AGING STUDIES OF THIN TPB FILMS

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Introduction

• For the conversion of LAr scintillation light it has been widely demonstrated that the most efficient way of using TPB is to evaporate it on a specular surface;

• In case of big experimental installations the time between film production and set-up operation can be of the order of months;

• It is extremely important to investigate the aging of the films in order to study an adequate way of stocking and possibly mounting them;

• We studied the aging of thin TPB films when exposed to ambient light and to atmosphere;

• The shifting efficiency of the film has been monitored with a set-up using gaseous argon excited by alpha particles to produce VUV (128 nm) photons and working at room temperature.
Film production

- Evaporated films (on 3M VM2000 or VIKUITI plastic reflective foils) are prepared in an evaporator installed in the Mounting Hall of LNGS;
- The chamber is a stainless steel cylinder with diameter 60 cm – and height 30 cm;
- Two water cooled copper crucibles. Each one allows to load up to 4 grams of TPB ($T_{\text{evaporation}} = 240^\circ C$);
- Quartz sensor to monitor the thickness of the film;
- Turbo molecular pump: the evaporation is performed at a pressure of $10^{-6}$ mbar;
- Produced foils are stocked in a dark room inside nylon bag filled with 5.0 argon.
Samples tested for this work are circular with a diameter \( d = 8 \, \text{cm} \);
- Test chamber of dimensions: 4.5 cm height – 8.0 cm diameter;
- At one end of the chamber it is positioned the film to be tested;
- On the other end a 2” ETL photomultiplier is installed;
- The chamber is lined up with a reflective foil (3M VM 2000);
- The chamber is flushed with high purity (6.0) argon gas (to limit the outgassing);
- The lateral surface of the cell is perforated to allow the flow of GAr easily circulating inside it;
- VUV scintillation light (128 nm) is produced by \( \alpha \) particles emitted by an \( \alpha \) source glued on the PMT surface;
- VUV light is down-converted (~430 nm) by the TPB film and detected by the photomultiplier.


\( \alpha \) source

Sample

reflector

PMT

Test sample

8 cm
WATER GAr set-up

- Scintillation chamber is installed inside a **stainless-steel vacuum tight cylinder**;
- The cylinder is closed on the top by a **gate valve** (**pneumatic**) that allows easy and fast substitution of the sample to be analyzed;
• **Alpha source** is constituted by an *alloy of Aluminum and Uranium*;

• The **energy spectrum** of emerging alpha is continuous and *linearly increasing* (Monte Carlo simulation) up to the maximum energy ($\sim$ 5 MeV);

• The **spectrum of photoelectrons** collected by the photomultipliers is little distorted by the fact that light is *converted only on the sample surface* and by the **relative position of sample and source**;

• Photo-electrons spectrum *increases linearly up to maximum* and then *decreases linearly to zero*;

• Our **reference point for the determination of the light yield** (LY) and conversion efficiency of the sample (in photo-electrons) *is taken to be in the middle of the descending slope of the high energy part of the spectrum*.
Testing procedure

- WATER SS chamber is pumped down to a pressure $< 10^{-4}$ mbar;
- The chamber is flushed with 6.0 Argon at pressure of 2 bars (Range of $\alpha \sim 3$ cm) and flux of $7 \text{Nm}^3/\text{h}$;
- Gar scintillation waveforms are *digitized with a PCI Aquiris board (DP235) @ 1 GHz*;
- 10000 wfms with 40 Ksamples (40 $\mu$sec) are acquired for each run;
- *SER spectrum is reconstructed by integrating single photo-electrons found in the tail of the wfms*;
- Number of photoelectron produced by each $\alpha$ particle is determined by integrating the scintillation wfm (for 15 $\mu$sec after the onset) and normalizing it by average SER;
- The spectrum is fitted with the *function determined with MC simulation* (linearly increasing+linearly decreasing functions) convoluted with a Gaussian function (electronic noise) and the $LY$ @ the reference point is determined;
- *An average wfm is calculated and $\tau_{\text{slow}}$ is determined by fit.*
Calibration

• The value of $\tau_{\text{slow}}$ is closely linked to the degree of purity of GAr in the chamber;
• GAr can be polluted by the outgassing of the internal materials mainly with $N_2$, $O_2$ and $H_2O$ ➔ **collisonal quenching of the slow component of scintillation light**. No photon absorption due to GAr density and small distances (~5 cm);
• **Typically different measurements give different value of** $\tau_{\text{slow}}$ (different outgassing of the sample, different level of vacuum, ...) ➔ the LY needs to be referred to the same $\tau_{\text{slow}}$ for all the samples.

- Number of photons produced at a given energy: $N_{\text{ph}} = A + B \frac{\tau_{\text{slow}}}{\tau_0}$ (A and B constant);
- $\text{LY} = \varepsilon_0 \varepsilon_{\text{sample}} (A + B \frac{\tau_{\text{slow}}}{\tau_0})$ ➔ *sheaf of lines in the plane* $\tau$-LY;
- The calibration procedure consists in determining the **common midpoint** $P_0$ of the sheaf of lines;
- The characteristic lines of few samples have been measured and simultaneously fitted requiring they have a common point;
- The knowledge of $P_0$ allows to extrapolate the LY for pure argon ➔ 3 $\mu$s (reference value) for each sample;
Efficiency vs. Film thickness

- A set of 7 films with thicknesses ranging from 50 µg/cm² to 1400 µg/cm²
- Produced in the same evaporation with the same substrate (VM200)

- The light yield is perfectly constant up to a thickness of 1000 µg/cm²;
- The absorption/conversion of 128 nm photons seems to be a ‘skin effect’ for the thicknesses explored. The only difference is in how easily the converted photons succeed in escaping the film.
- It is convenient to use films with thicknesses around 200 µg/cm² for three reasons:
  - The film is uniform;
  - Less TPB is needed;
  - The film is mechanically more robust especially when bended at liquid Argon temperature;
Long term aging of the films

- Three TPB films evaporated on VM 2000 foils (~ 200 µg/cm²) have been exposed to the diffuse light and atmosphere of our lab (Hall di Montaggio – LNGS);
- Efficiency measurements have been performed during ~ 2 years;
- The three samples deteriorate exactly in the same way up to day 100;
- In day 100 one sample (blue dots) is put in a dark vacuum chamber, one (red dots) in a dark chamber and the third one left in open air (black dots);
- The samples kept in the dark maintain unchanged their efficiency for more than one year and a half;
- This demonstrates that the action of light is essential for the loss of efficiency of the films.
Long term aging of the films – Decay times

- Black points (sample exposed to light and air) have been fitted with a double exponential function;
- Two very different decay times;
- A fast decay with $\tau_{\text{fast}} = 48$ days;
- A slow decay with $\tau_{\text{slow}} = 1400$ days;
- The ratio of the initial amplitudes of the two components: $\text{Fast}/\text{Slow} \sim 0.9$

Looking closer at the aging of the first 70 days the structure is more complicated than a single exponential. More decaying components could be present.
Accelerated aging (I)

- In order to investigate in a more controlled way the loss of efficiency of evaporated films a dark room has been set up in the Mounting Hall of LNGS;
- The light source is an *incandescence tungsten bulb* (100 Watt) ➔ Black body spectrum peaked in the near infrared (*not TOO far from daylight spectrum*);
- **Two samples with the same characteristics** have been considered: 200 µg/cm² evaporated TPB on 3M VM2000 substrate, same batch of TPB used, evaporated in the same day, ~ same initial light yield;
  - ✓ *One of the samples enclosed in a nylon bag filled with GAr and exposed to the lamp. Other sample exposed directly to the lamp (to investigate the effect of storing the sample in an almost inert atmosphere)*;
- Aging test of films of **different thicknesses**:
  - ✓ Samples from ~ 100 µg/cm² to 2000 µg/cm² have been tested
Storing the samples in an almost inert atmosphere does not affect the aging.

The aging is accelerated by a factor 15 with respect to diffuse lab light.
Aging vs thickness (I)

PRELIMINARY

![Graph showing relative light yield vs time for different thicknesses of material. The thicknesses are 2000 µgrams/cm², 950 µgrams/cm², 530 µgrams/cm², 100 µgrams/cm², and 300 µgrams/cm².](image)

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Aging vs. thickness (II)

All decay slopes have been fitted simultaneously with the functions:

\[ RLY = A e^{-t/\tau(i)} + B \]

with: \( A+B = 1 \)

A and B are the same for all the thicknesses.
Conclusions

- The aging properties of evaporated TPB thin films have been studied;

- The films have been exposed to the diffused light of our lab in open air and the decay of their shifting efficiency has been monitored with WATER GAr set-up;

- When the samples are put in dark or dark+vacuum they don’t show any aging;

- A more controlled test performed in a dark room under controlled illumination and atmosphere showed that storing samples in a inert atmosphere do not modify the aging behavior;

- Aging speed depends on the thickness of the sample => unexpected result. Related to the roughness of the samples?