Stability of Tetraphenyl Butadiene thin films in liquid xenon

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Motivation

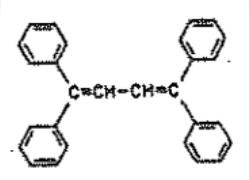
Background:

- Liquid xenon emits at 175 nm
- Can be detected using photomultipliers with quartz window
- Hamamatsu launched a new SiPM model sensitive to LXe light

Still …

- PMTs continue to be a major source of radioactive background
- Long term performance of VUV sensitive SiPMs is not known
- Some manufacturers have better SiPMs in terms of cross talk and dark noise but those are not sensitive to VUV
- If a “safe” wavelength shifter can be found, this would significantly widen the choice of photon sensors

TPB – tetraphenyl butadien



Emission spectrum; excitation with λ =128, 160, 175, and 250 nm

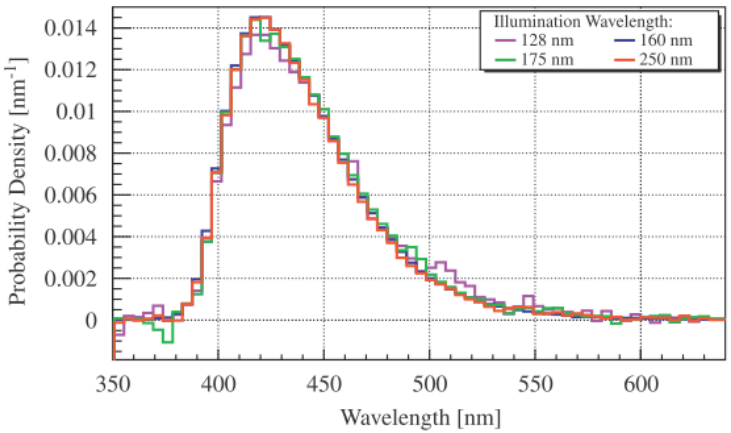


Fig. 7. Visible re-emission spectrum for a TPB film illuminated with 128, 160, 175, and 250 nm light. All spectra are normalized to unit area.

Photon conversion efficiency (1.5 μm film)

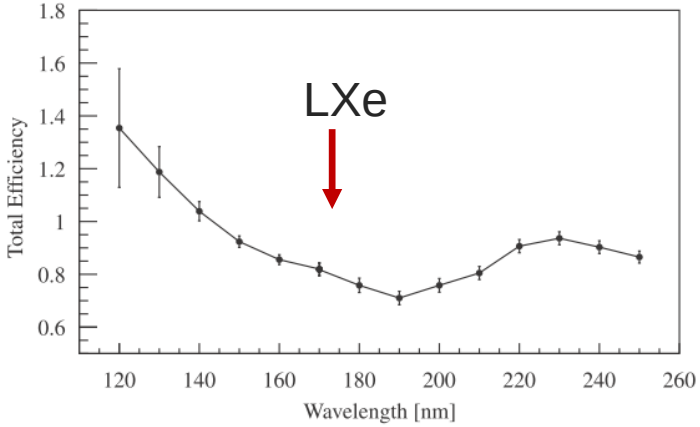


Fig. 9. Total integrated fluorescence efficiency as a function of input EUV photon wavelength, assuming a Lambertian angular distribution of re-emitted light from both sides of the TPB film, similar to sodium salicylate.

From NIMA654(2011)116

- TPB is being used in plastic scintillators since ~1960s.
- TPB is widely employed in large liquid argon detectors nowadays.(no degradation reported)
- Molecular weight 360 g/mol (*cf* 230 for *p*-terphenyl) – should be less soluble in LXe
- Emission maximum 455 nm (*cf*. 335 for *p*-terphenyl) – more comfortable wavelength for semiconductor photon detectors.
- Decay time ~1.7 ns

Method

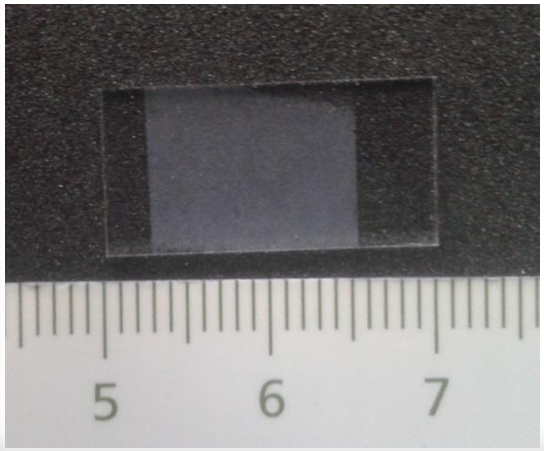
- TPB thin films thermally deposited in vacuum on glass or quartz substrate were immersed into liquid xenon for about 20 hours (some of them up to 40 h).
- The samples measured before and after exposure to LXe and compared with control samples using 3 methods:
- Electron microscopy – to check for possible morphological changes of the film surface;
- X-ray photoelectrom spectroscopy (XPS) – sensitive to chemical changes at the surface;
- UV-visible light transmission measurements – can detect changes in the layer thickness.

Samples

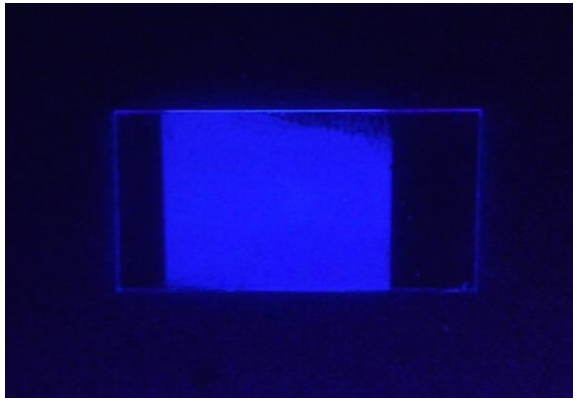
Table 1
Deposited TPB samples and respective characterization method.

Sample	Substrate	Thickness	Method
TPB_{SEM}	Glass	1.9 μm	SEM
TPB_{SEMC} (control)			
TPB_{XPS}			XPS
TPB_{XPSC} (control)			
TPBa	Quartz	62 nm	UV–visible transmission
TPBb			
TPBc			
TPBd (control)			

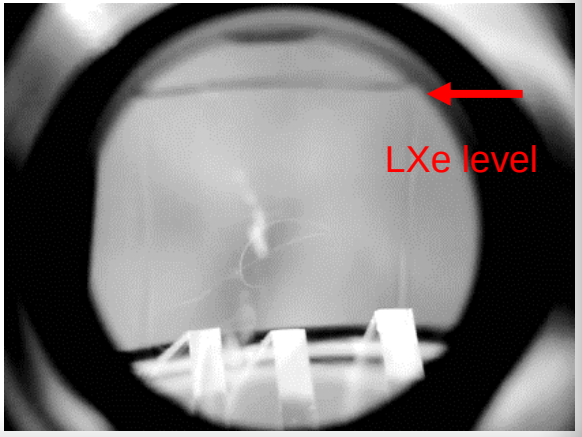
Under visible light



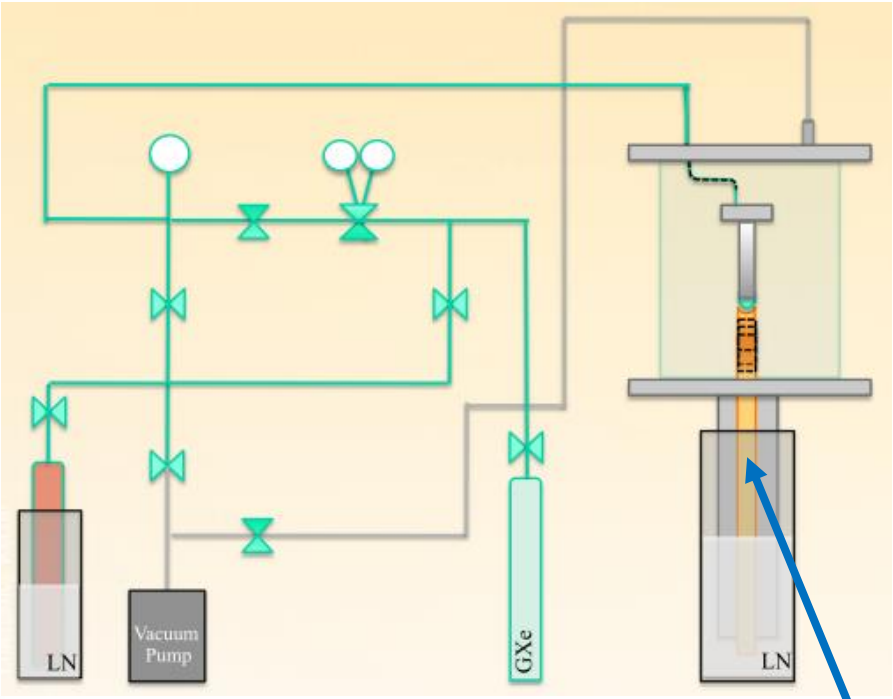
Under UV light

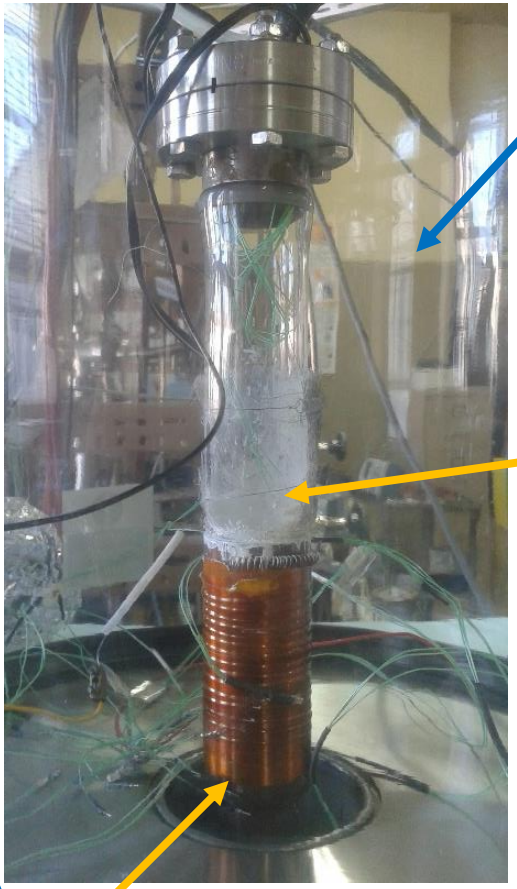


3 samples in LXe



Setup





Vacuum thermal insulation

TPB samples here

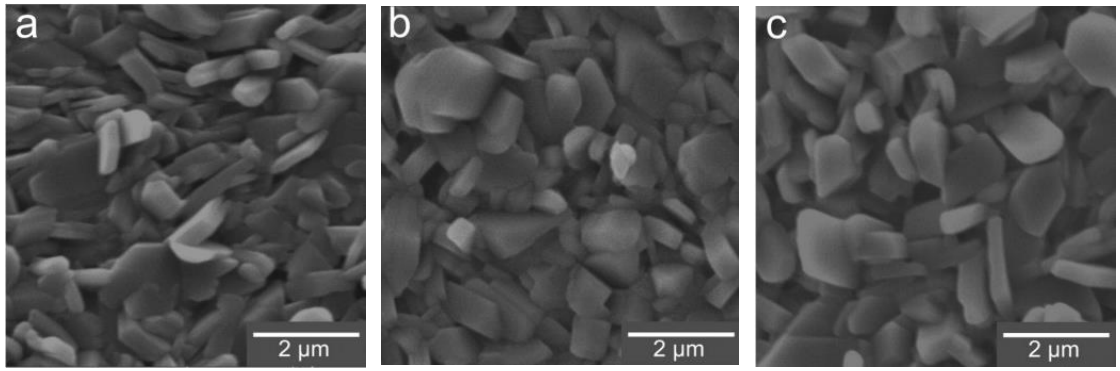
Cold finger with heater

Liquid xenon at
$T = -100ºC\ to\ -95ºC$
$p = 1.6 - 2\ bar$

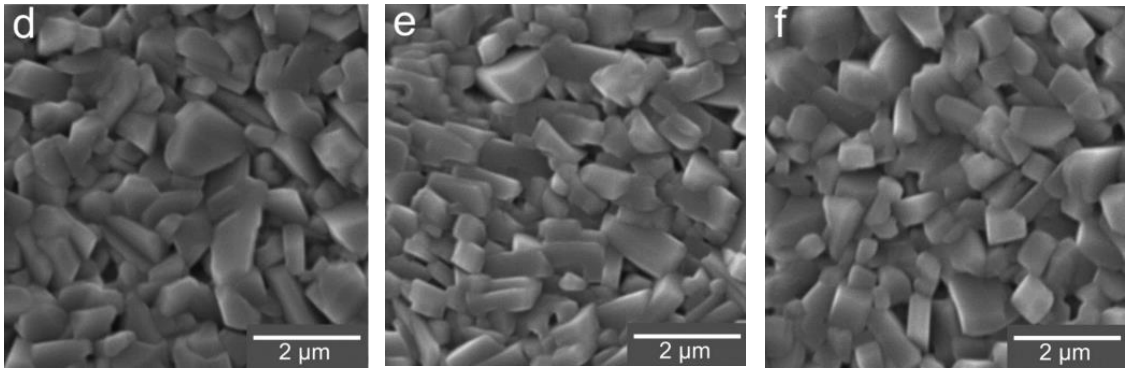
Electron microscope images

Target: possible structural changes

Exposed sample (20h in LXe; measured in 3 different places)



Control sample



Thickness 1.9 μm

Electron microscopy – grain size

Table 2
Average grain size of the LXe exposed and respective control samples.

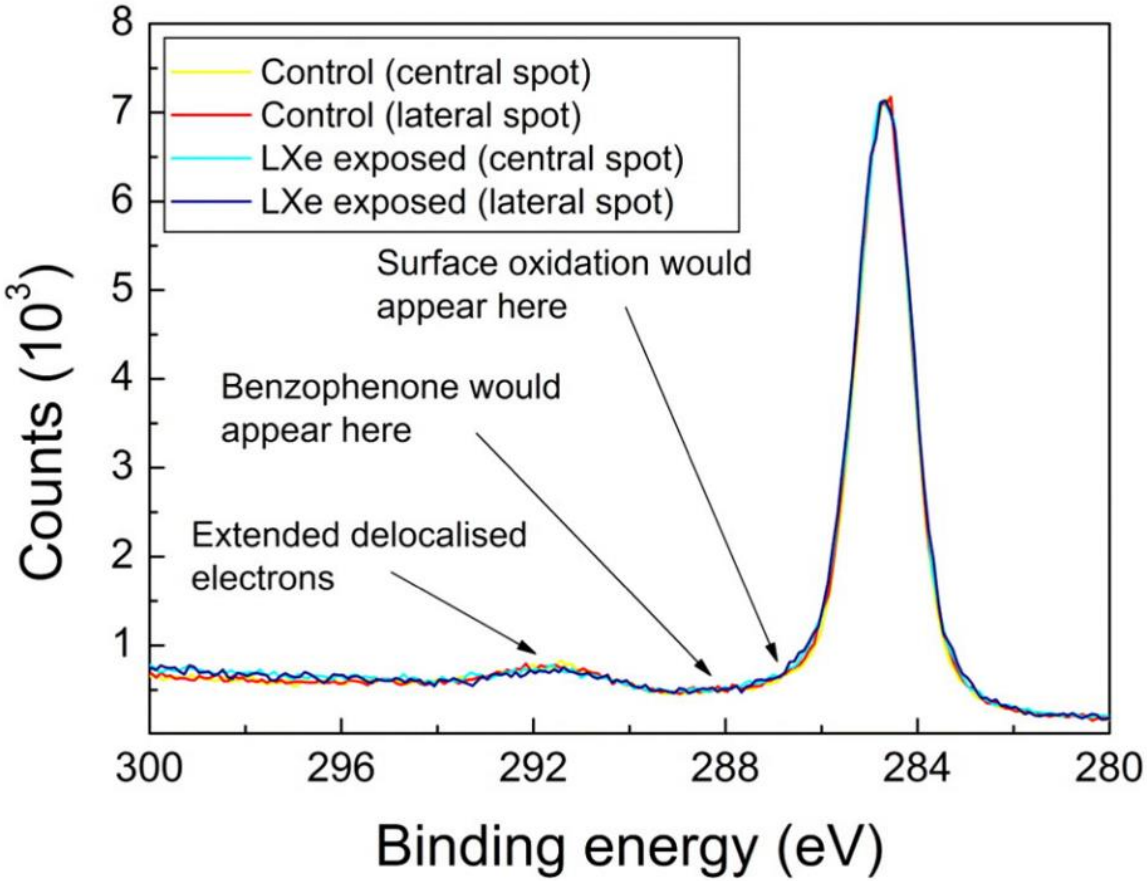
Sample	Position (as in Fig. 2)	Average grain size (μm)	
		Local	All
LXe exposed	a	0.55 ± 0.02	0.60 ± 0.02
	b	0.61 ± 0.02	
	c	0.66 ± 0.03	
Control	d	0.62 ± 0.03	0.60 ± 0.01
	e	0.57 ± 0.02	
	f	0.61 ± 0.02	

Conclusion:

no detectable changes in surface morphology were found

X-ray photoelectron spectroscopy

Target: chemical changes



Benzophenone is a common product of TPB degradation

Conclusion:

no detectable chemical changes observed

UV-visible optical transmission (I)

Target: layer thickness

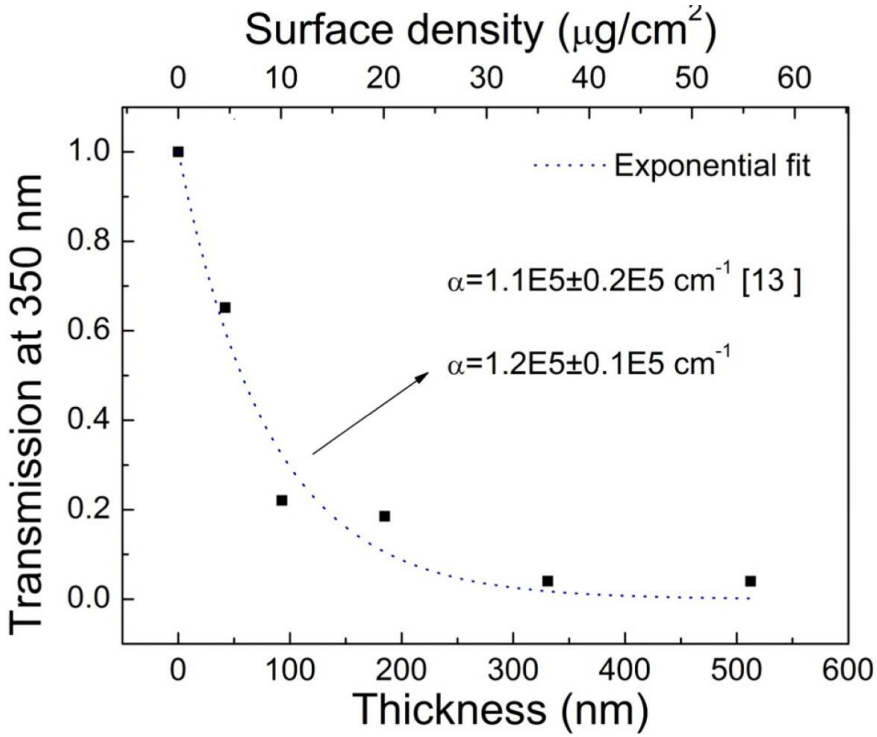


Fig. 4. Measured optical transmission at 350 nm of TPB thin films as a function of thickness. Films with thickness between 25 nm and 100 nm are good candidates for LXe degradation test since a small decrease in their thickness will result in a large increase in the transmission values. The value of the absorption coefficient α obtained from the fit agrees very well with that known from the literature [13].

Preliminary test:

transmission at λ =350 nm as function of TPB layer thickness (not exposed to LXe)

$$I(x) = I_0 e^{-\alpha x}$$

From fit

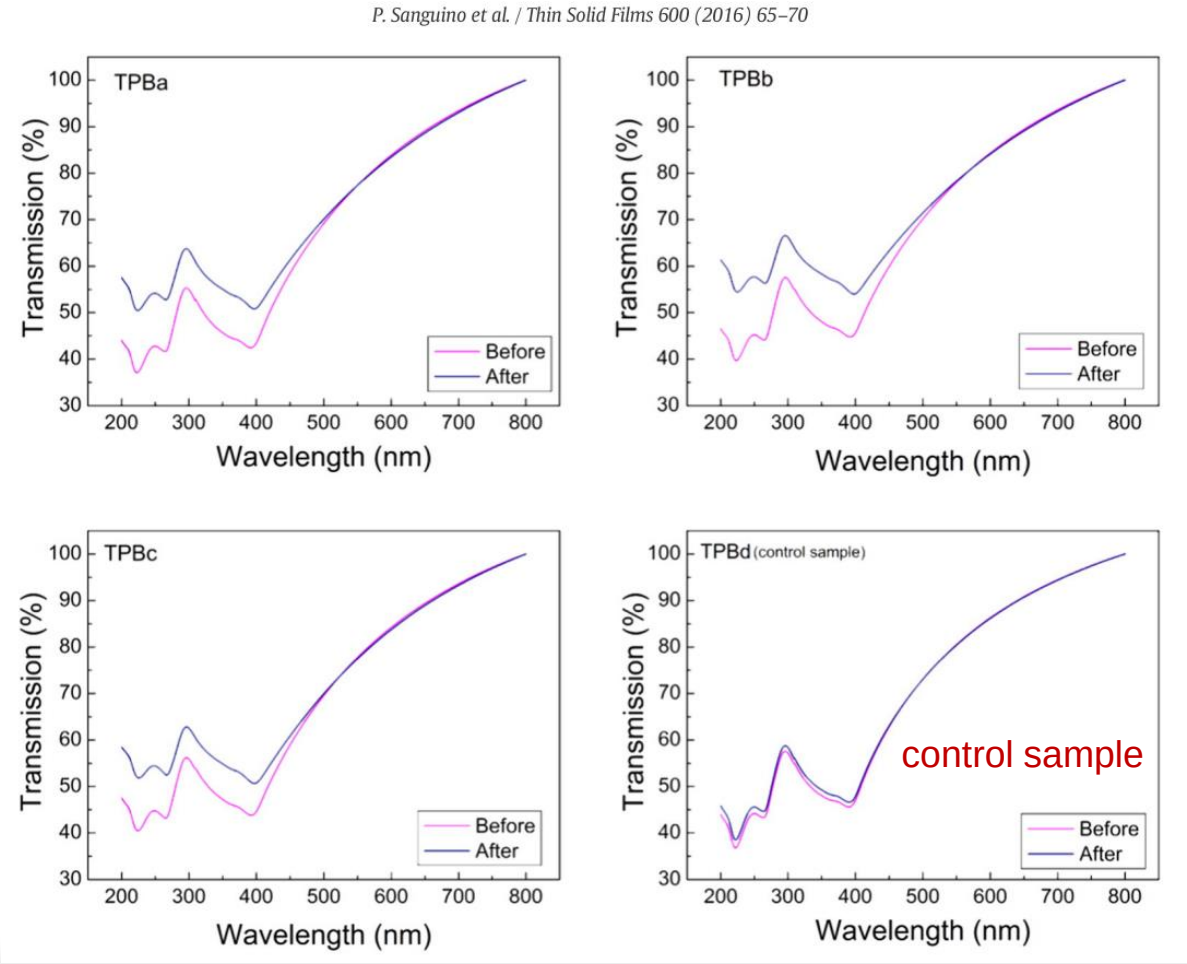
$$\alpha = (1.2 \pm 0.1) \times 10^5 \text{ cm}^{-1}$$

From Berlman

$$\alpha = (1.1 \pm 0.2) \times 10^5 \text{ cm}^{-1}$$

UV-visible optical transmission (II)

Transmission before and after 20h exposure to liquid xenon



UV-visible optical transmission (III)

Transmission variation after 20h exposure

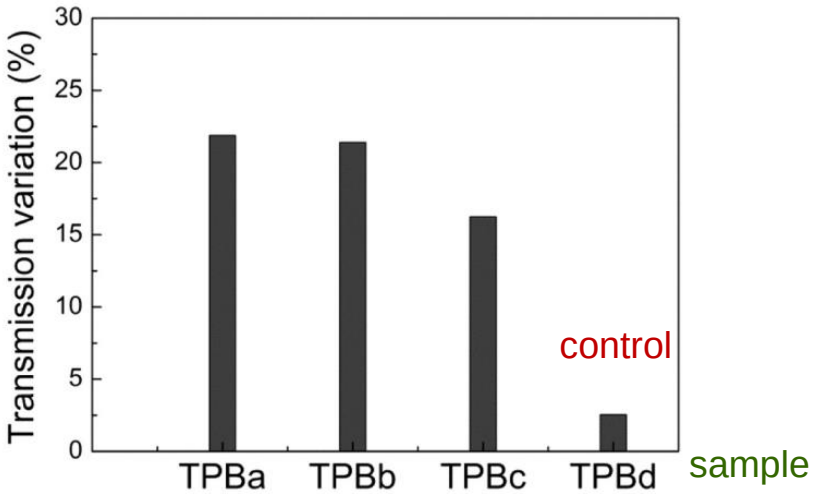


Fig. 6. Variation of optical transmission at the wavelength of 350 nm of TPB samples (TPBa, TPBb, and TPBc) after being immersed in LXe during 20 h. Control sample TPBd was not exposed to LXe.

TPB thickness variation after 20h exposure

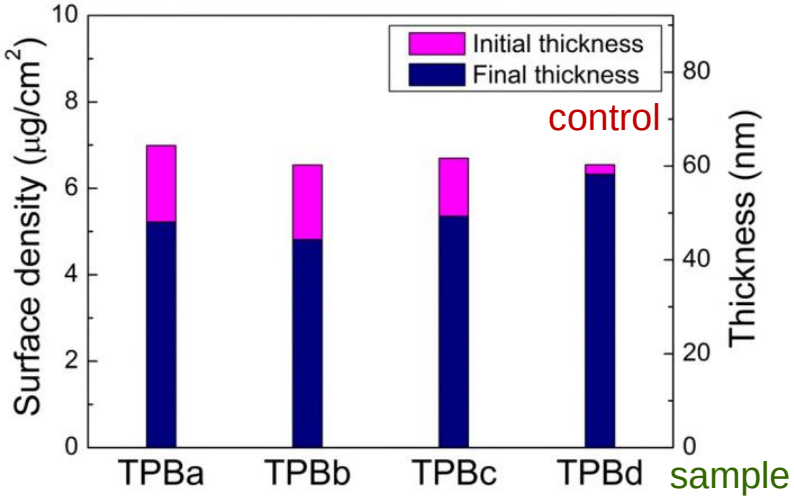


Fig. 7. Initial and final thickness of TPB samples after being submerged in LXe for 20 h. Control sample TPBd was not exposed to LXe.

Conclusion:

There is indeed a loss of material in contact with LXe

Conclusions

1. No morphological changes or chemical degradation of TPB in contact with liquid xenon were found.
2. The increase in UV-visible light transmission indicates layer by layer removal of TPB observable already in the time scale of ~1 day.
3. If TPB has to be used, a protective layer should be deposited on top of it to avoid direct contact with the liquid.
4. Since solubility depends on the molecular weight, wavelength shifters with higher molecular weight can be explored (e.g., metal-organic, semiconductor-organic compounds).