystallinity degree data are shown in the figure

Mechanical properties of PEN

Taken from Godfellows

Chemical Resistance

Acids - concentrated	Good-Poor
Acids - dilute	Good
Alcohols	Good
Alkalis	Good
Aromatic hydrocarbons	Good
Greases and Oils	Good
Halogenated Hydrocarbons	Good
Ketones	Good

Electrical Properties

Dielectric constant @1MHz	3.2 @
Dielectric strength (kV mm^{-1})	160 @
Dissipation factor @ 1kHz	0.005
Dissipation factor @ 1MHz	0.0048
Surface resistivity (Ohm/sq)	10^{14}
Volume resistivity (Ohm.m)	10^{15}

→ 4 kV/25μm

Mechanical Properties

Coefficient of friction	0.27 - biax film
Elongation at break (%)	60 - biax film
Tensile modulus (GPa)	5-5.5 - biax film
Tensile strength (MPa)	200 - biax film

Physical Properties

Density (g cm^{-3})	1.36
Flammability	VTM-2 - UL94, 0.075mm
Optical transmission (%)	84 @ 0.075mm
Resistance to Ultra-violet	Fair
Water absorption (%)	0.4

Thermal Properties

Coefficient of thermal expansion (x10^{-6} K^{-1})	20-21 - biax
Thermal conductivity @23C (W m^{-1} K^{-1})	0.15
Upper working temperature (C)	155

Taken from Tejin DuPont Films

Item		Unit	Q51 Type							
Thickness		μm	12	16	25	38	50	75	100	250
Tensile strength	MD	MPa	310	310	310	270	270	270	270	210
	TD		310	310	310	270	270	270	270	210
Tensile elongation	MD	%	85	85	85	90	90	90	100	120
	TD		85	85	85	90	90	90	100	120
Thermal Shrinkage (150 deg C×30 mins.)	MD	%	1.0	1.0	0.8	0.6	0.6	0.4	0.4	0.4
	TD		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Thermal Shrinkage (200 deg C×10 mins.)	MD	%	2.6	2.6	2.5	1.3	1.3	1.0	1.0	0.8
	TD		3.5	3.0	3.0	1.3	1.2	1.0	1.0	0.4
Breakdown voltage		kV/mm	–	–	300	250	250	200	180	–
Coefficient of friction	μs	–	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	μk		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Haze		%	8.0	10.0	13.0	14.0	15.0	25.0	28.0	43.0

→ 7.5 kV/25μm
→ 18 kV/100 μm

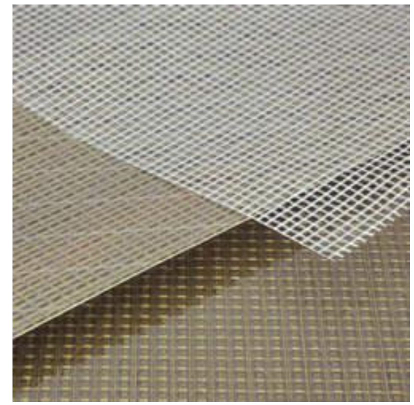
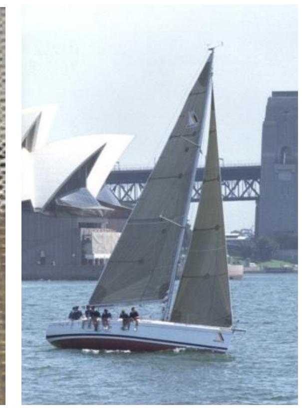
Comparison of tensile strength to other materials:

MATERIAL	Yield strength	Young´s modulus
PEN	> 200 MPa	5 – 13 GPa (higher value at 77K)
Copper	~70 Mpa	130 GPa
Stainless st.	400 – 550 Mpa	~ 200 GPa
HDPE	15 – 40 Mpa	~ 3 GPa
PET	55 Mpa	~ 1 GPa
Kapton (with Carbon fibre)	85 (140) Mpa	2.5 GPa

Applications of PEN

Used in a wide range of applications. Mainly electronics

Food insdustry: Bottles

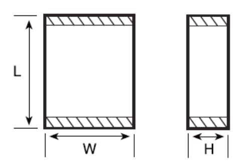
Sports: canvas for sailing boats

Electronics: Capacitors

C51
CLN51 series

金属化聚萘乙酯膜表面安装直流固定电容器(PEN)
Metallized polyethylene naphthalate film surface mounted D.C. capacitor (Stacked version)

■ 外形图 Outline Drawing



■ 特点

- 采用无外封装叠片式技术，体积小
- 性能稳定，具有良好的温度特性、频率特性、电压特性、时间稳定性和防潮特性
- 可靠性高，自愈性好
- 无压电效应，无极性，无非线性失真
- 等效串联电阻低，噪音电平低
- 抗脉冲能力强
- 抗热冲击、抗机械冲击能力强

■ Features

- Uncoated, stacked construction, small size
- Stability versus temperature, frequency, voltage, time and humidity
- Reliable quality due to self-healing effect
- No piezoelectric effect, non-polar construction, non-linearity distortion
- Low ESR, low noise level
- High dv/dt ability
- No cracking under thermal impact or mechanical bump

Entertainment: membranes for headphones

Eur. Phys. J. C (2013) 73:2445
DOI 10.1140/epjc/s10052-013-2445-3

THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

High voltage capacitors for low background experiments

C. O'Shaughnessy[1,2,a], E. Andreotti[3], D. Budjáš[4], A. Caldwell[1], A. Gangapshev[5,6], K. Gusev[4,7], M. Hult[3], A. Lubashevskiy[6], B. Majorovits[1], S. Schönert[4], A. Smolnikov[6]

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[3]Institute for Reference Materials and Measurements, Geel, Belgium
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[5]Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
[6]Max-Planck Institut für Kernphysik, Heidelberg, Germany
[7]Joint Institute for Nuclear Research, Dubna, Russia

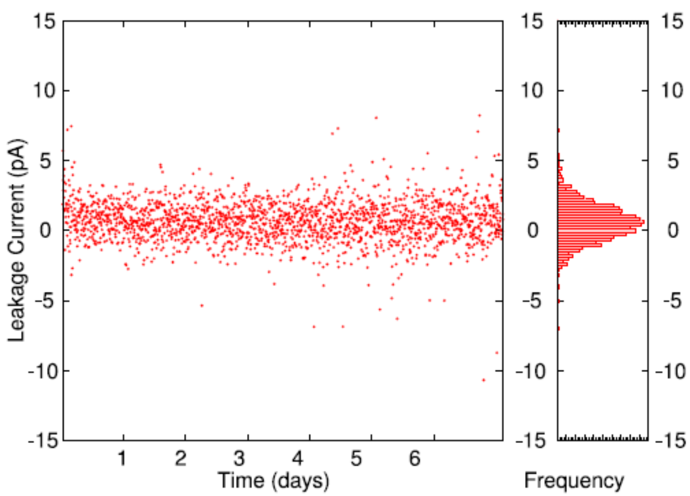
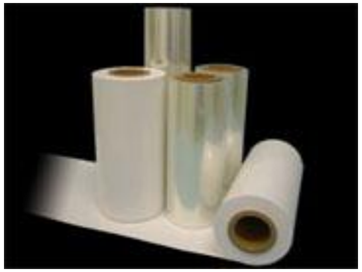


Fig. 4 Long-term measurement of the leakage current with the capacitor biased to 5 kV at 77 K. The right hand projection is a binned frequency distribution showing the Gaussian profile

HV capacitor tested in LAr for several days: No (micro-)discharges observed

→ Can be used for HV cables!

Commercial availability of PEN



Films in different thicknesses (1.3um – 0.25mm)

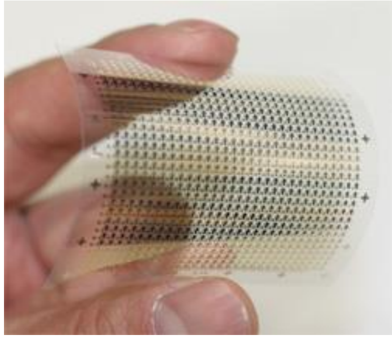
Tejin DuPunot Films, Goodfellows, GTS

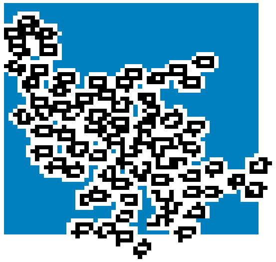
(for example: 5m x 0.3m EUR 551)

↓

Use for further processing to flat band cables

Challenge: Radiopurity of limnation processes!





Granules, ca. 5mm

Goodfellows

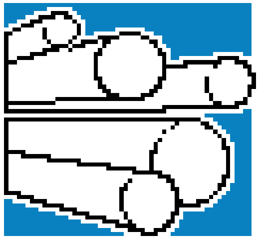
(2 kg EUR 384)

↓

Use for further processing to structural materials

Easy to make plates of 5 x 500 x 500 mm3 plates using conventional injection molding

(for example Fraunhofer Institute for Chemical Technolgy)



Rods, diameter: 12mm or 25mm BLACK!

Goodfellows

(l:500mm, d: 25mm, EUR 500)

↓

Immediate use for structural material (provided its clean)

Would be custom made material: remove additives

Radiopurity of PEN

Samples received from Ami Doduco

ICPMS meaurements

	Peso	K	Pb	Th	U	^{40}K	^{232}Th	^{238}U
	[%]	[ppb]	[ppb]	[ppt]	[ppt]	[mBq/kg]	[mBq/kg]	[mBq/kg]
Pure PEN	100	< 393	26 ± 3	< 16	< 16	< 12	< 0.07	< 0.2
Cu	77.59	3210 ± 160	16.3 ± 0.1	< 124	134 ± 2			
Cr	0.21	< 183	1.4 ± 0.2	~7.3 ± 3.7	<7			
PEN	16.2	< 66	4.2 ± 0.4	< 3	< 3			
Whole sample		3210^{+170}_{-160}	21.9 ± 0.5	7^{+42}_{-4}	134^{+3}_{-2}	97 ± 5	$0.03^{+0.17}_{-0.02}$	$1.66^{+0.04}_{-0.02}$
Cu	82.03	1646 ± 21	7.0 ± 0.4	< 135	< 135			
Cr	0.25	< 270	3.5 ± 0.2	<10	<10			
PEN	17.72	< 85	4.3 ± 0.3	<3	<3			
Whole sample		1646^{+97}_{-21}	14.8 ± 0.5	<148	< 148	$49.9^{+2.9}_{-0.6}$	< 0.6	< 1.8
Cu	17.29	1290 ± 170	8.6 ± 0.4	< 76	< 76			
Cr	1.68	< 3041	10.4 ± 0.5	< 122	< 122			
PEN	81.03	<365	55 ± 3	< 144	< 90			
Whole sample		1290^{+1040}_{-170}	74 ± 3	< 342	< 288	39^{+35}_{-5}	< 1.4	< 3.6
Pure PET	100	480 ± 110	53 ± 5	522 ± 52	3714 ± 37	14.6 ± 3.3	2.1 ± 0.2	46.1 ± 0.5

→ **No 228Th, 226Ra detectable by gamma screening**

Radiopurity of PEN

PEN received GTS-Flexible

		^{40}K [mBq/kg]	^{232}Th [mBq/kg]	^{238}U [mBq/kg]
PEN (from M.L.big roll)	γ-spectroscopy	510 ± 20	135 ± 3	242 ± 3
	ICP-MS	370 ± 50	110 ± 10	200 ± 30

→ **Massive contaminations!**

Radiopurity of PEN

Teonex Q51 (PEN) received from Tejin DuPont Films:

GERDA sample:
Gamma screening (Baksan) :
Ra-226: <2.0 mBq/kg (90% C.L.)
Th-228: <1.4 mBq/kg (90% C.L.)
K-40: <3.6 mBq/kg (90% C.L.)

	Kapton(average)	PEN3
K [mBq/Kg]	<47	<12.4
Th [mBq/Kg]	$0.45_{-0.15}^{+0.15}$	$0.06_{-0.02}^{+0.06}$
U [mBq/Kg]	10_{-3}^{+3}	<0.40

CUORE sample:
Gamma screening:
Ra-226: <1.3 mBq/kg (90% C.L.)
Th-228: <1.0 mBq/kg (90% C.L.)
K-40: <13.2 mBq/kg (90% C.L.)

→ Radiopure PEN can be procured.
However, careful screening is obligatory!

R&D on lamination

Nuclear Instruments and Methods in Physics Research A 718 (2013) 211–212

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Electrical characterization of the low background Cu-PEN links of the CUORE experiment

C. Brofferio [a,b], L. Canonica [c,d], A. Giachero [a,b], C. Gotti [a,e,*], M. Maino [a,b], G. Pessina [a,b]

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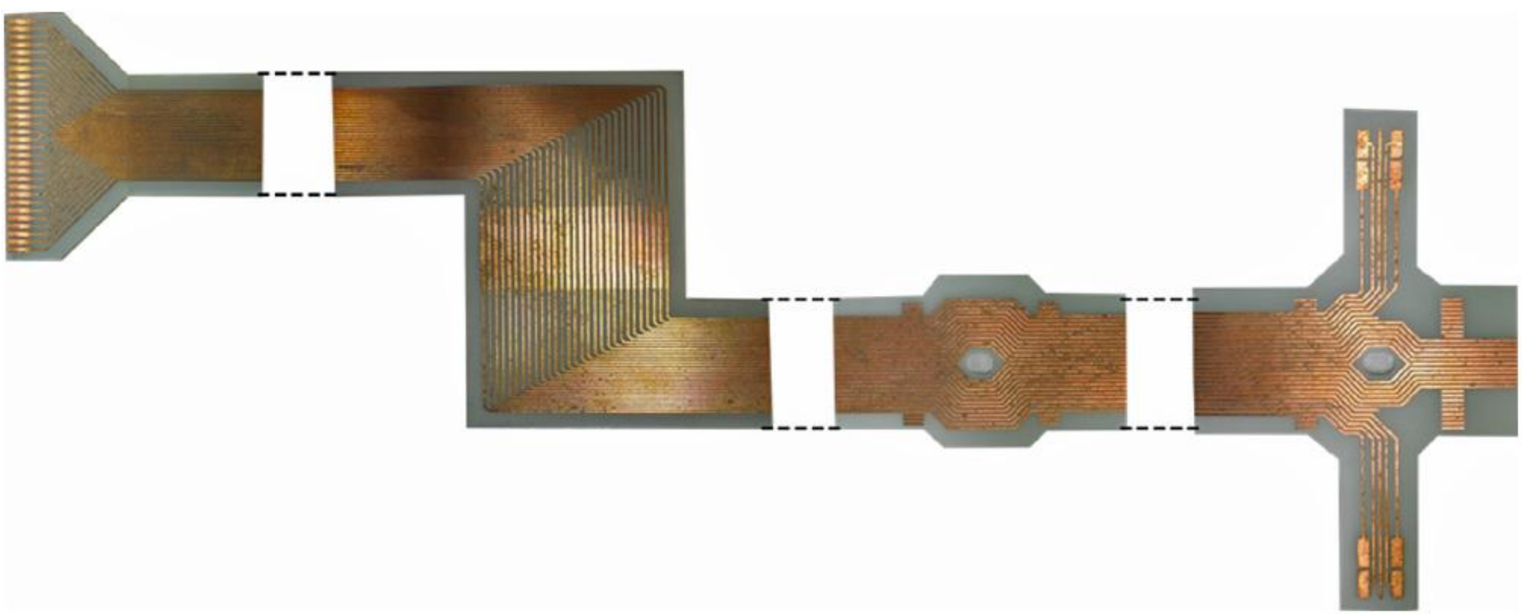
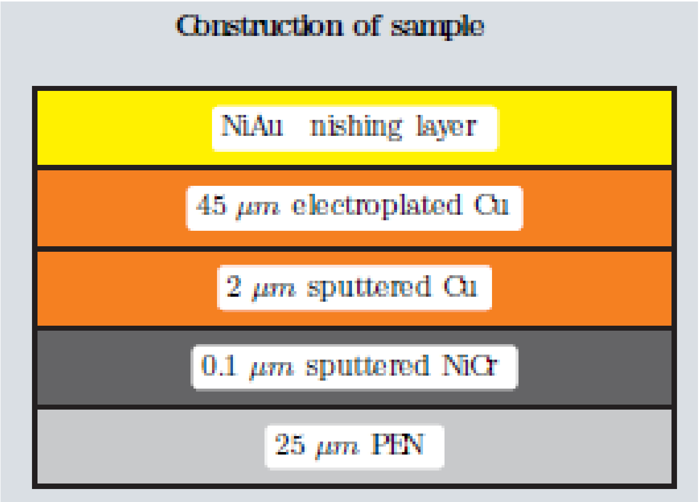
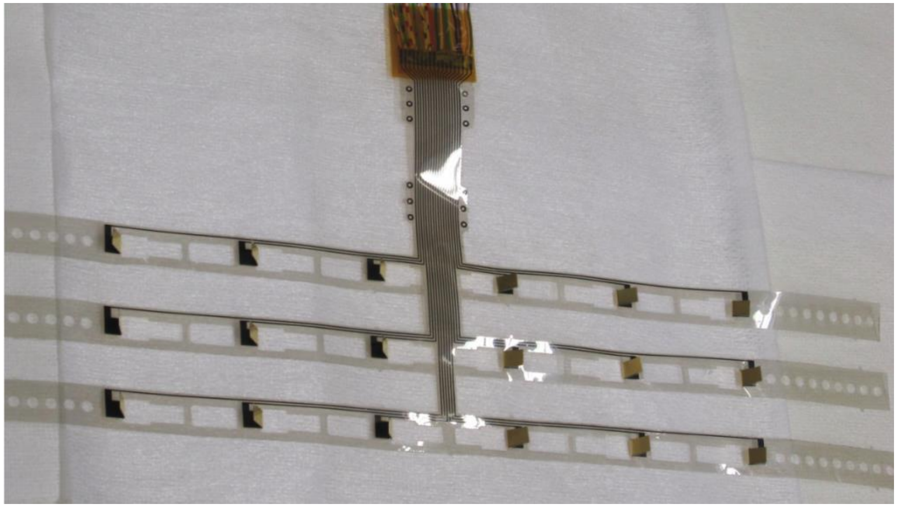
[e] Università di Firenze, Dipartimento di Elettronica e Telecomunicazioni, Via S. Marta 3, I-50139 Firenze, Italy



R&D on lamination



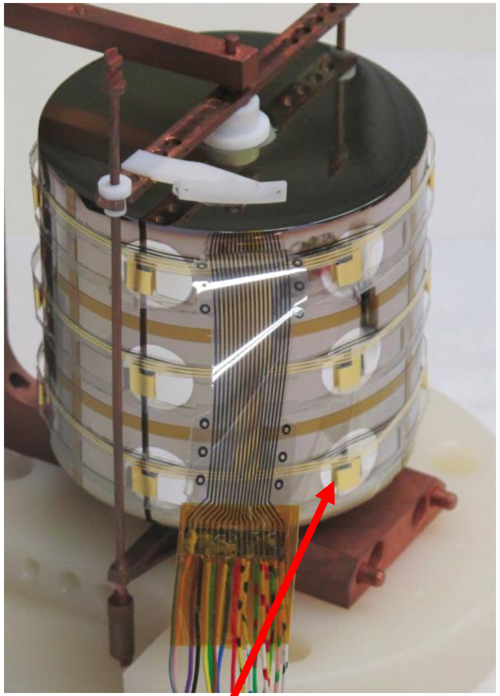


PEN lamination process for GERDA proved to work:

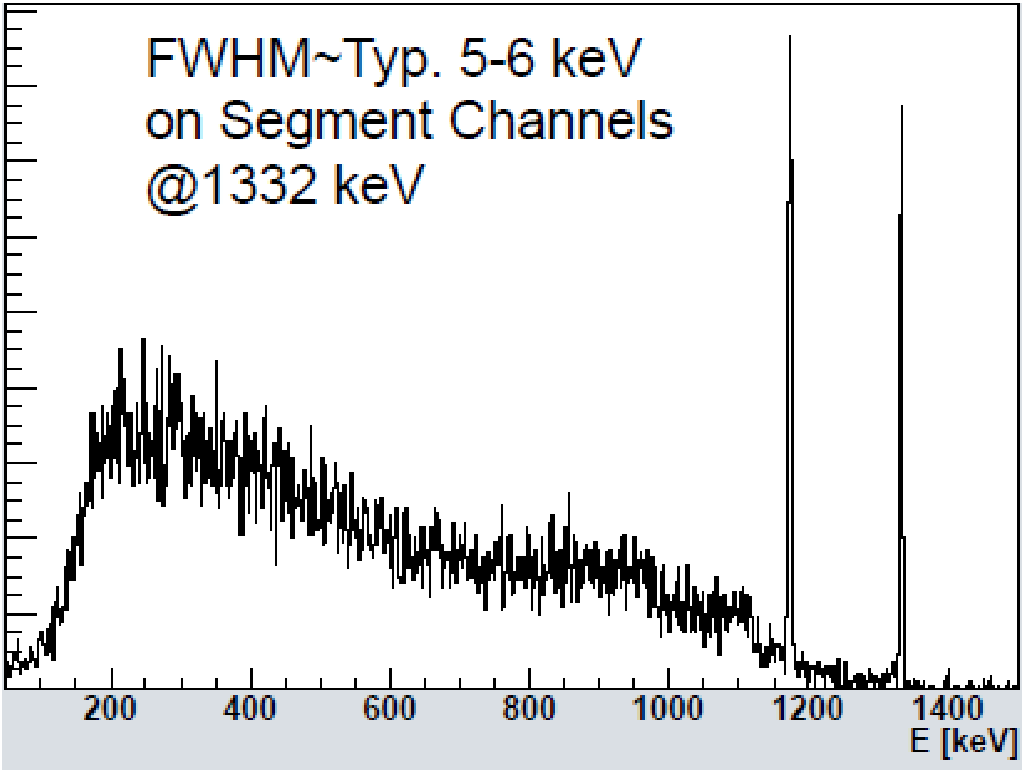
1) Procure TEONEX Q51 (DuPon Teijin)
2) Sputter 150nm NiCr tie coat (GFO)
3) Sputter 2μm Cu (GFO)
4) Electroplate 45μm of Cu and NiAu finishing (Lüberg)
5) Processing into FPC boards (Lüberg) NiCr tie coat problematic!

R&D time: 2008-2010

R&D on lamination



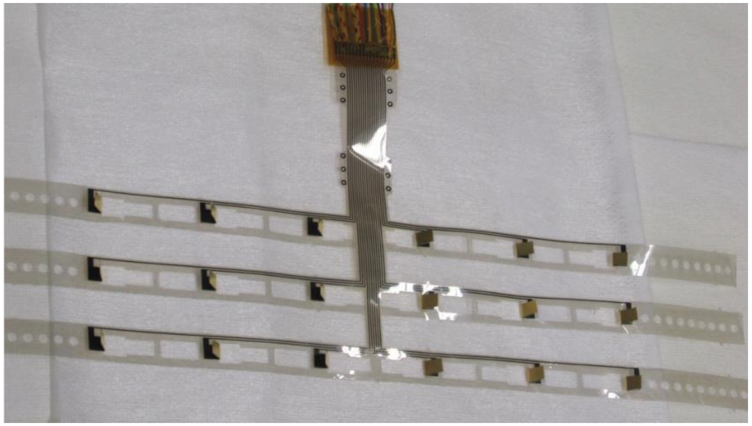
Contacts require bending.
All 18 contacts good!



R&D on lamination

ICPMS analysis performed by S. Nisi et al at LNGS:

		Metal Layer	PEN	Whole sample N2
K	ppb	<10000	$3700\pm_{800}^{+1100}$	3700_{-800}^{+3500}
Pb	ppb	24000±3600	260±40	24000±3600
Th	ppt	2300±350	1000±50	3300±400
U	ppt	1000_{-200}^{+700}	500±50	1500_{-250}^{+750}



→ PEN can be used as very front end cable

Lamination processe have to be controlled

PEN Scintillation properties

A Letters Journal Exploring the Frontiers of Physics

July 2011

EPL, **95** (2011) 22001 www.epljournal.org
doi: 10.1209/0295-5075/95/22001

Evidence of deep-blue photon emission at high efficiency by common plastic

H. Nakamura[1,2(a)], Y. Shirakawa[2], S. Takahashi[1] and H. Shimizu[3]

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[2] *National Institute of Radiological Sciences - 4-9-1, Anagawa, Inage-ku, Chiba 263-8555, Japan*
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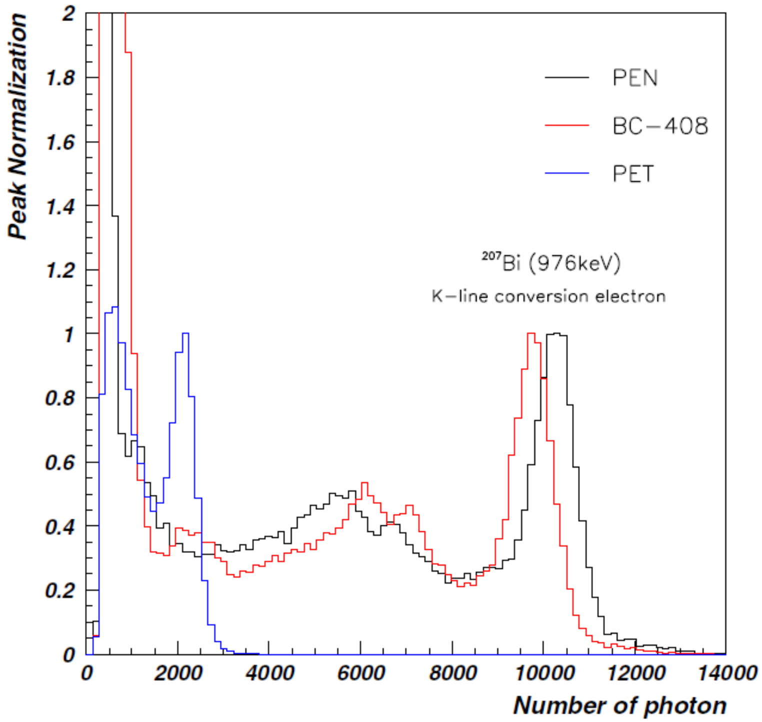
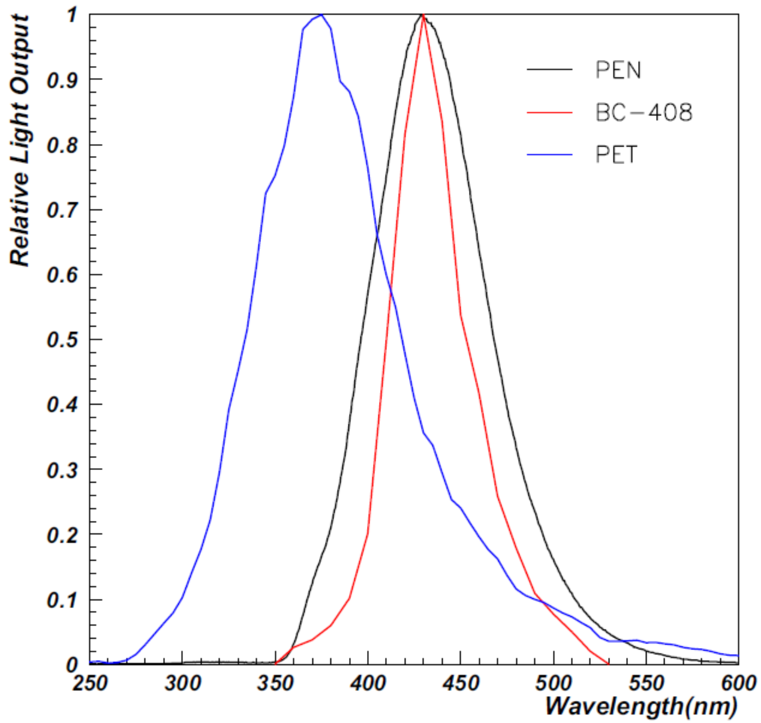
received 18 April 2011; accepted 26 May 2011
published online 29 June 2011

PEN Scintillation properties

Table 1: Properties of the three samples used in the present study.

Material	Polyethylene naphthalate	Organic scintillator (ref. [14])	Plastic bottle (ref. [13])
Supplier	Teijin Chemicals	Saint-Gobain	Teijin Chemicals
Base	$(C_{14}H_{10}O_4)_n$	$(C_9H_{10})_n$	$(C_{10}H_8O_4)_n$
Density	$1.33\,g/cm^3$	$1.03\,g/cm^3$	$1.33\,g/cm^3$
Refractive index	1.65	1.58	1.64
Light output	~10500 photon/MeV	10000 photon/MeV	~2200 photon/MeV
Wavelength max. emission	425 nm	425 nm	380 nm





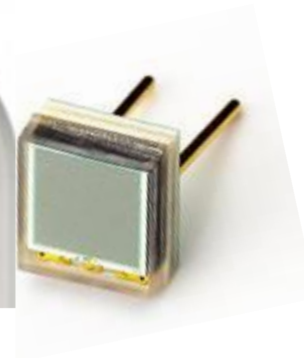
How could PEN help us?

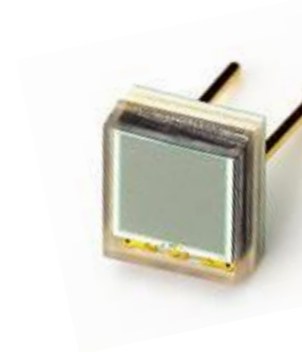
- PEN can be clean
- PEN can be laminated on
- PEN has good mechanical properties
- PEN scintillates

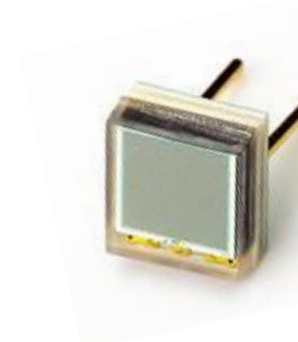
Maybe we can replace most of the structural materials with self vetoing PEN?

This could include:

Detector end cap
Readout and HV cables







CONCLUSIONS:

- PEN has rather good mechanical properties
- PEN can satisfy low background requirements
- PEN is suitable for HV

→ PEN is promising material for flexible cables

- PEN does seem to scintillate very well

→Could PEN be used as self vetoing structural material?

→ **Needs further R & D**