Multicenter comparison of alpha particle measurements and methods typical of semiconductor processing:

Round II Update

Jeffrey D. Wilkinson, Brett M. Clark, Richard Wong, Charles Slayman, Barry Carroll, Michael Gordon, Yi He, Keith Lepla, Jennifer Marckmann, Brendan McNally, Mike Tucker & Tommy Wu
Purpose

• How much variation is there in practical measurements of alpha particle emissivity?

• Are alpha counting results from various sources comparable?
α particles – What are they?

- Energetic $^2$He$^{++}$ nucleus – energetically favorable decay product, particularly for heavy nuclei.
- Directly ionizing making them ~1000X more likely to cause errors / particle than neutrons.
- Typical range of 30 to 70 µm in solid materials.
- Single, discrete decay energy, unique to the emitting nucleus.
- For ULA materials the emitting isotope and its energy are not known.
- Contamination during manufacturing may limit performance of ULA materials.
Round 1 - Methods

- Standardized low alpha (LA) and ultralow alpha (ULA) prepared for counting.
- Round robin comparison with 9 participating centers and varying equipment and lab procedures.
- Results collected confidentially.
Selected LA Results

- Mean emissivity spans more than 2X.
- Repeated measurements at a single center agree with each other.
- No evidence of sample instability.
Conclusions

• Alpha emissivity measurements are repeatable at a single lab for LA and ULA sources, within the measurement uncertainty.

• Comparing LA emissivity values between labs is subject to 2X variability.

• Extrapolating LA accelerated test methods to predict soft error rates should be done cautiously.

• A suitable emissivity standard is needed for proper calibration of instruments.
Possible Role of Threshold

• An $\alpha$ traversing a “thick” source (> 10 $\mu$m), loses energy creating a continuous energy spectrum incident on the counter.

• Discriminator threshold is set to reject electronic noise and beta emission.

• A sample dependent fraction of the low energy alphas will also be rejected.

Ref: JESD89A, 2005
Round II

Hypothesis
Does the variation in low energy discrimination impact the LA count results?

Methods
• Two standardized samples – one “thick” and 1 “thin” – were developed.
• The thin source is high enough to be unaffected by any reasonable discriminator setting.
• Samples are sent to each lab sequentially using a detailed, standardized procedure.
Round II Samples

Synthetic cordierite glass ceramic (red) and “thick” spectrum.

\[ \approx 0.2 \text{ hr}^{-1} \]
\[ 400 \text{ cm}^2 \]

\[ 94 \pm 3\% \text{ min}^{-1} \]
\[ 4.52 \text{ cm}^2 \]

\[ ^{230}\text{Th} \text{ sample (gold) on silicon wafer for handling.} \]

Measured spectra courtesy of Brendan McNally, XIA and Mike Gordon, IBM
Ceramic emissivity

<table>
<thead>
<tr>
<th>Round</th>
<th>N</th>
<th>σ</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>28%</td>
<td>2.3 X</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>25%</td>
<td>2.2 X</td>
</tr>
</tbody>
</table>
Thorium emission

The "simple" case has similar variability.

Higher than calibrated value!

<table>
<thead>
<tr>
<th>Round</th>
<th>N</th>
<th>σ</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>15%</td>
<td>1.7 X</td>
</tr>
</tbody>
</table>
Alpha Counting - Efficiency

- Alpha counter calibration characterizes the counter’s detection efficiency.
- Some alphas miss the count volume, others do not have sufficient track length to produce an adequate signal.
- A low signal discriminator must be used to prevent false counting from electronic noise and alpha/beta crosstalk.
Thorium counting efficiency

- Counter efficiency may be calibrated with a large area or point source.
- Some loss of signal near the periphery is expected.
- Thorium sample was centered in sample tray and has no loss to the periphery.

Figure 3. Example of gas proportional counter efficiency at different positions.

Figure from Alpha Radiation Measurement in Electronic Materials: Standard Method, JEDEC Alpha Test Method, 6/20/2012.
Thorium emission, $\eta = 1.00$

Is this a useful calibration for the ceramic since it is smaller than the sample tray?
Ceramic – $\eta = ^{230}\text{Th}$

Either the thorium is not a valid efficiency measurement or the variability is not caused by incorrect efficiency calibration.

<table>
<thead>
<tr>
<th>Round</th>
<th>N</th>
<th>$\sigma$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>28%</td>
<td>2.3 X</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>25%</td>
<td>2.2 X</td>
</tr>
<tr>
<td>2*</td>
<td>8</td>
<td>21%</td>
<td>2.2X</td>
</tr>
</tbody>
</table>
Losses below the entrance window

- Low angle alphas may be absorbed before entering the counting volume or in the entrance window.
- Gap between sample and entrance window lowers efficiency.
Gap Efficiency Modeling

Alpha count vs. Sample Gap

\[ \eta = 87\% @ G=0 \]

Calibrated emission

Simulation - 250 \( \mu g/cm^2 \) Mylar™ window, 1 MeV residual

Measured emission data courtesy of Mike Gordon, IBM
Adjusted thorium efficiency

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>σ</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (reported)</td>
<td>8</td>
<td>17%</td>
<td>2.3 X</td>
</tr>
<tr>
<td>All (gap)</td>
<td>8</td>
<td>13%</td>
<td>1.7X</td>
</tr>
<tr>
<td>C- (gap)</td>
<td>7</td>
<td>8%</td>
<td>1.3 X</td>
</tr>
</tbody>
</table>
Accelerated test accuracy

What about the other end of alpha SER?

• Accelerated alpha measurements are made using high flux sources.
• Sources are not standardized.
• Method JESD89A recommends “minimum” spacing between source and DUT.
Alpha source examples

- Flux spans 1000X.
- 300 nCi source measured flux is approximately 2X higher than nominal value.
Source uniformity

- Non-uniformity in sources manufactured by wet deposition.
- At 5 mm gap most of this variation is averaged out.

Contact photograph of Am-241-300 nCi source. Black lines obscure image artifacts.
Normalized spectra

- Am-241-4500 spectrum shifted towards low energy by nickel window.
- Thick thorium spectrum extends to 0 – the low energy discrimination choice is critical.
Cross sections for SRAM-250

- Measurements of cross sections for various sources using identical SRAM cell.
- Coated cells have a 2 um polyimide coating for scratch resistance.
- Cross section ($\sigma$) varies depending on die coating and source.

<table>
<thead>
<tr>
<th>Source</th>
<th>Cell</th>
<th>VDD</th>
<th>$\sigma$ (A.U.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241-300</td>
<td>SRAM (std)</td>
<td>V1</td>
<td>1.1</td>
</tr>
<tr>
<td>Am-241-300</td>
<td>SRAM (polyimide coated)</td>
<td>V1</td>
<td>6.5</td>
</tr>
<tr>
<td>Am-241-300</td>
<td>SRAM (std)</td>
<td>V2</td>
<td>470</td>
</tr>
<tr>
<td>Am-241-4500</td>
<td>SRAM (std)</td>
<td>V2</td>
<td>80</td>
</tr>
<tr>
<td>Thorium</td>
<td>SRAM (std)</td>
<td>V2</td>
<td>320</td>
</tr>
</tbody>
</table>
Conclusions & Looking Forward

• There is somewhat more than 2X variation when counting LA samples (and, presumably ULA samples).
• LA counting variability is not strongly dependent on the low energy threshold.
• For windowed counters the entrance gap is an important factor to match to the calibration conditions.
• Calibration to a similar source should be standard practice. Suitable calibration sources are needed.
• Accelerated alpha cross section measurements are subject to large variability due to source construction and experimental setup.
• The implications of systematic errors in rate projections from alpha measurements should be carefully considered.