Flip Chip Packaging Materials Alpha Characterization

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Introduction

- All sub micron IC's are susceptible to Single Event Effects (SEE's) to some extent.
- Traditionally FPGA's were targeted as being more sensitive due to their use of SRAM for configuration storage.
- Soft Error Rates (recoverable) include Singe Event Upsets (SEU's) that are categorized as single bit or multi bit upsets.
- Some reported SEU bit failures seen on flip chip product have been found to be located 40-60 um from the bump center (doughnut hole failures)
- 40-60 um is in the Alpha particle range.
- There is a potential that these failures are coming from alpha emitters from the flip chip packaging material set.

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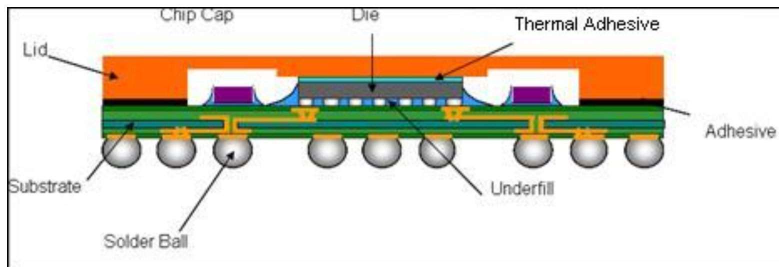
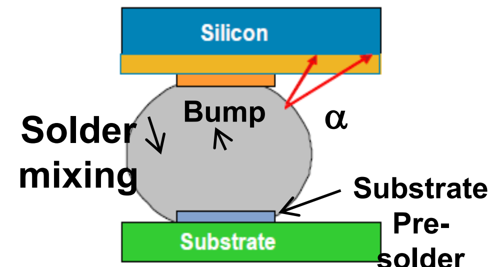
Flip Chip Package Potential Alpha Emitters

- **Flip Chip Packaging has materials that may be sources of Alpha emitters that could cause SEU failures.**
  - Solder Bump
  - Package substrate Pre Solder on Pad (SOP)
  - Underfill
  - Chip Capacitor Solder paste
  - Bump and/or Assembly Alpha Cross Contamination





- **The 40-60 um Alpha material range means that the solder bump and substrate pre-solder have the highest potential to cause alpha failures.**
- **The Solder Bump and substrate SOP contain the lead isotope 210Pb. 210Pb decay chains contains the strong alpha emitter 210Po.**

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Flip Chip Package Material Set and Controls

- **Xilinx's flip chip assembly materials are rated as Ultra Low Alpha (< 0.002 cph/cm^2).**
- **These include:**
  - Package Substrate SOP: Solder Paste used on SOP is ULA
  - Solder Bump: Tin and Lead solutions and anode are ULA
  - Underfill: Underfill filler is ULA
- **Additional controls include:**
  - Substrates are manufactured on a dedicated ULA line
  - Solder bumps are processed on a dedicated ULA bumping line
  - ULA underfill is only used at the assembly line
- **Suppliers measure alpha count of materials as part of Incoming Inspection**

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Alpha Characterization Challenges: Parameter Settings

- **Raw material, substrate and assembly suppliers use different Alpha Count measurement tools. (Alpha Science/Sumika)**
  - Variation in alpha count measurements from supplier to supplier is seen
  - This may be due to different parameter settings used

Category	Supplier	Materials	Equipment	Gas	Test Sample	Area (cm^2)	Measure ment Efficency	Duration (hrs)	Region of Interest (# of hrs included)
Substrate	#1	SOP	LACS-4000M (Sumika)	PR gas	Solder Powder	1000	80%	99	18-98
	#2	SOP	LACS-4000M (Sumika)	PR gas	Solder Powder	1000	88%	40	20-40
	#3	SOP	LACS-4000M (Sumika)	PR gas	Solder Powder	1000	88%	40	20-40
Solder Bump	#1	EU Printed Bump	LACS-4000M (Sumika)	PR gas	Bumped Metal Wafer	4000	84%	72	36
	#1	EU Plated Bump	Alpha Science 1950SE	PR gas	Bumped Metal Wafer	1000	84%	72	36
	#2	EU Plated Bump	Alpha Science 3950-4	PR gas	Blanket Wafer	3600	84%	52	48
	#3	EU Plated Bump	LACS-4000M (Sumika)	PR gas	Blanket Wafer	394	80-82%	20	20

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Alpha Characterization Challenges: Background Count

- **Background count rate reported by our suppliers has variation**
- **Sources of background Alpha are:**
  - Alpha particle emission from counter material
  - Counter/Tray contamination
  - Radon in counting gas
- **Different # of set background hours measured by each supplier.**
- **Alpha Count results reported by our suppliers have a wide range.**

$$\text{Alpha Count} = \frac{Cg - Cb}{\text{Area} * \text{Effic}}$$

Material	Supplier	# of Background Hours Measured	Background Count Rate, Cb (cts/hr)	Gross Counts Rate, Cg (cts/hr)	Alpha Counts
EU plated bumped wafer	#1	72	4.97	8.14	0.002
EU plated blanket wafer	#2	48	6.91	6.42	-0.0005
EU plated blanket wafer	#3	20	2	2.2	0.0006

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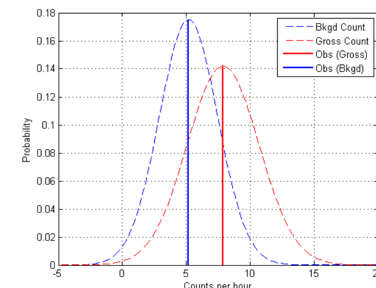
Alpha Characterization Challenges: Error Count Variation

- **Error Count in Alpha Emission Rate is calculated as follows:**

  $\frac{n * \sqrt{Cg/tg + Cb/tb}}{\text{Sample Area X Efficiency}}$ where n = Confidence Level, Cg = Gross Alpha/hr, Cb = Bkgr Alpha/hr & tg & tb = Sample Size(in hrs)

- **Suppliers show variations in Region of Interest measured (hours counted in measurement).**
- **Detector Efficiency number also varies from supplier to supplier.**
- **These variations lead to high or low Cb numbers as well as error counts reported as high as .002 CPH/cm² as reported below:**

Material	Supplier	Machine Efficiency	Region of Interest	Test Duration	Cg	Cb	Error Count Confidence Level	Error Count (cts/hrs/cm²) (+/- 2SD)
Substrate Solder Paste (LA solder paste)	#1	88	20-40 hrs.	99 hrs.	7.82	4.7	97%	0.002
Substrate Solder Paste (ULA solder paste)	#1	89	20-40 hrs.	71 hrs.	6.3	7.2	97%	0.0018
EU plated bumped wafer	#2	84	37-72 hrs.	72 hrs.	8.14	4.97	97%	0.0017
EU plated bumped wafer	#3	84	11-52 hrs.	52 hrs.	5.524	3.00	97%	0.0016



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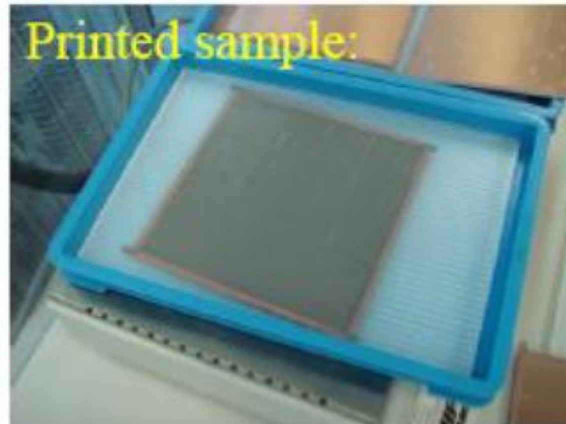
Alpha Characterization Challenges: Sample Size

- Alpha Count sample size should fit the Alpha Count beam size or alpha count results my be faulty.
- Example: Substrate SOP solder paste was reflowed onto a Cu test coupon to verify the Alpha count of substrate SOP.



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Alpha Characterization Challenges: Sample Size

- Supplier used a Cu SOP test coupon size of 400 cm^2. This size was less than the full 707 cm^2 area of the 300 mm measuring alpha count electrode.
- The 400 cm^2 test coupon alpha count results were out of spec. (.0095 cph/ cm^2)
- The Cu SOP test coupon was measured without solder paste and found to give off a large amount of alpha particles. (.0113 cph/ cm^2)
- A 707 cm^2 test coupon was then prepared from the same solder paste lot and used the full counting area. This was within spec. (.0020 cph/cm^2)
- Its believed that the Cu sides of the 400 cm^2 test coupon gave off additional alpha particles that caused the out of spec result.

Material	Supplier	Test Coupon Size	Alpha Count (Cts/cm^2/hr)
Substrate SOP Solder Paste Coupon, Lot #1	#1	400 cm^2	0.0095
Cu test coupon (FR4 board) without SOP	#1	400 cm^2	0.0113
Substrate SOP Solder Paste Coupon, Lot #1	#1	707 cm^2	0.0020
Substrate SOP Solder Paste Coupon, Lot #2	#1	707 cm^2	0.0020
Substrate SOP Solder Paste Coupon, Lot #3	#1	707 cm^2	0.0019

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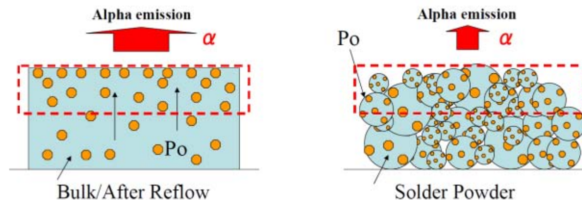
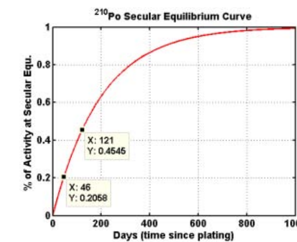
Alpha Characterization Challenges: Other Factors

- ## SOP Solder Measured in Powder vs. Reflow form:
- **Substrate SOP raw material suppliers measure solder powder alpha count right after manufacturing.**
- **One Supplier has found that if measured after solder paste reflow, that the alpha count could go out of spec.**
- **This is thought to be caused by the Po moving to the surface by Oxygen after solder reflow.**



- **Xilinx substrate suppliers measure the Alpha count of the SOP solder after reflow to mimic substrate manufacturing and data has shown each solder lot to be within ULA spec.**

- ## Secular Equilibrium:
- Activity levels of solder decay chains are not constant, emissivity increases before stabilizing
- Age of solder sample measured could affect alpha count



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Alpha Characterization Results

- **Due to variation in how suppliers measure Alpha Count, Xilinx used an outside 3rd party vendor to measure Alpha Counts on our Flip Chip material set.**
- **Materials were found to be below our spec. of < 0.002 cph/cm^2**

Material	Supplier	Alpha Count (Cts/cm²/hr)
Eutectic Plated Bumped Wafer, Lot #1	#1	0.000925, .001097 (same wafer measured twice)
Eutectic Plated Bumped Wafer, Lot #2	#1	0.001744
Leadfree Plated Bumped Wafer	#1	0.000887
Eutectic Plated Blanet Wafer	#2	0.00098
Leadfree Plated Blanket Wafer	#2	0.00081
Substrate SOP Solder Paste	#1	0.0020
Substrate SOP Solder Paste	#2	0.0019
Underfill	#1	0.00093

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Conclusions

- Dedicated ULA manufacturing lines at bump and substrate manufacturing are important to avoid cross contamination.
- Supplier alpha count measurement criteria, sample preparation and alpha contamination controls needs to be monitored.
- Industry specification for alpha count measuring by suppliers is needed.
- Xilnx's flp chip material set was confirmed to be within the ULA range.

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