The need for a large-area low emissivity alpha particle standard

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Outline

• Introduction to ultra-low alpha particle counting
• Level of detection vs counting time as a function of counter background
• Fundamentals of alpha particle counting
• Radon exposure on samples
• Influence of cosmic rays
• Static electricity influence on dielectric samples
• Efficiency vs sample geometry
• Select data from round robin counting
• Large area low emissivity alpha particle standard
• Summary
Introduction, why care about alpha particles?

• Single Event Upsets (SEU)
  – Alpha particles in the packaging near the transistors can cause SEU (flipped bits)
  – Most materials include trace amounts of Thorium and/or Uranium
    Sn which has largely replaced Pb has large emission even though no radioactive isotopes
  – The current specification is \( \varepsilon < 2\alpha/khr\cdot cm^2 \) (1.4 \( \alpha/hr \) on a 300 mm dia. wafer)
    This is less than the background in most detectors
  – The detectors can be used to screen materials used to make semiconductors
    Or to evaluate the contamination during the manufacturing process flow

• Search for dark matter
  – The detectors in use require ultra low backgrounds
  – Alpha particle detectors can be used to screen materials used to make DM detectors
Sources of alpha particles in semiconductor packaging
Alpha emissivity, contamination from U, Th on a Silicon Wafer

Particle emissivity of $0.5 \alpha$/khr-cm$^2$ corresponds to $\sim 0.1$ ppb U & 0.2 ppb Th in Si

Particle emissivity of $2 \alpha$/khr-cm$^2$ corresponds to $\sim 0.4$ ppb U & 0.6 ppb Th in Si

Those small levels are difficult to measure even with ICP-MS

Martinie, IEEE TNS, vol. 58, no. 6, December, 2011, 2798
Level of Detection vs Counting Time:

**Level of detection**

\[
LOD = n \sigma = n \sqrt{\frac{G - B}{t_G^2 + t_B^2}} A \epsilon
\]

where:
- LOD = level of detection
- \( n = 1.64 \) for 90% confidence
- \( G, B \), sample and background counts
- \( A \) = sample area
- \( \epsilon \) = counter efficiency

There is a clear benefit to:

- large-area samples,
- low detector background
- large counter efficiency

XIA UltraLo-1800: an example of a large-area $\alpha$-particle detector

- **Ultra-low background achieved using pulse shape discrimination**
  - The pulses from the ionization of the counter gas are fit for pulse height, rise time, and “rounding”
  - Pulses are further segregated into “alphas,” “ceilings, “rounds,” and “midair” events depending on the pulse height, rise time, “rounding”
  - If the ionization induces a signal on the guard ring it is rejected (events from the side walls)
  - The counter needn’t be constructed of ultra-low $\alpha$-particle materials (but it helps)
  - The lowest emissivity we have seen is $\sim 0.3 \, \alpha/khr-cm^2$ (5 $\alpha$/day on a 300 mm diameter wafer)- and it was repeatable!
XIA UltraLo-1800: large-area $\alpha$-particle detector

![Diagram of XIA UltraLo-1800 detector components](image)

- $\alpha_s$: Secondary $\alpha$-particle
- $\alpha_{ma}$: Mid-air $\alpha$-particle
- $\alpha_c$: Ceiling $\alpha$-particle
- Guard signal
- Anode signal
- Source on cathode
- Source on sidewall
- Source on anode

![Graph showing pulse height vs. rise time for different sources](image)
Some samples for alpha particle measurement

- Fully processed wafer
- Tin raw material
- Wafer “carcass” with solder balls
- Aluminum disk
Radon daughters plate out on samples exposed to air

From $^{238}$U decay chain:

- $^{238}$U
- $^{234}$Pa
- $^{214}$Po
- $^{210}$Pb
- $^{210}$Po

$\sim 4$ hr lifetime

From $^{232}$Th decay chain:

- $^{232}$Th
- $^{228}$Th
- $^{224}$Po
- $^{218}$Po
- $^{220}$Rn

$\sim 10$ hr $\frac{1}{2}$-life

Radon Issues - sample in dry box vs exposed to air

Sample stored in dry N₂

α’s from $^{214}$Po

- Energy: 7.7 MeV
- Time: 1st 4 hours

Sample exposed to air 24 hrs

α’s from $^{212}$Po

- Energy: 8.8 MeV
- Time: 1st 3 days

1st 4 hours wasted


1st 3 days wasted
\(\alpha\)-particle emissivity depends on neutron flux

- Same detector: 2 locations in the same building (basement & second floor near picture windows)
- Same bare wafer sample, radon excluded
- The number of all classes of events > on 2\textsuperscript{nd} floor
- Modeled the \(^{28}\text{Si}(n,\alpha)\) and \(^{40}\text{Ar}(n,\alpha)\) nuclear reactions: \(\varepsilon \sim 0.3 \alpha/\text{khr-cm}^2\) (for no \(\alpha\) in samples)
- The neutron flux is \(\sim 2X\) lower in the basement due to shielding

<table>
<thead>
<tr>
<th>Location</th>
<th>Alpha</th>
<th>Mid-air</th>
<th>Round</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement</td>
<td>30</td>
<td>11</td>
<td>55</td>
<td>29</td>
</tr>
<tr>
<td>2\textsuperscript{nd} floor</td>
<td>53</td>
<td>67</td>
<td>186</td>
<td>38</td>
</tr>
<tr>
<td>Basement</td>
<td>25</td>
<td>22</td>
<td>48</td>
<td>27</td>
</tr>
<tr>
<td>Ratio</td>
<td>1.9</td>
<td>4.1</td>
<td>3.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The effect of static on electrically insulating samples

From the triboelectric series, glass can charge to +HV (and Teflon to –HV)

Static electricity of either polarity will perturb the originally homogeneous electric field within an ionization counter. Both polarities have the effect of reducing the count rate.

We used the natural radioactivity from a glass wafer that had been charged & measured the natural discharge rate and ways to force discharge.

<table>
<thead>
<tr>
<th>Measured glass for 8 days</th>
<th>Measured glass for 7 days</th>
<th>Measured glass for 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Put low activity ~85 pCi $^{230}$Th source on top w/HV off, 3 days</td>
<td>Used 0.1 $\mu$Ci $^{241}$Am source close to glass, 3X3 pattern 5 minutes each position</td>
<td>Used antistatic tool on four corners of the glass</td>
</tr>
<tr>
<td>Removed source and continued counting</td>
<td>Continued counting</td>
<td>Continued counting</td>
</tr>
</tbody>
</table>

Source not effective  
Source partially effective  
Antistatic tool effective


natural discharge time ~ 3 weeks
The effect of geometry on the detection efficiency

Alpha particles emitted near the edge of the detector have a 50% chance of detection (and 1/2 will be vetoed due to charge collected on guard electrode)

All alpha particles for small samples will be collected

Need to model the detection efficiency as a function of sample geometry and correct the alpha particle count with $1/\text{eff}$. 

Vector represents $\alpha$-particle track length in counter gas (function of gas pressure and alpha particle energy)

Particles are not counted if trajectory causes ionization which leaves charge in the guard ring
The effect of geometry on the emissivity

Analytic model used to calculate the efficiency for the detector in 300 mm mode

Black line: 300 mm disk, efficiency > 85% up to ~ 7 MeV

Red line: 300 mm OD, 290 mm ID ring, efficiency > 50% up to 7 MeV
Alpha Measurements, select results of round robin studies

Two round robins- similar results

Low Alpha Ceramic Sample

Huge variation on LA samples
Probably due to source to cathode height variation

All participants used new XIA counters

Only new XIA ionization counters

Alpha Measurements, select results of round robin studies

All participants used new XIA counters

Excellent consistency, altitude dependence (neutrons)

Requirements for an industry-wide standard

- Lab to lab variability (in the first consortium) was larger than the current alpha-particle specification
- JEDEC 221 standard
  - Describes best practices for accurate low level measurements
  - Lacks standard for inter- or intra-lab comparison
- Source requirements
  - Thick source, not monoenergetic (like emission from most samples),
    \[1 \text{MeV} < E\alpha < 8.8 \text{ MeV}\]
  - Emissivity \(\sim 2 \alpha/\text{kh}\text{r-cm}^2\) up to \(\sim 20 \alpha/\text{kh}\text{r-cm}^2\)
  - Stable emission with respect to time, energy
  - Robust for shipping/ handling
  - Material should be difficult to contaminate
  - Material should probably be electrically-conductive
  - Emissivity should be uniform within \(\sim 1 \text{ cm}^2\) area
  - Ideally we would have several “identical” standards available
  - Need to ensure that the sample isn’t contaminated by radon
Summary

• Detecting low levels of alpha particles in materials is challenging

• Radon, cosmic rays, static electricity, and sample geometry can affect the results

• Users of low-background alpha particle detectors need NIST-traceable standards to ensure proper operation of their detectors

  – Preferably the standard would have an emissivity near the level of the samples to be measured