Wavelength Shifting Reflector Foils for Liquid Ar Scintillation Light

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Double Beta Decay

2 $\nu\beta\beta$ decay known for:
- $^{48}\text{Ca}$,
- $^{76}\text{Ge}$,
- $^{82}\text{Se}$,
- $^{96}\text{Zr}$,
- $^{100}\text{Mo}$,
- $^{116}\text{Cd}$,
- $^{128}\text{Te}$,
- $^{150}\text{Nd}$,
- $^{238}\text{U}$,
- $^{130}\text{Ba}$,
- $^{136}\text{Xe}$
with $T_{1/2}$ between $7 \cdot 10^{18}$ y and $2.5 \cdot 10^{24}$ y.

0 $\nu\beta\beta$ decay, controversial claim for $^{76}\text{Ge}$ with $T_{1/2} = 1.19 \cdot 10^{25}$ y [1]
- Existence would imply total lepton number violation.
- Implies that neutrinos are massive Majorana particles.

GEDA[2] Phase I goal: Detection or exclusion $T_{1/2} = 2.2 \cdot 10^{25}$ y at 90% C.L..

Situated at LNGS (Italy).

18 kg enriched Ge-detectors:
- Detector = active material,
- very high energy resolution,
- directly immersed in 65 m³ of liquid Ar.

Water tank for shielding and to veto muons by their Cherenkov light.

Current background in region of interest (ROI): $2 \cdot 10^{-2}$ counts/(kg keV y) $\cdot$ 5 keV $\cdot$ 18 kg = 1.8 counts/y.

Phase II limit goal $T_{1/2} = 15 \cdot 10^{25}$ y:
+ 20 kg of Ge and one order of magnitude less background:
  - Ar as active veto,
  - pulse shape analysis of BEGes.
Liquid Ar as an active veto

Main BG in ROI:
\( \beta \) and \( \gamma \) from \(^{214}\text{Bi}\), \( \beta \) from \(^{42}\text{K}\) and \( \gamma \) \(^{208}\text{Tl}\):
- Often in coincidence with an energy deposition in LAr.

Ar is a scintillator => can be used as a veto.
128 nm => needs to be converted to longer wavelength before detection.
- Performed by reflector foils coated with Tetraphenyl butadiene (TPB).
- Conversion yield determines rejection efficiency.

Light is produced by triplet and singlet state excimers with very distinct life times.

Typical suppression factors (measured [1]) in the ROI (source in active volume):
- \(^{208}\text{Tl}\): 1180, \(^{214}\text{Bi}\): 4.6 [1].

Candidate Coatings
(measured in LAr)

10/1 PS/TPB on VM2000 (a multi layer polymer foil):
Uniform, clear, stable if thin, 0.073 mg/cm² ± 15%.

20% TPB + 80% Makroolon on VM2000:
Uniform, milky, stable, 0.082 mg/cm² ± 10%.

Tetratex (a PTFE fabric) dipped in pure TPB solution:
Uniform, diffuse, stable, 0.88 mg/cm².
Liquid Ar Set-up at Uni Zürich

Cooling by LN₂ flowing through Cu coil in the dewar condensing high purity Ar gas (6.0).

Ar is excited by α-particles from \(^{241}\text{Am}\). The scintillation light is shifted by a surrounding cylinder of WLS reflector foil and detected by a R11065-10 PMT.
Results

Efficiencies are measured relative to an uncoated VM2000.

To compare efficiencies of different coatings at the same triplet lifetime a linear function is fit to the peak position versus triplet lifetime of VM2000.

Highest efficiency for TPB on Tetratex.

For all coatings:

- WLS appears to resist cooling cycles (visual inspection of the setup and the coating with a UV lamp).

<table>
<thead>
<tr>
<th>Coating Description</th>
<th>rel. efficiency</th>
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<tbody>
<tr>
<td>VM2000</td>
<td>1.0</td>
</tr>
<tr>
<td>VM2000, PS + TPB (10/1), 0.073 mg/cm²</td>
<td>1.5</td>
</tr>
<tr>
<td>VM2000, 80% M + 20% TPB, 0.082 mg/cm²</td>
<td>2.3</td>
</tr>
<tr>
<td>Tetratex, pure TPB, 0.88 mg/cm²</td>
<td>3.3</td>
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</table>
Commercial Scintillators as WLS

BC408, UPS-923A and BCF-10 fibre dissolved in Toluene (3.3 g/100 ml) and wet coated onto VM2000.

⇒ thickness of:

- UPS-923A: 0.16 mg/cm²,
- BCF-10: 0.26 mg/cm²
- and BC 408: 0.25 mg/cm².

Efficiency measured using GAr scintillation light, relative to VM2000:

- 1.2 for BC408 and UPS-923A,
- 1.5 for BCF-10 fibre (like PS + TPB from LAr).

Result: These commercial scintillators with a high light yield coated to VM2000 are less efficient than TPB on Tetratex.
TPB Concentration Optimisation

Concentration/thickness dependent efficiency measured using GAr scintillation light (error bars statistical only).

Most coatings measured several times (unmounted between measurements):
⇒ fluctuation ≈ 8.6 %.

Optimal thickness at about 0.8 mg/cm$^2$ (error bars from fluctuation).

Coating test successfully performed on a 45 cm x 93 cm sheet of Tetratex.
Conclusion

TPB on TetrateX is an efficient, stable and low radioactivity wavelength shifting reflector foil which is easily scalable to several square meter.

It is planned to be installed in GERDA in summer 2013.
Backup slides
Radiopurity

For GERDA $\approx 2 \text{ m}^2$ ($\approx 200\text{g}$) of reflector foil are needed.

Radioactivity from ICP-MS, measured by LNGS chemistry laboratory ($\pm 30\%$) [mBq/kg] (weight of TTX $\approx 0.1 \text{ kg/m}^2$). Coated TTX simulated by A. Wegmann (MPIK Heidelberg):

- Raw Bi: Th $2.7 \cdot 10^{-5} \text{ cts/(kg keV y)}$, Bi $8.2 \cdot 10^{-6} \text{ cts/(kg keV y)}$,
- after LAr and AC: Th $6.7 \cdot 10^{-7} \text{ cts/kg keV y}$, Bi $8.2 \cdot 10^{-7} \text{ cts/kg keV y}$.

Radon emanation measurement performed by H. Simgen at the MPIK Heidelberg: $< 105 \mu\text{Bq}$ for about $4 \text{ m}^2$ at 90% C.L..
Installation Suggestion

Stich TTX to Cu shroud (0.1 mm) in 4 channels, using 0.1 mm thick Nylon wire:

- Ring of 1 mm holes ~ 4 cm apart at the top.
- Larger distance at the bottom and 4 rows going from top to bottom.
- Tested with 10 LN₂ cooling cycles.
Installation Suggestion

Stability test:
Hang 0.1mm thick Cu on TTX.

After 34 days: TTX stretched by 2 mm (left), 33 mm (right).

Remaining stretch after hanging on the Cu for 1 day: -2 mm (left), 21 mm (right).

No issues with the stitches.
Reminder

Wavelength shifting (WLS) done by Tetraphenyl-butadiene (TPB) coated on VM2000 or Tetratex (a PTFE fabric) with or without a polymer.

Performed stability tests:

- Thermal cycles in liquid N\textsubscript{2},
- long term storage in liquid N\textsubscript{2}.

Shifting efficiency pre-selection was performed with a fluorescence spectrometer at MPI Heidelberg.

Must be possible to coat foils large enough for GERDA.

Experience from evaporatively coated foils produced by other groups show:

- High shifting efficiency [1] [2] [3] [4] [5],
- up to about 0.3 mg/cm\textsuperscript{2} stable on VM2000 (apparatus for samples of several cm) [5],
- but unstable with apparatus for large samples (several 10 cm) [3].

[3] Own experience with samples from ArDM and the thin film workshop at CERN and private conversation with people from ArDM.
[5] Private conversation with E. Segreto from WARP and visit of their laboratory.
Analysis procedure

Triplet lifetime:

- Fit exponential to mean trace of events > 50 photo electrons.

Select $\alpha$ events by component ratio (fast light / total light).

Fit histogram of integrated pulses with a Gaussian.

Mean Trace with exponential fit.

Energy spectrum of events with a component ratio > 0.45.
VM2000 with 80% Makrolon + 20% TPB
Fluorescence efficiency

Fluorescence spectra (excitation wavelength 260 nm), measured with the fluorimeter at MPI Heidelberg.

QE of PMT R11065 is highest between 300 and 400 nm.
Mechanical Stability

Evaporated Tetratex coating: unstable (can be blown off).

Dipped coatings of Tetratex: fragile (can partly be wiped of).

Dipped coatings of VM2000: stable (resist touching, not scratching).

Samples were stored for 2 month and 11 days in liquid N$_2$:

- No change observed by eye with day light and UV light.
- Microscope:
  - Cracks in PS+TPB coatings in thicker regions.
  - No change observable for other coatings.

Cracks in PS + TPB coatings on VM 2000 after storage in liquid N$_2$. Consistent with coating falling off in LARGE.
R 11065 QE

Spectral Response Characteristics

 Tube Type: R11065-10
 Serial No.: BB0022
 Date: Oct 25, 2011
 Tested by: H. Okih
 Note

Max. Q.E. 33.7 %
Wavelength of max. 380 nm
PMT Characterisation

3” Hamamatsu PMT R11065-10
(Picture from Hamamatsu Catalog)

Candidate to be used in GERDA.
Very low radioactivity.
High quantum efficiency and gain.
  - Gain measured by the single PE spectrum.
For cryogenic temperatures.

Spectrum of all pulses above $3\sigma_{\text{baseline}}$.
Fit-function:

$$\text{Exp} + G(\mu, \sigma) + G(2\mu, \sqrt{2} \cdot \sigma) + G(3\mu, \sqrt{3} \cdot \sigma)$$
R11065 Characterisation

After-pulses

About 20% of this traces contain at least one after pulse.

- Reduced energy resolution,
- effects determination of triplet lifetime,
- results in wrong values of the CR.

Workaround:

- Use first 900 ns only.
Impurities cause non radiative de-excitation of excimers and a reduction of the triplet lifetime:

- Good quantity to monitor the purity.

Half-life Limit:

\[ T_{1/2}^{0\nu} = \sqrt{\frac{m \cdot t}{\Delta E \cdot B}} \]