The need for an industry-wide, large-area, ultra-low emissivity standard

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Outline

• Introduction to single event upsets and the need for ultra-low emissivity materials
• Sources of alpha particles in materials used in semiconductors
• Large-area alpha particle detectors in use
• Requirements for industry-wide low-emissivity α-particle standard
• Results from the alpha particle consortium and an XIA study
• Working together on an industry standard
• Summary
Single Event Upsets, Definition and Origin

• Single Event Upsets
  – Errors in computer chips (memory & logic) that don’t cause permanent damage
  – Created by passage of energetic ionizing radiation through the sensitive volume of chips
  – This can be a major reliability problem in servers, laptops, smart phones, pacemakers, electronics near radiation sources

• Sources of single event upsets:
  – Alpha particles from chip packaging (ceramic, underfill, interconnects, contamination)
  – Cosmic rays which create highly ionizing particles when they interact w/ silicon
  – Alphas from interaction from thermal (slow) neutrons $^{10}\text{B}$ interactions $^{10}\text{B}(n,\alpha)$

• With technology scaling (shrinking dimensions)
  operational voltages decrease, the critical charge required to flip a bit also decreases, however the size of sensitive area decreases too
Sources of alpha particles

- Pb, Sn, Sn-alloys

Diagram showing plastic package, solder bump or C4, copper wires, contact studs, chip wiring insulation, and CMOS transistors.
210Pb and 210Po, transition from Pb to Pb-free

Alpha activity increases for ~ 2.5 years for newly refined Pb, then decreases

Evidence of Po in some Sn, diffusivity of Po in Sn under study, 210Po in decay chain of 238U
$^{238}U$ decay chain $\rightarrow ^{206}Pb$ (stable)
$^{232}$Th decay chain $\rightarrow ^{208}$Pb (stable)
$^{210}\text{Po}$: Brett Clark, SCV SER Workshop 2012

Alpha emissivity increases in time from $^{210}\text{Po}$ diffusion (not approach to secular equilibrium)
The emissivity increases due to heating
Each heating cycle caused less influence than the previous heating cycle

Po concentration of $1\times10^{-4}$ ppt can cause alpha emissivity of $>2\alpha$/khr-cm$^2$
This is not measurable directly.
Alpha emissivity, contamination from U, Th on a Silicon Wafer

0.1 ppb U and 0.2 ppb Th in a silicon slab causes an alpha particle emissivity of $0.5 \alpha/\text{khr-cm}^2$.

These levels are measurable with neutron activation or special ICP techniques.

Alpha component to SEU, scaling data for SRAM

1 FIT = 1 fail in $10^9$ years
Alpha component at 40 nm is ~ 40% of total, and emissivity is 0.92 $\alpha$/khr-cm$^2$
The alpha component is decreasing due to “stringent material selection”

**LOD drives need for large area samples, low background detectors**

**Level of detection**

\[
LOD = n\sigma = n^* \sqrt{\frac{G}{t^2_G} + \frac{B}{t^2_B}} \quad \frac{A*\varepsilon}{A*\varepsilon}
\]

where:

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

There is a clear benefit to large-area samples, low background and large detection efficiency.

**Graphs:**

- **300 mm diameter sample**
- **200 mm diameter sample**
### Large-area alpha particle detectors in use by the Semi industry

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proportional counters</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Alpha Sciences</td>
<td>- Background controlled by counter materials (ultra-low emissivity materials)</td>
</tr>
<tr>
<td><a href="http://www.alphacounting.com/Model_4950.html">http://www.alphacounting.com/Model_4950.html</a></td>
<td>- Thin, ΔE counter (no energy info)</td>
</tr>
<tr>
<td>Ordella</td>
<td>- Fragile window (Alpha Sciences)</td>
</tr>
<tr>
<td><a href="http://www.ordela.com/PDF/8600A-LB.pdf">http://www.ordela.com/PDF/8600A-LB.pdf</a></td>
<td>- High background (&gt; 2 α/khr-cm²)</td>
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<tr>
<td></td>
<td>- Need to measure background often due to fluctuations</td>
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<tr>
<td></td>
<td>- Sensitive to EMI noise, vibration</td>
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<tr>
<td></td>
<td>- Poor signal/ noise for ULA samples</td>
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<tr>
<td></td>
<td>- Single sample (Ordella)</td>
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<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>- Large amplitude signal</td>
<td>- Active signal discrimination</td>
</tr>
<tr>
<td>- Relatively inexpensive</td>
<td>- Small amplitude signal</td>
</tr>
<tr>
<td>- Simple to operate</td>
<td>- More expensive</td>
</tr>
<tr>
<td>- AS, multiple wafers, &lt; 3600 cm²</td>
<td>- Single sample</td>
</tr>
<tr>
<td><strong>Ionization counters</strong></td>
<td></td>
</tr>
<tr>
<td>XIA LLC</td>
<td></td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>- Active signal discrimination</td>
<td>- Small amplitude signal</td>
</tr>
<tr>
<td>- Very low background (≈0.3 α/khr-cm²)</td>
<td>- More expensive</td>
</tr>
<tr>
<td>- Energy information available</td>
<td>- Single sample</td>
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<tr>
<td>- Insensitive to noise, vibration</td>
<td></td>
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<tr>
<td>- Can accommodate large sample (1800 cm²)</td>
<td></td>
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</tbody>
</table>
Results from Alpha Consortium, Aluminum alloy, first round

Variability is large, what is the “correct” emissivity?

Jeff Wilkinson, SCV SER Workshop 2012, Wilkinson, et al. IRPS, 2011, pp. 5B3.1-5B3.10
Results from Alpha Consortium, ceramic, second round

Still see the same 2.3X range between labs

Variation is not due to the energy discriminator settings on the counters

Energy range alphas
$E > 1 \text{ MeV}$ $100\%$
$E > 2 \text{ MeV}$ $90\%$
$E > 3 \text{ MeV}$ $71\%$

Variability is large, what is the “correct” emissivity?

Results from Alpha Consortium, $^{230}$Th point source, second round

Detector efficiency set to 1

NIST-traceable source

$\alpha$ - emission rate 94 $\alpha$/min

Still very large variation between labs (confirmation that differences have nothing to do with energy threshold)

Alpha emission rate is orders of magnitude greater than ULA

Variability is large, this time we know the “correct” emissivity for this source

Results from XIA controlled study

LA Aluminum

ULA Ti

Huge variation and “negative” emissivities

Significantly less variability

Results from XIA controlled study


Requirements for an industry-wide standard

• In the first alpha-particle consortium, the lab to lab variability 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

• Large-area source requirements
  – Thick source (to mimic most samples with Th & U), 4 MeV < E_\alpha < 8.8 MeV
  – Emissivity \sim 2 \, \alpha/\text{kHz}\cdot\text{cm}^2 \text{ up to } \sim 20 \, \alpha/\text{kHz}\cdot\text{cm}^2
  – “Known” emission rate (hard to know)
  – Stable emission with respect to time, energy
  – Robust for shipping/ handling
  – Material should be difficult to contaminate
  – Emissivity should be uniform within \sim 1 \text{ cm}^2 area
  – Ideally we would have several NIST-traceable standards available
  – Minimize contamination by radon (or handling)

• Concerns
  – ‘altitude’ effect- results from SULA and some ULA samples will depend on altitude/ shielding
Radon daughters plate out on samples exposed to air

From $^{238}$U decay chain

$^{222}$Rn 3.8$d$

$^{238}$U $\rightarrow$ $^{234}$Pa $\rightarrow$ $^{234}$U $\rightarrow$ $^{234}$Th $\rightarrow$ $^{230}$Th $\rightarrow$ $^{226}$Ra $\rightarrow$ $^{222}$Rn

$\sim$ 4 hr lifetime

From $^{232}$Th decay chain

$^{226}$Ra $\rightarrow$ $^{222}$Rn $\rightarrow$ $^{220}$Rn $\rightarrow$ $^{216}$Po $\rightarrow$ $^{212}$Po $\rightarrow$ $^{210}$Po $\rightarrow$ $^{208}$Po

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

Radon Issues - data

Sample stored in dry N₂

Possible material for a large-area, ultra-low emissivity standards

- Titanium sheet (from consortia measurements)
- Oxygen free copper sheet
- Sn sheet
- Electrically-conductive material on substrate

“low-alpha particle emission electrically conductive coating”

US Patent 8815725, Gaynes, Gordon, Lewandowski

- Si wafer
- Point sources, $^{230}\text{Th},^{147}\text{Sm}$
$^{147}\text{Sm}$, a low-energy $\alpha$-source

$T_{1/2} = 1.06 \times 10^{11}$ years

15% abundant

$E_\alpha = 2.25$ MeV

Specific activity = $127 \alpha/g$-sec

$$SA = \frac{\text{Ln}2}{T_{1/2}(\text{sec})} \times \frac{N_a(\text{atoms}/\text{mol})}{A(\text{g}/\text{mol})}$$

Energy spectrum of $^{\text{nat}}\text{Sm}$ sputtered on 200 mm wafer

Chart of the Nuclides, GE, 13th ed.
Summary

• The semiconductor industry needs material certified at the ULA (2\(\alpha\)/khr-cm\(^2\)) level, with lower levels in the foreseeable future, to ensure proper operation of alpha particle detectors.

• A new class of detectors is capable of making measurements of ULA materials reliably.

• We need a stable calibration source to routinely assess the performance and repeatability of measurements of our alpha particle detectors and to compare samples measured at different sites.

• We have requested the help from NIST to add credibility to this work, and to provide certification/calibration.

• We have several possible candidates for standards.
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