Alpha Emission Qualification of a 361pin Flip-Chip Package utilizing System Soft Error Testing

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Alpha Particles

All terrestrial materials contain trace amounts of radioactive atoms
For example, $^{210}\text{Po}$, $^{238}\text{U}$, and $^{232}\text{Th}$, at a few parts per trillion

These atoms sporadically emit Alpha particles as they disintegrate into more stable elements
Alpha particles are Helium nuclei with a double-positive charge, and are directly ionizing, i.e., their motion in Silicon creates an electron-hole charge track; this charge can disrupt a circuit and cause soft errors

Radioactive contaminants in packaging materials need to be controlled to lower the Alpha emission rate
Usage of Ultra Low Alpha (ULA) mold compounds and materials Certificate of Compliance (CoC) and tight supply chain control
Typical Alpha emission rates for semiconductor materials are shown in the table to the right

<table>
<thead>
<tr>
<th>Material</th>
<th>$\alpha$/cm$^2$-hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed Wafers</td>
<td>0.0009</td>
</tr>
<tr>
<td>Cu Metal (thick)</td>
<td>0.0019</td>
</tr>
<tr>
<td>Al Metal (thick)</td>
<td>0.0014</td>
</tr>
<tr>
<td>Mold Compound</td>
<td>0.024 - &lt;0.002</td>
</tr>
<tr>
<td>Underfill</td>
<td>0.002 – 0.0009</td>
</tr>
<tr>
<td>Pb-solders</td>
<td>7.200 - &lt;0.002</td>
</tr>
</tbody>
</table>

Alpha particles can be partially screened from reaching sensitive circuits
Additional passivation layers (10μm polyimide $\rightarrow$ 50% reduction)
A dummy metal layer can also act as an Alpha shield

Materials in Packages that are close enough to SRAM Cell
Wire bond packages: mold compound
Flip chip packages: solder bump, underfill, UBM, presolder
Alpha Particle Testing

A tester with an open-top DUT setup and a calibrated $^{232}\text{Th}$ foil positioned at a predefined distance (<2mm) from the chip surface is used.

Test flows
Static – Write data pattern (e.g., checkerboard) => Alpha exposure time x => Read-verify => log errors
Dynamic – During exposure time x, enter into an infinite Write-Read loop and log errors as they occur
Bitmapping – collect hundreds of individual, isolated events for bitmap studies
SEL – high-temperature and high-flux, static testing attempts to overwhelm the memory and cause latchup

SER/SEL FIT Rate Calculation
FIT rates are scaled to the flux of the dominant alpha emitter in the packaging materials (e.g., the mold compound for wire-bond packages)
The Alpha emission rate for Ultra-Low Alpha (ULA) mold compound is $\Phi_{\text{PKG}} = 0.001 \frac{\alpha}{\text{cm}^2 \cdot \text{hr}}$
SER is expressed on a per-Megabit basis, and SEL on a per-Device basis

\[
\text{SER: } \quad \text{FIT}\left[\frac{1}{\text{Mb}}\right] = \frac{(#\text{errors}) \cdot 10^9 \text{ hr}}{\text{density}[\text{Mb}] \cdot (\Phi_{\text{FOIL}}/\Phi_{\text{PKG}})}
\]

\[
\text{SEL: } \quad \text{FIT}\left[\frac{1}{\text{Dev}}\right] = \frac{(\#LU\text{events}) \cdot 10^9 \text{ hr}}{(\Phi_{\text{FOIL}}/\Phi_{\text{PKG}})}
\]

This Method works well for Wirebond Packages
Flip-Chip Package

Typical Flip Chip BGA Package

Subcon provided Alpha Emission Rates:
Underfill: 1 alpha/khr
Solder Bump: 2 alpha/khr

Additional FC Materials: UBM: ?, Pre-solder:?

Alpha Testing from front side impossible!!
Alpha Testing from back side requires Alpha Emission Rates for ALL materials close to SRAM cells!!

System SER (Life Testing) in “Zero-Neutron Environment” can do the job!!

Package independent Alpha particle upset requirements:

No Multi Bit Upsets from single events
No Multi Bit Upsets from multiple events
Can single Alpha Particles trigger Multi Bit Upsets (MBUs)?
Only grazing angle particles hitting in the same row can cause MBUs.
SRAM Array with 16-cell Bit Interleaving:

Alpha particles from solder bumps will not cause a MBU event from a single particle since the backend stack will screen the shallow angle Alpha particle hits.
SRAM’s accumulate soft errors in data retention mode (Accumulation Effect)

Birthday statistic can be used to calculate probability of MBU event

MBU probability depends on:
- Architecture (# of addresses)
- Intrinsic failure rate of SRAM cell
- Data bus width – x8,x16

Example: 16Mbit SRAM

MBU failure rate of SRAM in data retention mode depends strongly on Alpha emission of the package material:
- ULA (<1 α/khr): MBU = 0.08 FIT/Mb
- Std (<100 α/khr): MBU = 800 FIT/Mb

ULA packaging materials required in FC packages to suppress MBUs
EDAC Protected SRAM

Optimized EDAC (32+6bits internal data structure)
Allows for Single Error Correction (SEC)
Dedicated Error output (ERR) – ECC notifies user that a bit correction has been performed

SEC will correct accumulated SBU events in SRAM array
Errors stay in SRAM array until SRAM is re-written (scrubbed)
Accumulated MBUs cannot be corrected
How long will it take to accumulate 1000 SBUs in SRAM array:
ULA (1 $\alpha$/khr) = 11000 yrs @ NYC
Std (100 $\alpha$/khr) = 235 yrs @ NYC

Potential Issue only for Avionics applications

ULA packaging materials required to suppress MBUs
System SER Testing

Hundreds of devices are mounted in a system (up to 30Gb of SRAM) and written and read continuously every four minutes

Extraction of Alpha and Neutron SER through measurements at different altitudes and environments

Cypress-preferred locations
High Neutron flux environment: Mauna Kea – Hawaii, 9.2x acceleration over NYC
Zero Neutron flux environment: Soudan – Minnesota, $10^{-5}$ n/cm²·hr, used for true Alpha SER measurements (e.g., for flip chip package qualification)

Failure log example from Mauna Kea (305† events over 3 months)

High Neutron Environment
Mauna Kea (+14,700ft)

Zero-Neutron Environment
Soudan, Minnesota (-2,360ft)
System SER Tester

Custom SSER Tester:
164pc of 144M QDR SRAMs installed in Jan 2014 @ Soudan, MN mine (24.7 Gb)
17 SBU events, 3 MCU events till end of June detected (continue for another 6 months)
FIT Rate = 279 FIT/Mb equivalent to 1.07 $\alpha$/khr

361pin Flip Chip meets ULA criterion
Conclusions

System SER is the only reliable method to validate alpha emission of flip chip packages:

Advantages:
  Accurate
  Validates whole package at once

Disadvantages:
  Long measurement time (1yr)
  Expensive (Power, Support)