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Measurement of TPB re-emission efficiency for two-phase argon detectors

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Asian Forum for Accelerators and Detectors

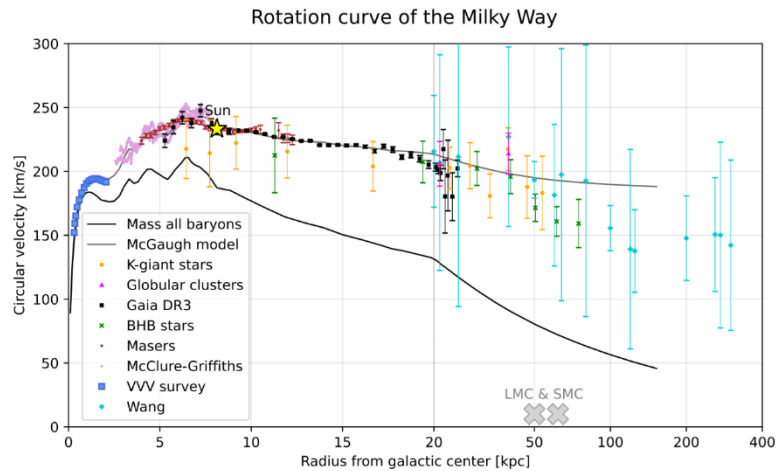
13-17 October 2026 Shanghai, China

*This work is supported in the framework of the State project "Science" by the Ministry of Science and Higher Education of the Russian Federation under the contract 075-15-2024-541.

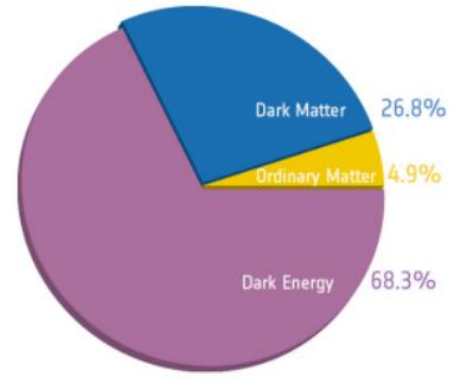
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Current status of the Dark Matter problem

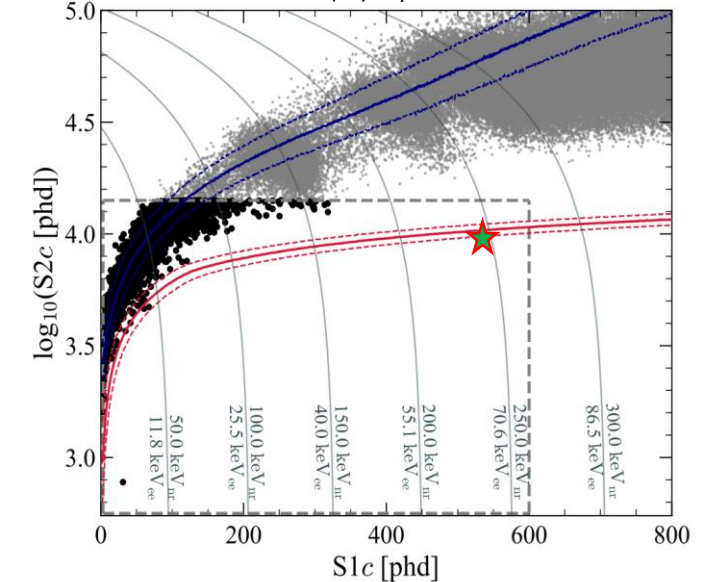


Circular velocity of the Galaxy rotational curve

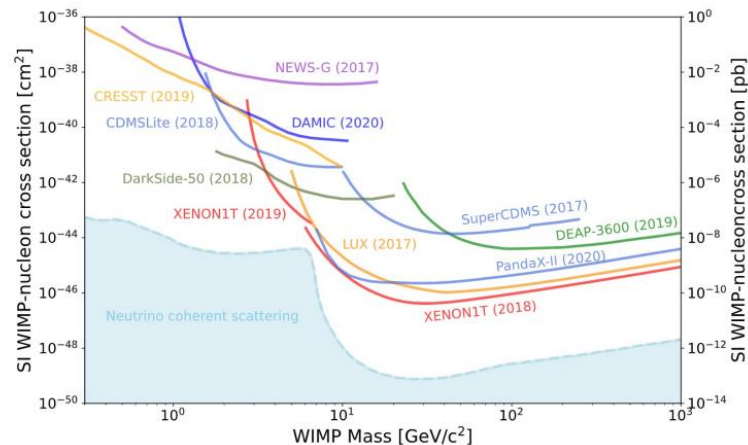


Energy density distribution in the Universe

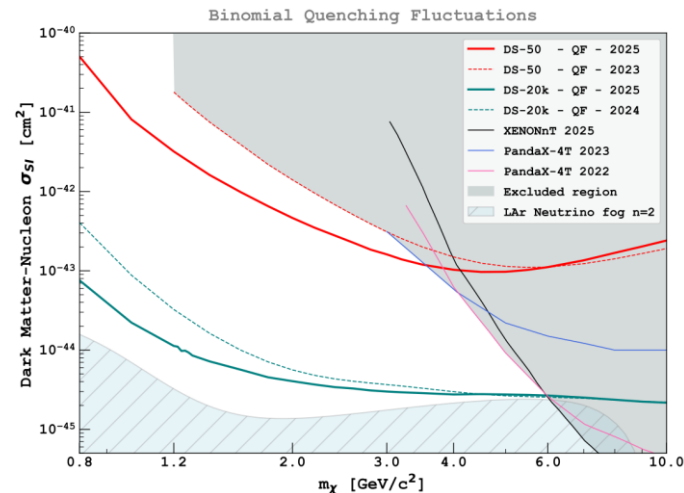
D.S. Akerib et al. Search for dark matter particle interactions in an extended nuclear recoil energy window with the LUX-ZEPLIN (LZ) experiment



S2/S1 event separation. The red and blue lines represent the Nuclear Recoil and Electron Recoil bands.



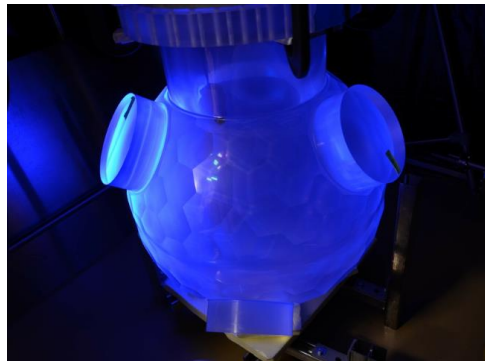
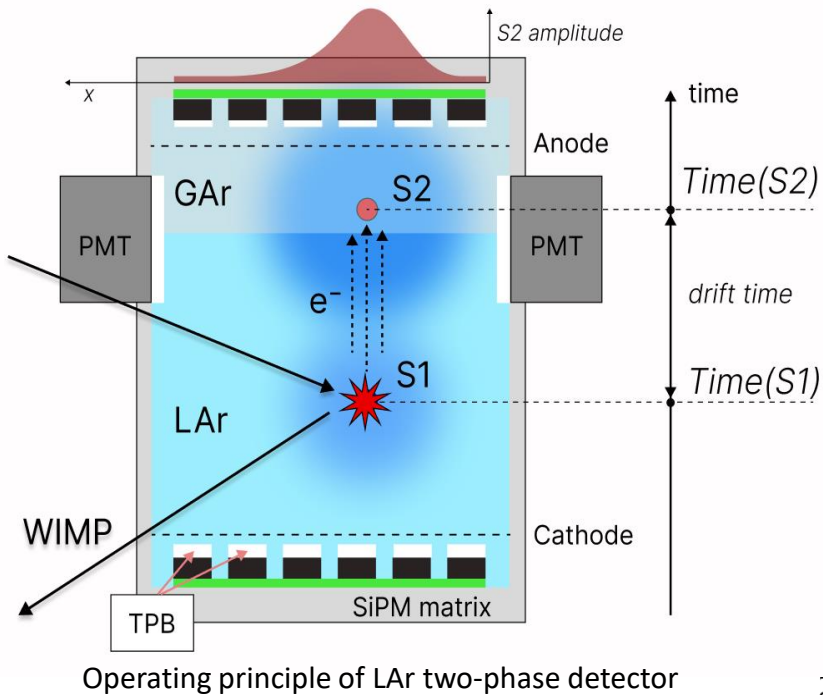
Constraint on WIMP cross-section (spin-independent) and mass



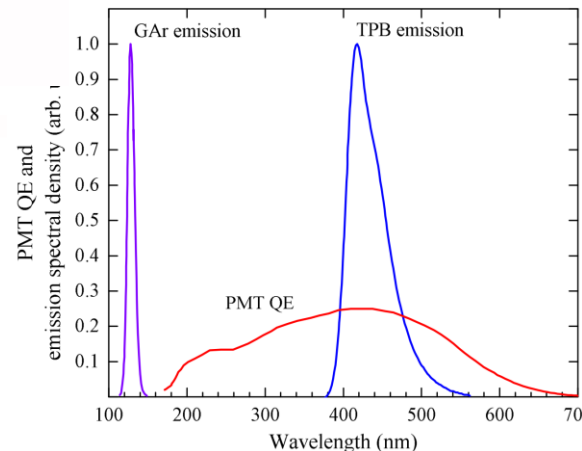
<https://doi.org/10.1088/1748-0221/21/03/C03016>

Astrophysical and cosmological observations have provided compelling evidence for the existence of dark matter (DM) that would constitute most of the matter content of the Universe. Weakly Interacting Massive Particles (WIMPs) are among the best motivated candidates for dark matter, arising naturally in many theories beyond the Standard Model

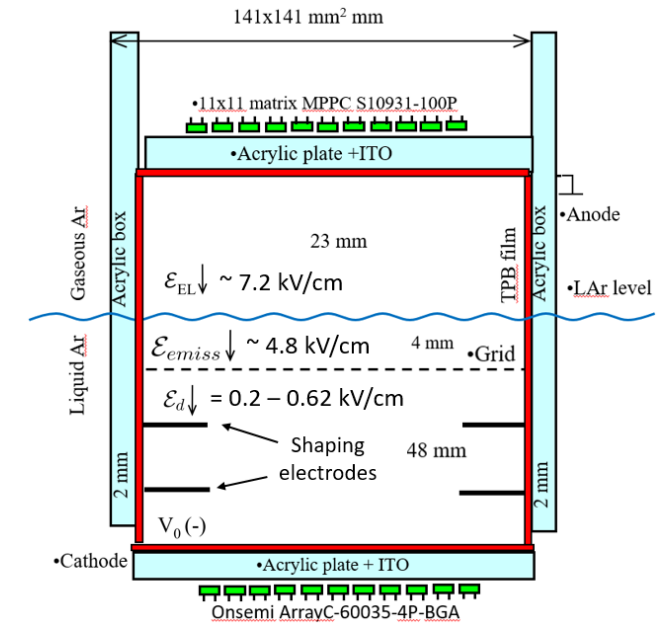
Two-Phase detector, mechanism of scintillations



B. Broerman. et al. Application of the TPB Wavelength Shifter to the DEAP-3600 Spherical Acrylic Vessel Inner Surface



Quantum efficiency spectrum (QE) of PMT at room temperature, emission spectrum of argon and re-emission spectrum of the TPB film at room temperature for an incident light wavelength of 128 nm.

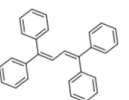


Configuration of two-phase LAr detector prototype at the BINP (Novosibirsk)

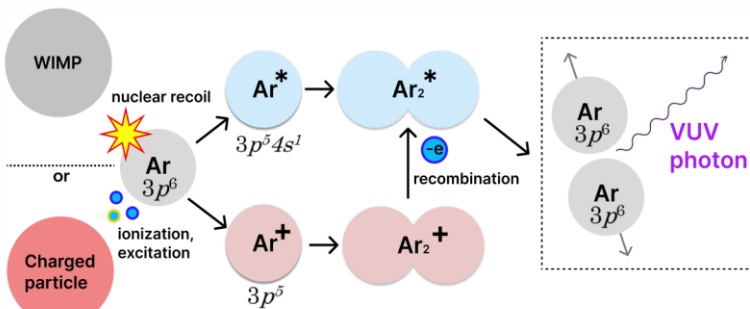
Two-phase detectors provide both an ionization signal (S2) and primary scintillation light (S1) from nuclear recoil. The scintillation light yield of liquid argon (LAr) occurs predominantly in VUV range.

The traditional method for detecting VUV light remains the use of a wavelength shifter. The most suitable for a LAr detector is the organic compound 1,1,4,4-tetraphenyl 1,3-butadiene (TPB).

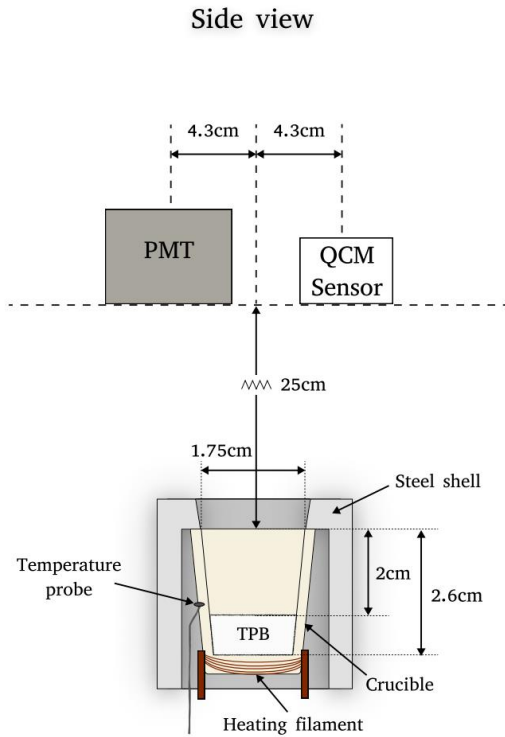
Tetraphenyl Butadiene



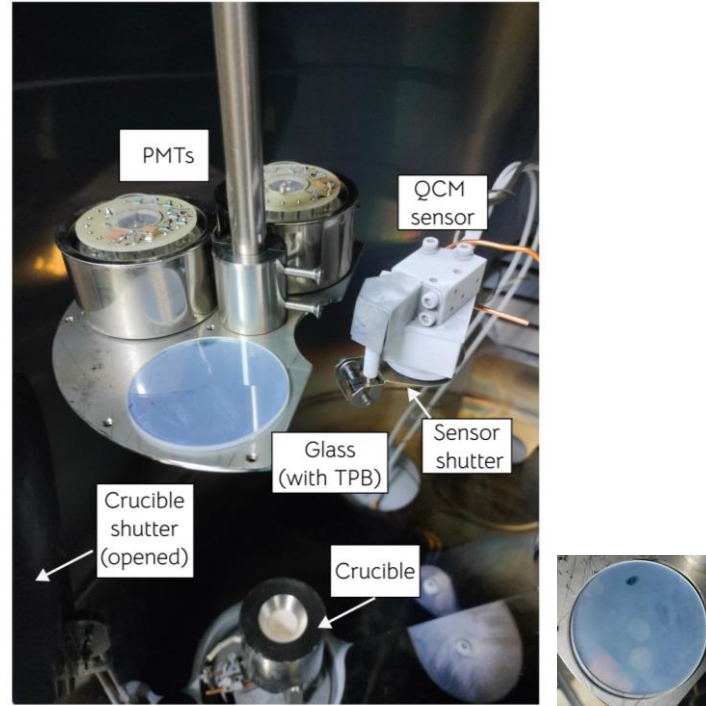
The process of excimer state formation in LAr followed by emission in VUV range (128 nm)



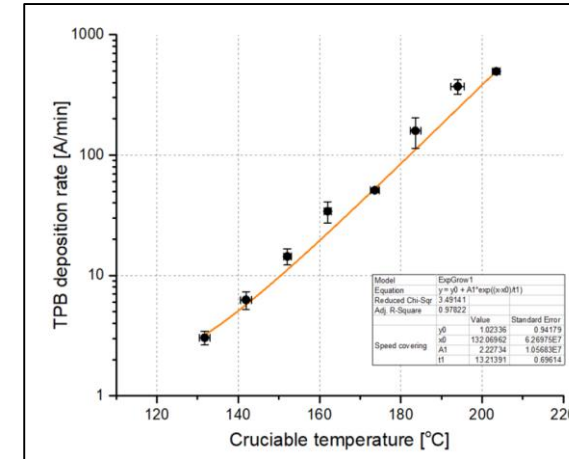
Vacuum deposition of TPB films



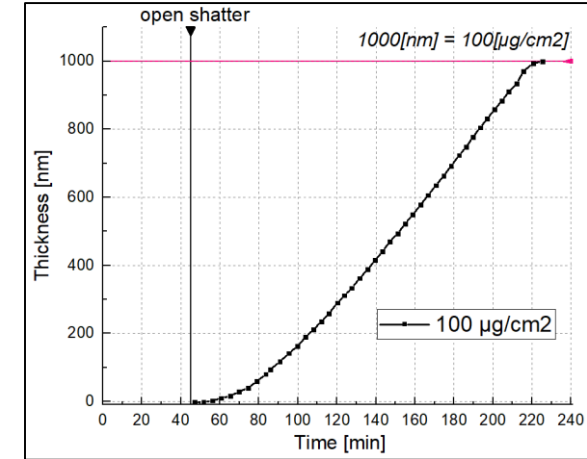
Schematic representation of the TPB vacuum deposition process



Vacuum chamber for TPB deposition

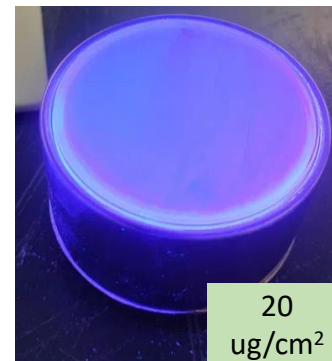
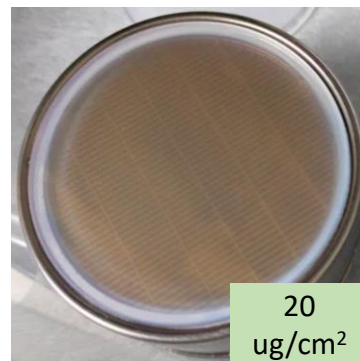
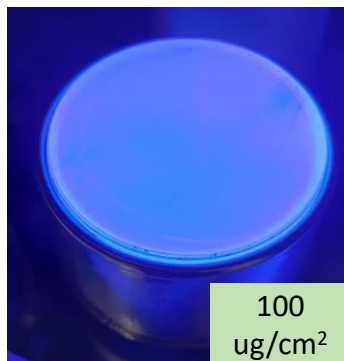
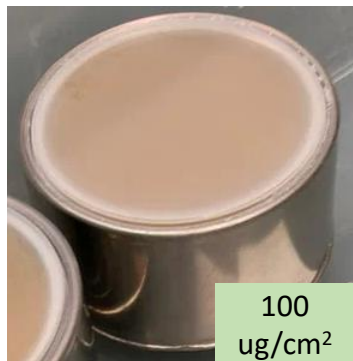


The deposition rate of the TPB film depends on the crucible temperature



Dependence of coating thickness on time from the start of crucible heating

PMTs entrance glass with a deposited TPB layer

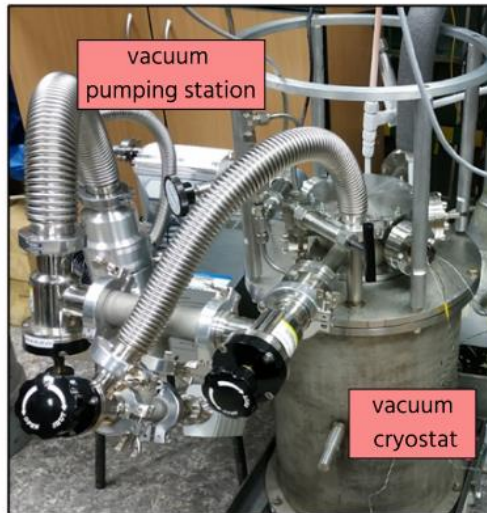
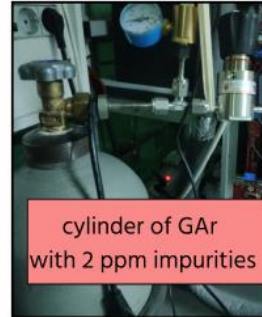


There are various methods for applying TPB to a surface. The highest TPB re-emission efficiency can be achieved using vacuum deposition. This method involves heating TPB powder to sublimation temperature followed by evaporation of TPB onto a surface. However, such a coating is subject to the effects of aging; a loss of re-emission efficiency

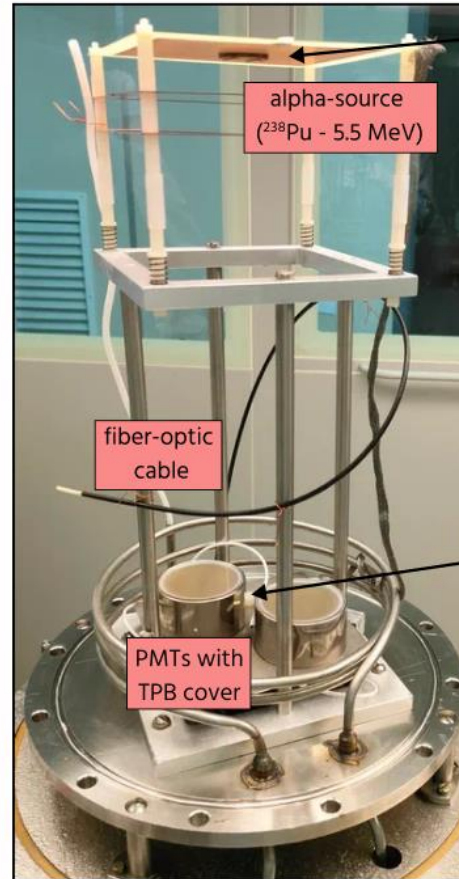
Experimental setup



External shell of the volume



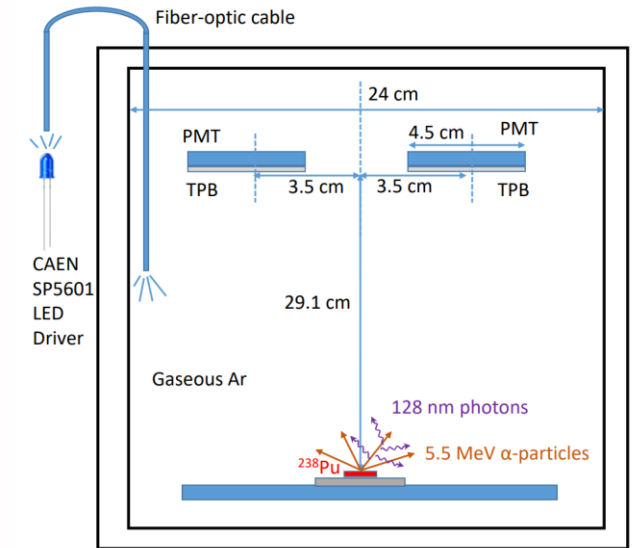
Experimental setup for measuring the re-emission efficiency of TPB films.



Alpha-source



PMTs

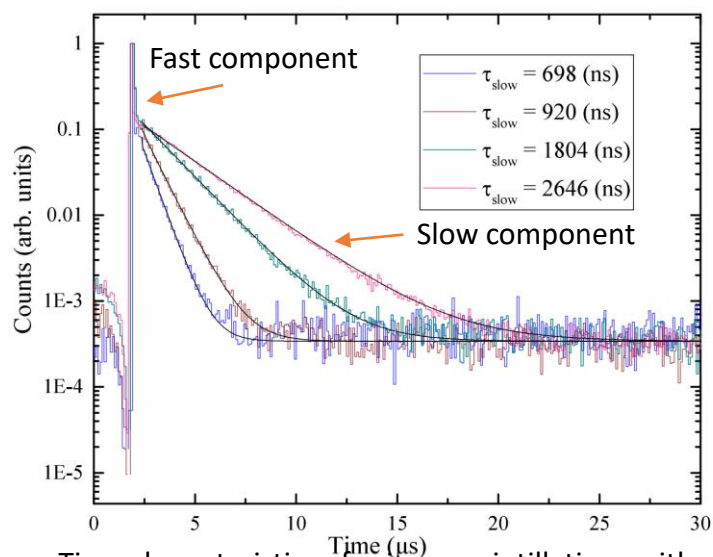


Schematic view of the internal chamber after installation of two PMTs

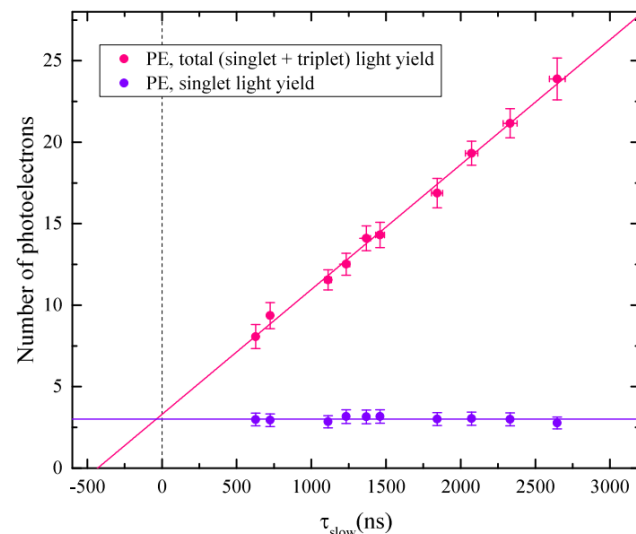
Gaseous argon (GAR) was released into the evacuated inner volume of the cryostat, and primary scintillations induced by irradiated alpha particles were recorded.

The incident light was absorbed by TPB coatings on the PMT surface. Re-emitted light were detected by both photomultiplier tubes. Subsequently, the signal passed through the amplification chain.

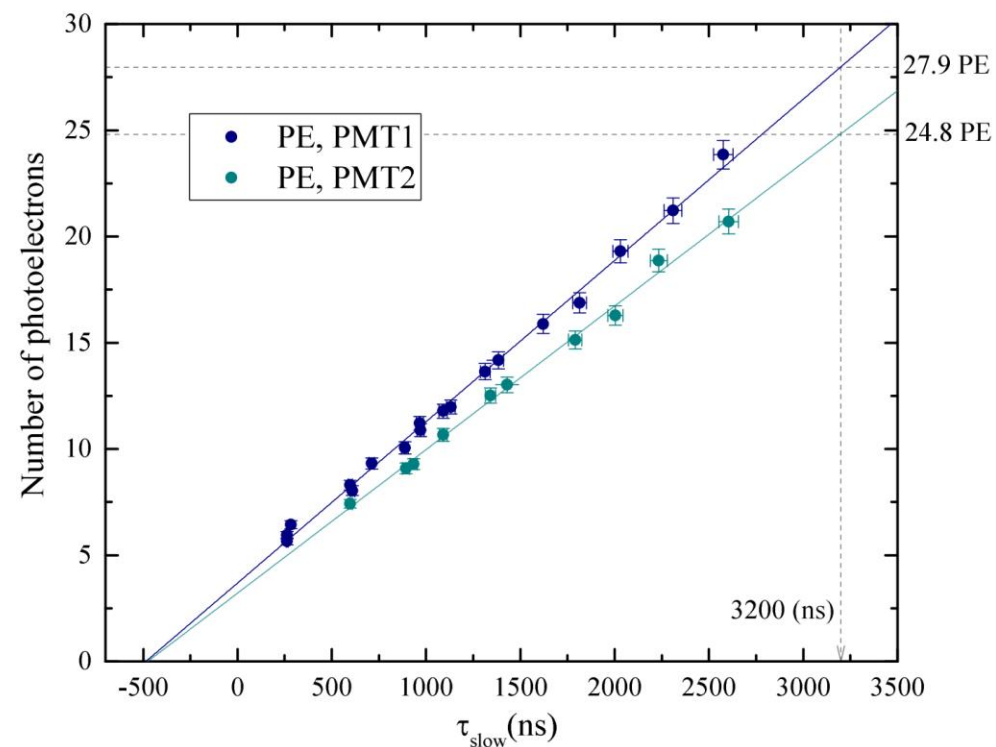
Light yield of primary gaseous argon scintillations



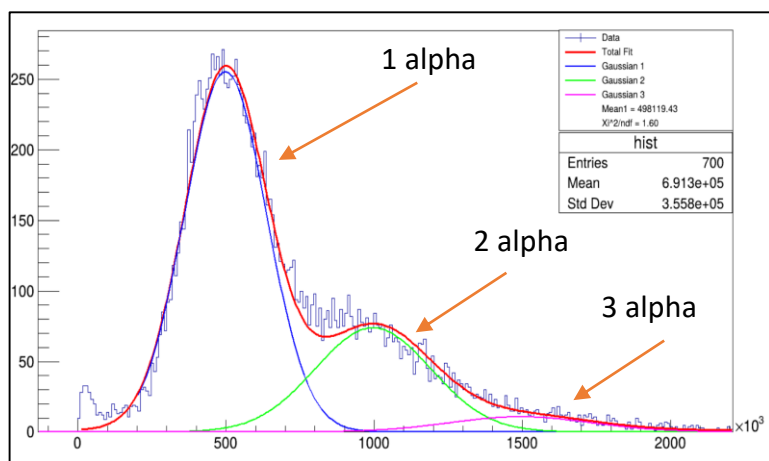
Time characteristics of primary scintillations with different contributions of the slow component



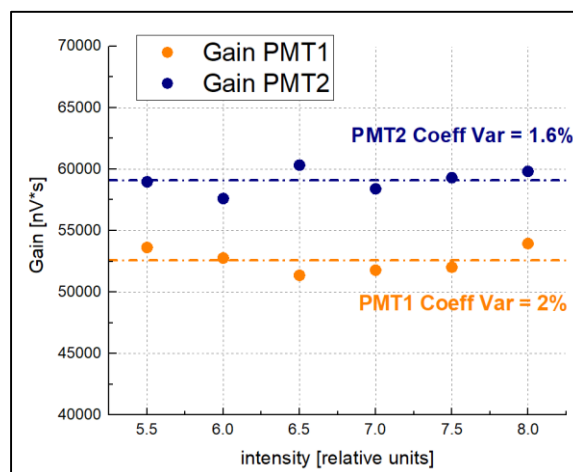
Total light output of scintillations (red dots) and light output of the fast component (purple).



Light yield of primary scintillations depending on the time characteristic of the slow component



Event selection based on a signal from a single alpha particle within the event



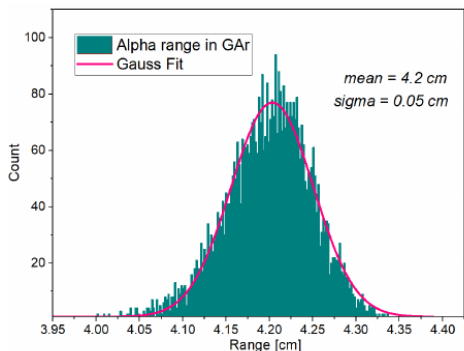
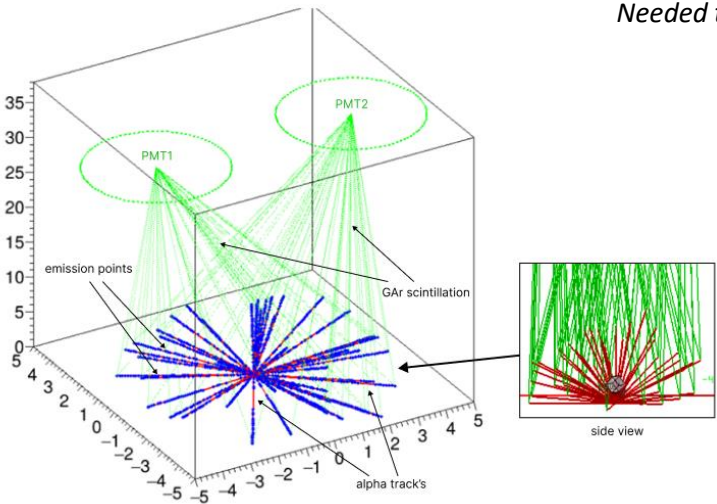
Calibration gain for two PMTs at different calibration light intensities

There are two contributions to GAr light yield, fast and slow, the latter depends significantly on the level of contaminants in GAr as well as radiation slow time constant. The total light yield of GAr expressed as the number of photoelectrons was plotted as a function of radiation slow time constant for two PMT.

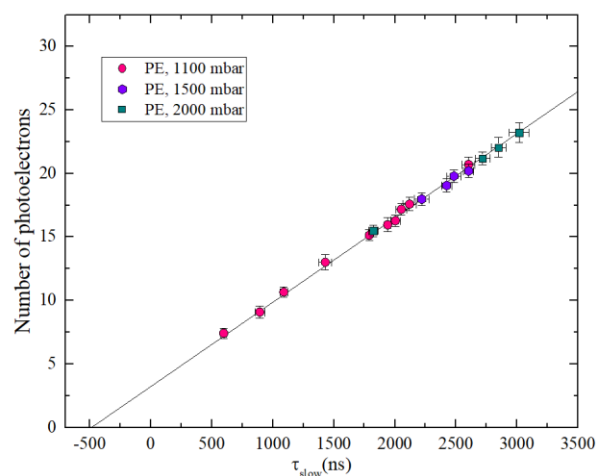
Re-emission efficiency measurement of TPB films

$$N_{PE} = Y_{GAr} \cdot E \cdot q \cdot CE_{VUV} \cdot \varepsilon_{TPB} \cdot CE_{vis} \cdot < QE >$$

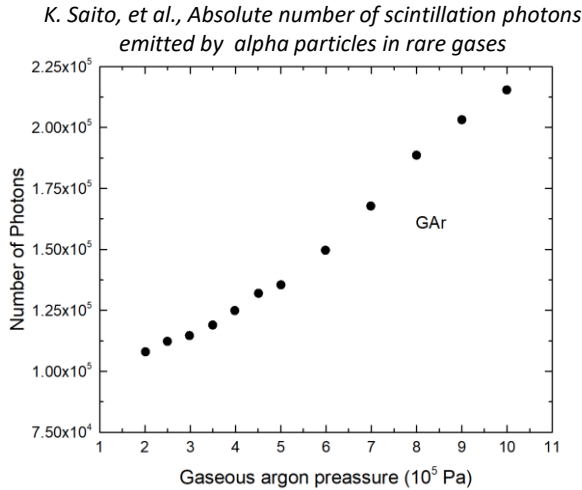
Needed to be expressed



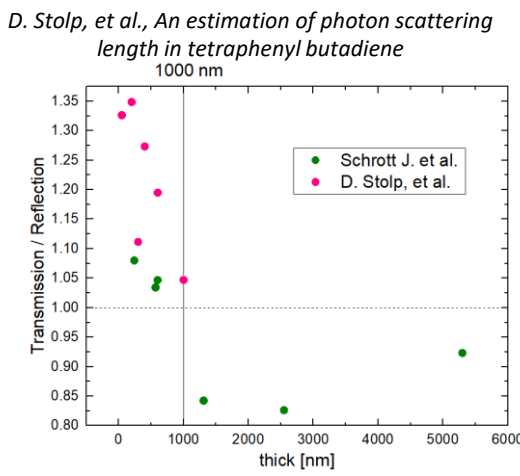
and range spread of alpha particles in argon at 1100 mbar



Number of photoelectrons at various gas pressures: 1100, 1500, and 2000 mbar.



The number of scintillation photons in GAr due to 5.49-MeV alpha particles depending on gas pressure



Transmission/reflection value for the shifted light depends on the thickness of the TPB

	Value	Uncertainty
N_{PE} (for one PMT)	26.3 PE	3%
Y_{GAr}	19050 photon/MeV	5%
E	5.462 MeV	0.6%
CE_{VUV} (for one PMT)	0.001738	5%
CE_{vis}	0.5	10%
$< QE >$	0.24	6%
q	1	$\leq 1.5\%$
ε_{TPB}	1.21	13%

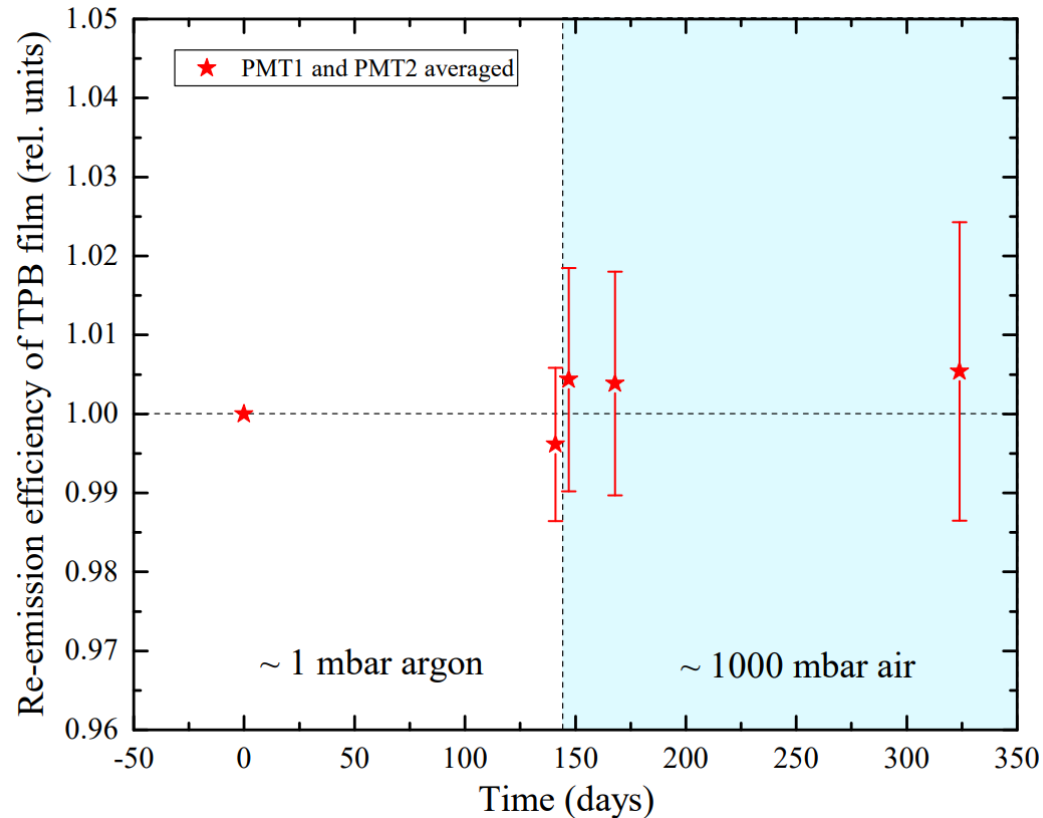
A table of parameters with uncertainty used in calculating the re-emission efficiency of TPB films

There are two contributions to GAr light yield, fast and slow, the latter depends significantly on the level of contaminants in GAr as well as emission slow time constant.

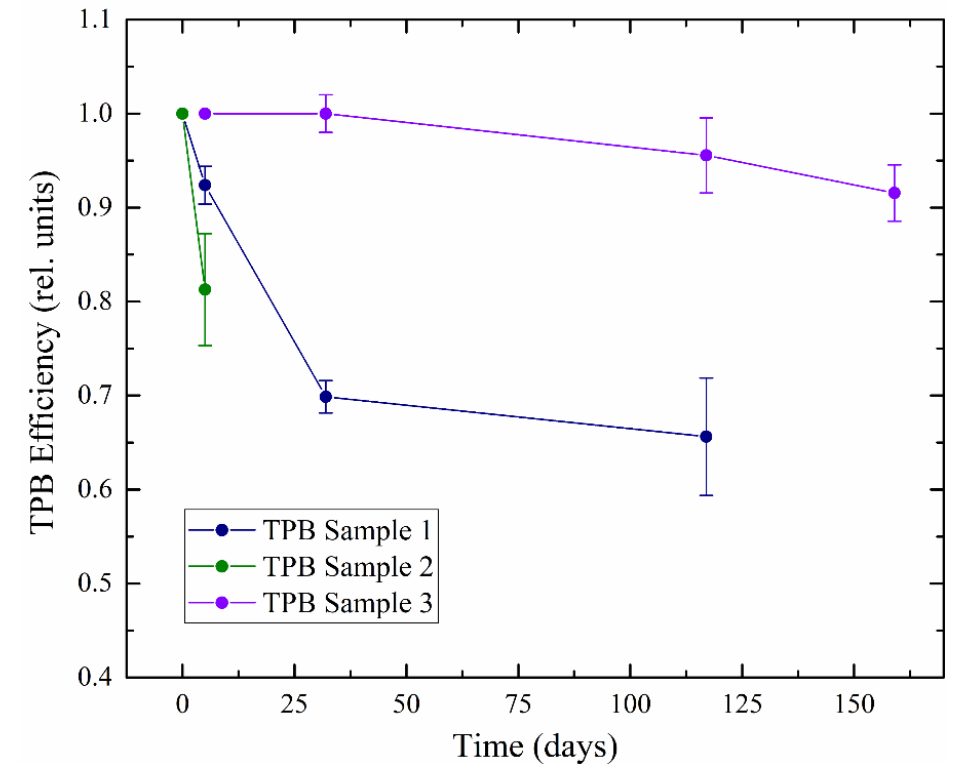
The total light yield of GAr expressed as the number of photoelectrons was plotted as a function of emission slow time constant for two PMTs.

Aging effect of TPB films

Over five months of observations under GAr condition, for a coating thickness of $100\text{ }\mu\text{g}/\text{cm}^2$, the number of photoelectrons followed the expected linear relationship for both TPB samples. In addition, over approximately six month under atmospheric gas conditions, the TPB efficiency remained stable.



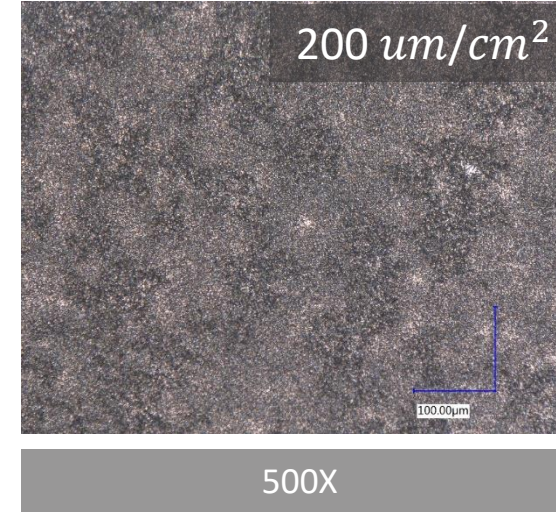
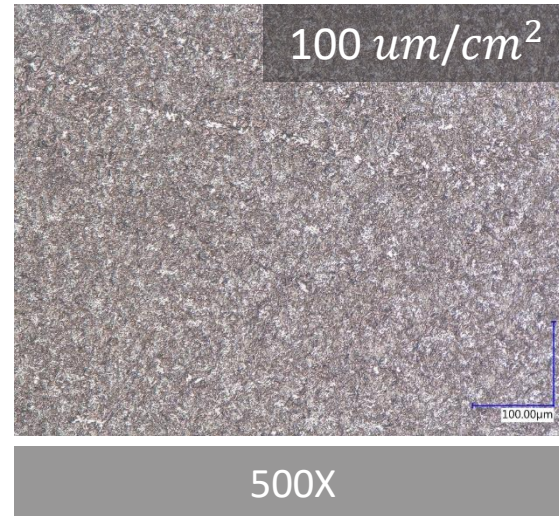
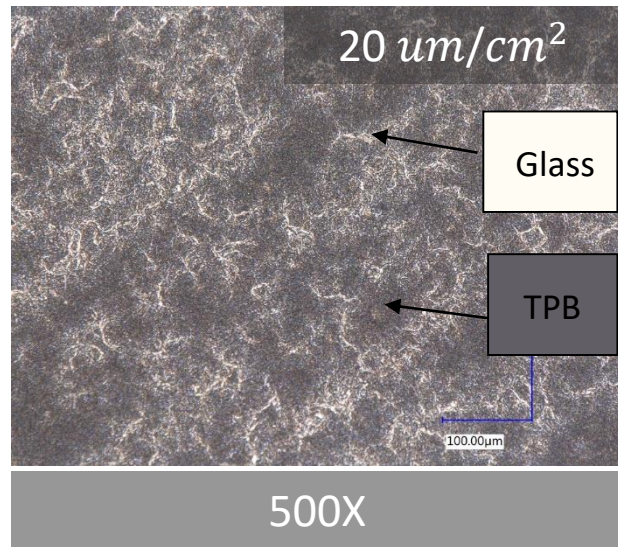
Re-emission efficiency of TPB film (in relative units) with a thickness of $100\text{ }\mu\text{g}/\text{cm}^2$ as a function of exposure time in argon or air.



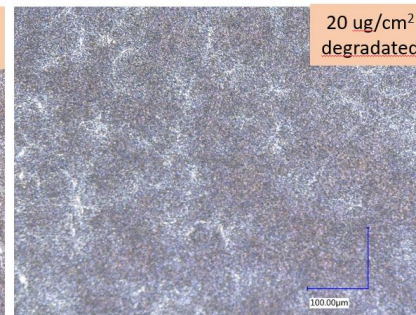
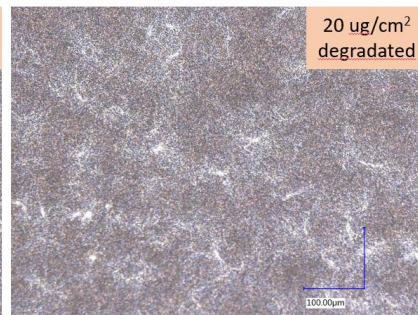
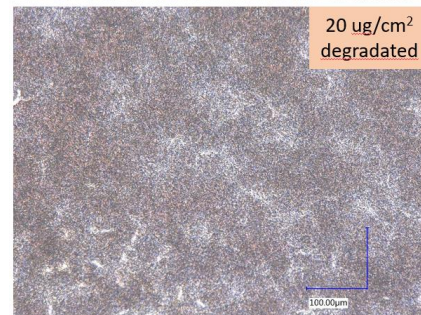
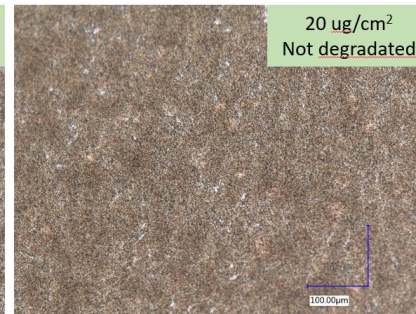
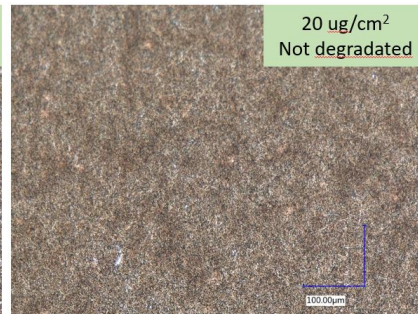
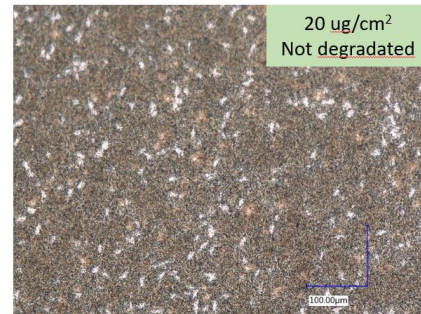
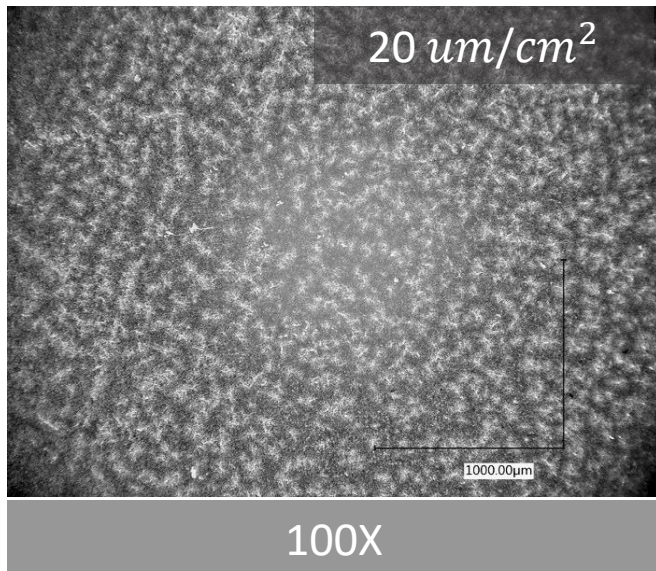
Re-emission efficiency of TPB (in relative units) with a thickness of $20\text{ }\mu\text{g}/\text{cm}^2$ as a function of exposure time in gaseous argon for three film samples.

During the monitoring of the $20\text{ }\mu\text{g}/\text{cm}^2$ deposition process, a decrease in the number of photoelectrons was recorded, which indirectly indicates a reduction in the TPB re-emission efficiency.

TPB films structure (optical microscope)



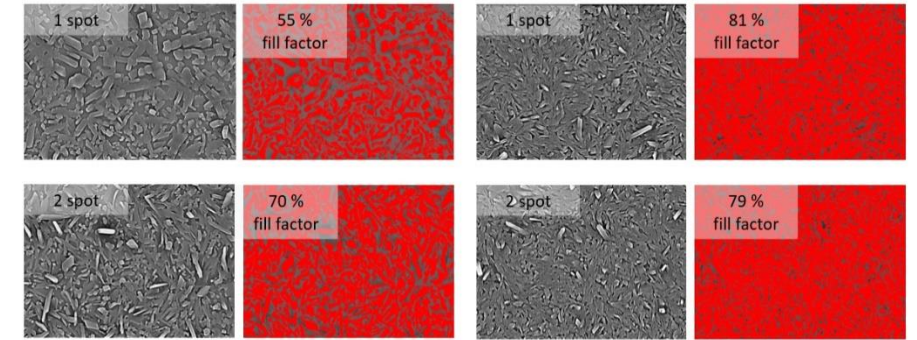
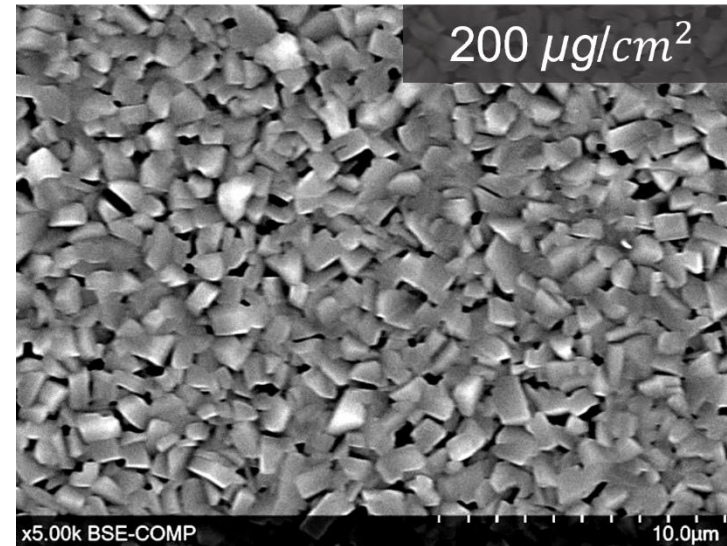
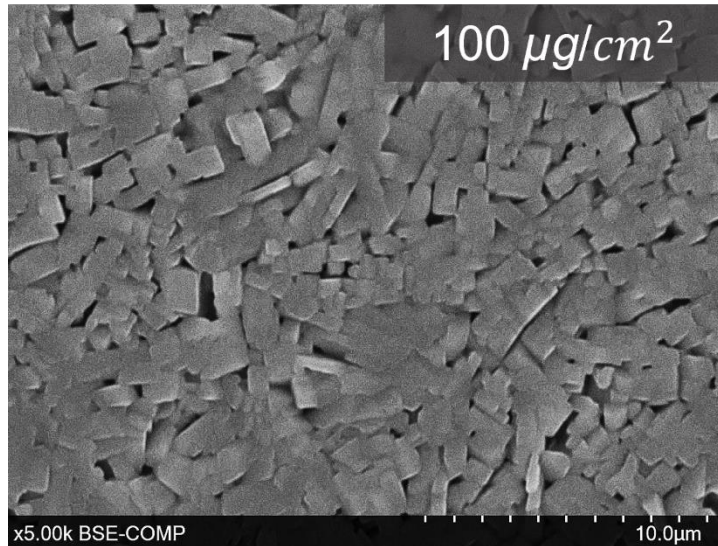
Keyence VHS-6000 optical microscope



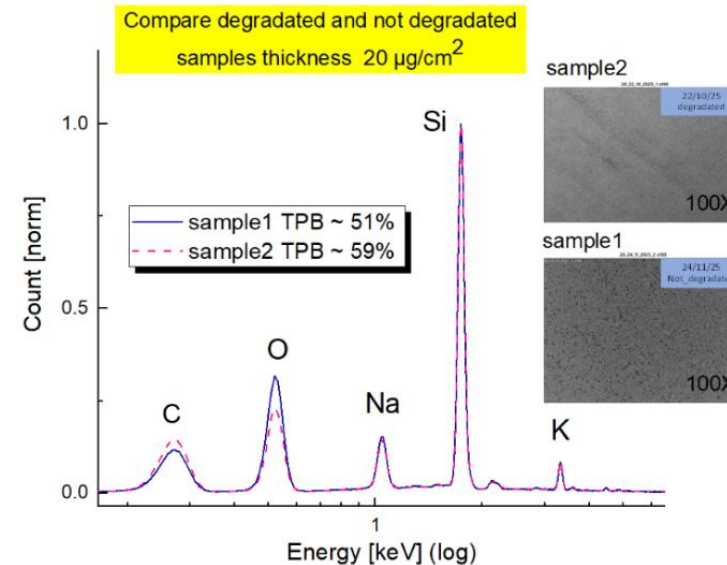
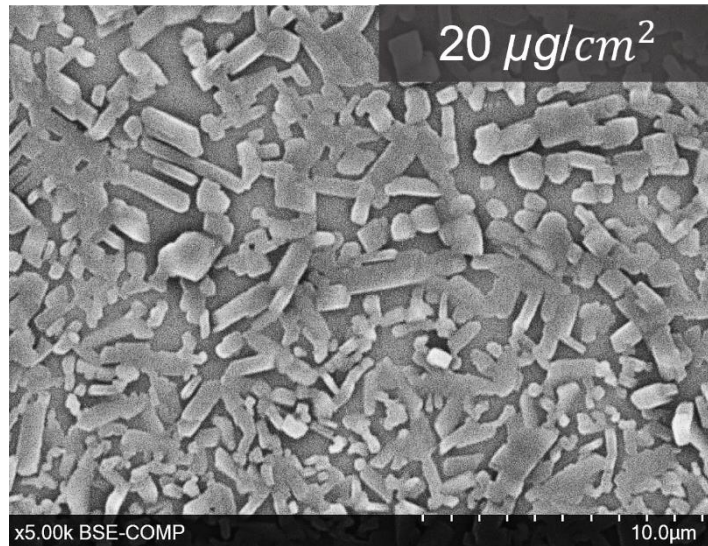
Analysis of the images reveals defects on the deposited surface at a thickness of 20 $\mu\text{g}/\text{cm}^2$ (cracks appear as light lines). For 100 $\mu\text{g}/\text{cm}^2$ and 200 $\mu\text{g}/\text{cm}^2$ defects didn't been revealed.

Surface defects (cracks) on 20 $\mu\text{g}/\text{cm}^2$ are visible on the aged samples, having formed either during the spraying process or during service. No such defects were found on the non-aged samples.

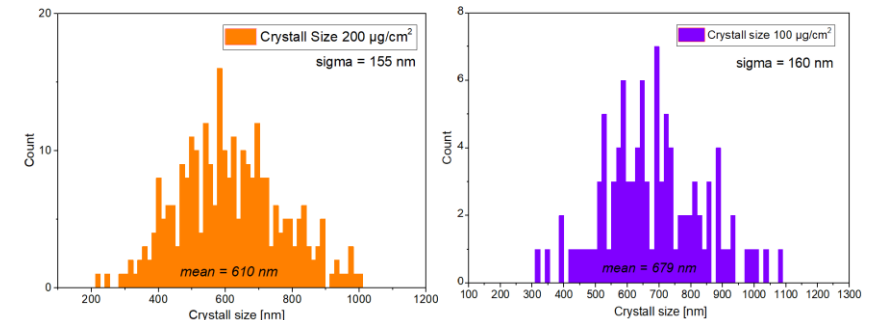
TPB films structure (electron microscope)



Comparison of aged film and non-aged with fill factor on different spot



Comparison of XRF energy spectra for aged and non-aged TPB samples.



Histograms of crystal size for sputtering thickness 100 $\mu\text{g}/\text{cm}^2$, 200 $\mu\text{g}/\text{cm}^2$

Different crystalline structures and varying degrees of glass substrate coverage are observed for films of different thicknesses. Based on XRF analysis results, the TPB concentration in the aged sample is 8–10% lower than in the non-degraded sample. In addition comparison fill factor received from electron microscopy images report a lower surface density of aged TPB covering

Conclusions

- The re-emission efficiency of the TPB was calculated to be 1.21 re-emitted photons per absorbed VUV photon.
- The coating with a thickness of $100\text{ }\mu\text{g/cm}^2$ showed no signs of aging after exposure to air for six months.
- Indirect evidence was experimentally obtained indicating instability in the re-emission efficiency of $20\text{ }\mu\text{g/cm}^2$ TPB films across three samples; the maximum efficiency loss was 35% (from 121% to 86%).
- Images of TPB films were obtained using optical and electron microscopy. The surface crystal structure was investigated, and X-ray analysis was performed. Degraded and non-degraded samples with a coating density of $20\text{ }\mu\text{g/cm}^2$ were compared.

Reference	Re-emission efficiency of a TPB film at $100\text{ }\mu\text{g/cm}^2$	Intrinsic quantum efficiency of TPB	TPB aging factor
This work	1.21 ± 0.16	-	1
Lally et al. [21]	0.81 ± 0.07	-	0.78
Graybill et al. [19]	1.81 ± 0.22	~ 2	0.35
Benson et al. [23]	0.40 ± 0.03	$0.60 \pm 7\%$	1
Gehman et al. [17]	1.09 ± 0.11	-	-
Gehman et al. [17] data re-analyzed by Benson et al. [23]	0.36 ± 0.04	-	-

Thank you for your attention

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