Assessment of Soft Errors due to Alpha Emissions from Presolder on Flip Chip Devices

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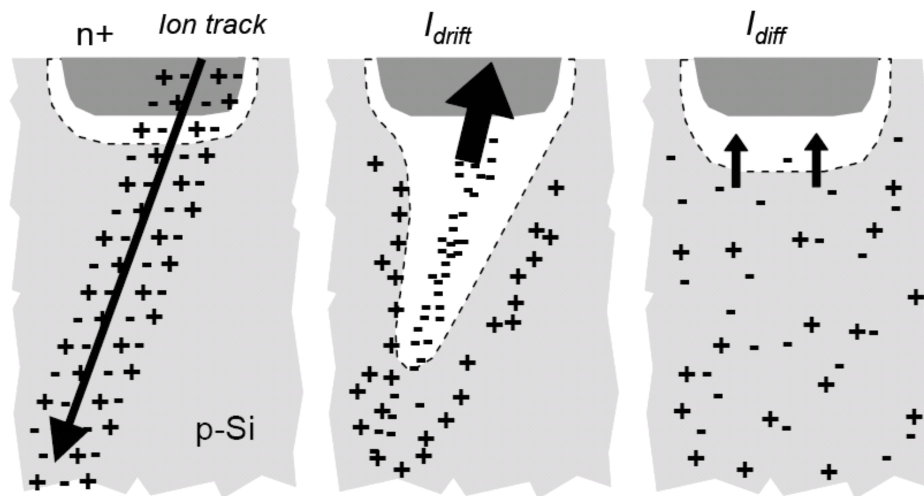
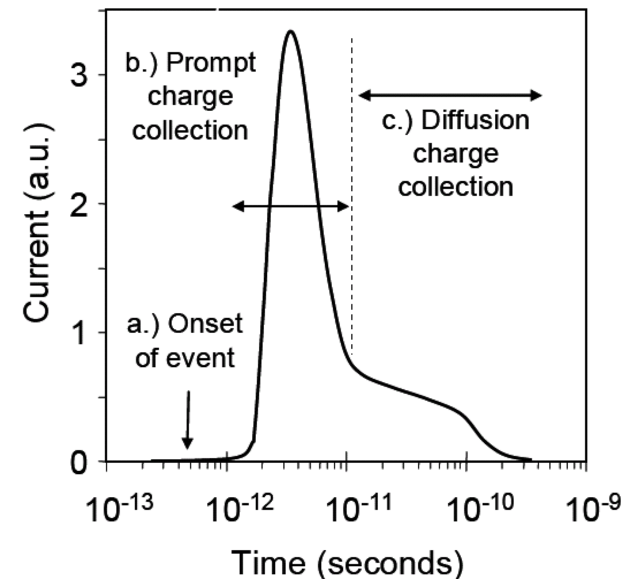
Introduction

- Cause of Soft errors
  a. Ion creates electron hole pairs in the silicon
  b. Charges drift and collect at nodes, producing a prompt current
  c. Later charges diffuse toward the nodes, producing lower current
- If the current is large enough, storage nodes such as SRAMs can switch states





R. C. Baumann, ***IEEE Trans. Device Mater. Reliab.***, vol. 5(3), p. 305-316, Sept. 2005

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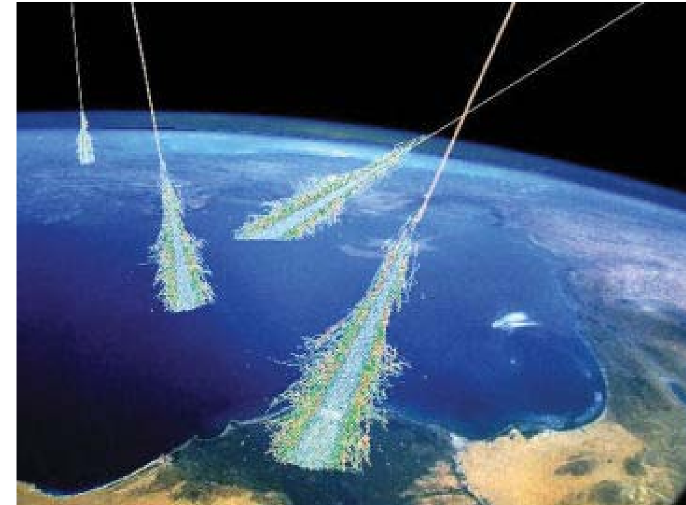
Source of High Energy Particles



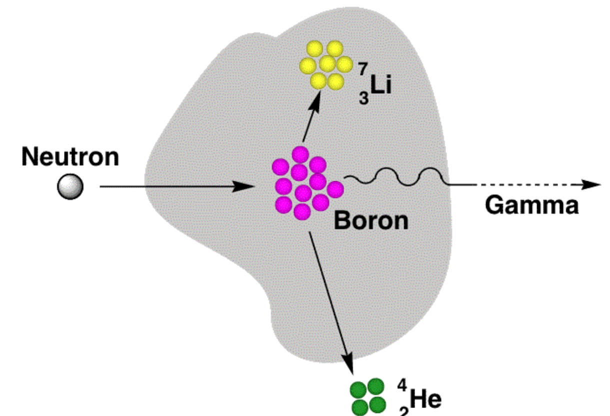
- High energy cosmic neutrons

  High energy particles from space collide with atmosphere form a shower of particles at terrestrial level

  These high energy particle can collide with silicon atoms

- Boron-10 Fission

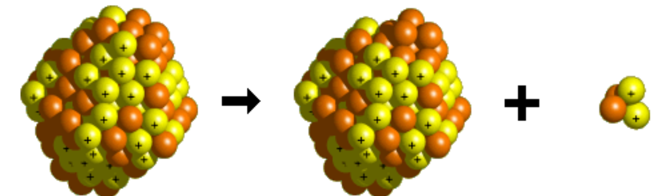
  B-10 captures a thermal neutron and fissions into a Li ion and an alpha particle



- Alpha particle

  Ion emitted from Uranium and Thorium (and daughter species) decay

  U and Th are trace contaminates in package materials; solder, underfill, molding compound



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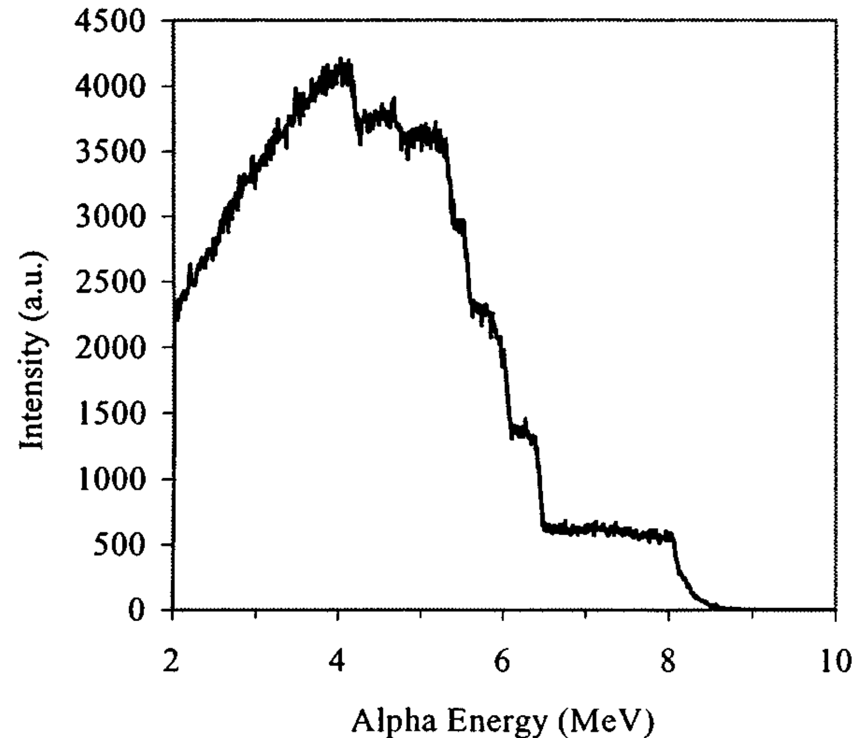
Most Alpha Particles below 6.4 Mev

Thorium decay chain	
Species	Energy (MeV)
Th-232	4.1
Th-228	5.5
Ra-224	5.8
Rn-220	6.4
Po-216	6.9
Bi-212	6.3
Po-212	8.9

Uranium decay chain	
Species	Energy (MeV)
U-238	4.3
U-234	4.9
Th-230	4,8
Ra-226	4.9
Rn-222	5.6
Po-218	6.1
Po214	7.9
Po-210	5.4



Alpha energy spectrum for Th foil

Actual energy spectrum is broadened to lower energies due to energy loss

Particles emitted inside the material lose energy as they pass to the surface

Baumann, IEEE Trans on Dev and Materials Rel, V1, No.1 March 2001 pp17-22

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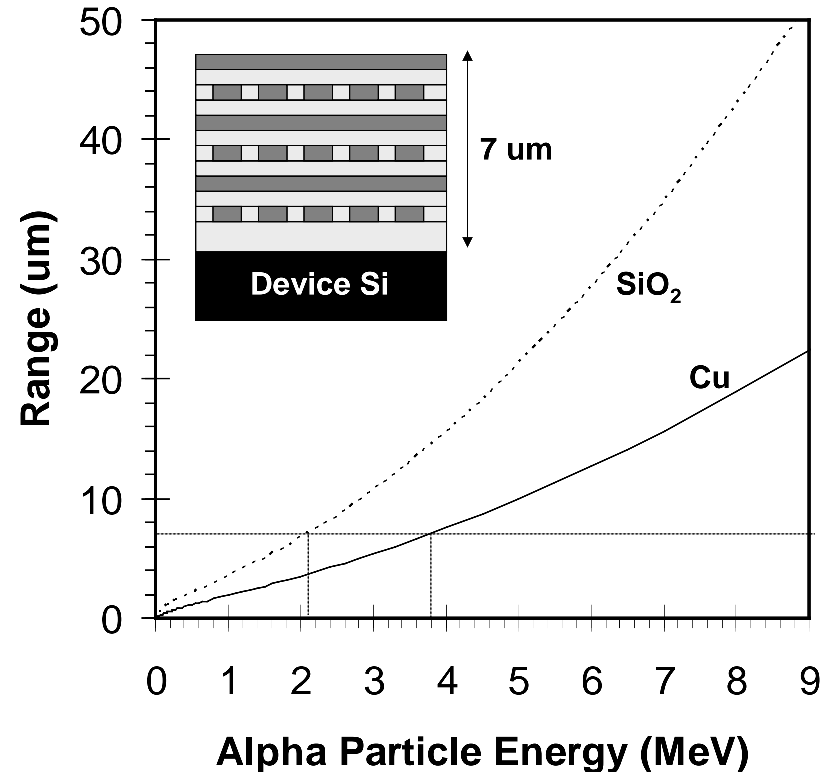
Penetration Depth of Alpha Particle

- Alpha particle penetration depth is a function of the material and the energy
- Copper: about 10 to 20um
- Oxide: about 20 to 50um
- Underfill: about 30 to 70um
- Alpha emitters must be close to the silicon surface to cause soft errors



JEDEC committee 13.4 draft "Alpha Radiation Measurement in Electronic Materials" 2008

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Soft Errors from Alpha Particles

- Materials near the silicon surface that can emit alpha particles

Wire bond packages:	molding compound
Flip chip packages:	solder bump
	underfill
	presolder on substrate

- General Terminology

Uncontrolled alpha emission:	1-20 alpha/cm^2/hr
Low alpha emission:	0.02 alpha/cm^2/hr
Ultra low alpha emission:	0.002 alpha/cm^2/hr

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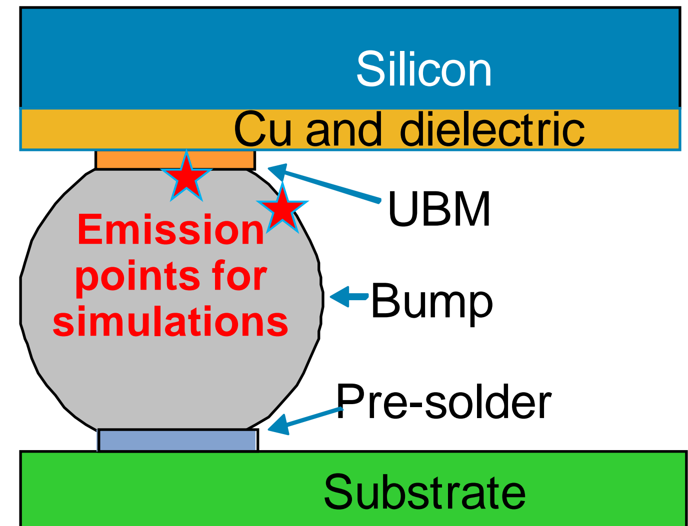
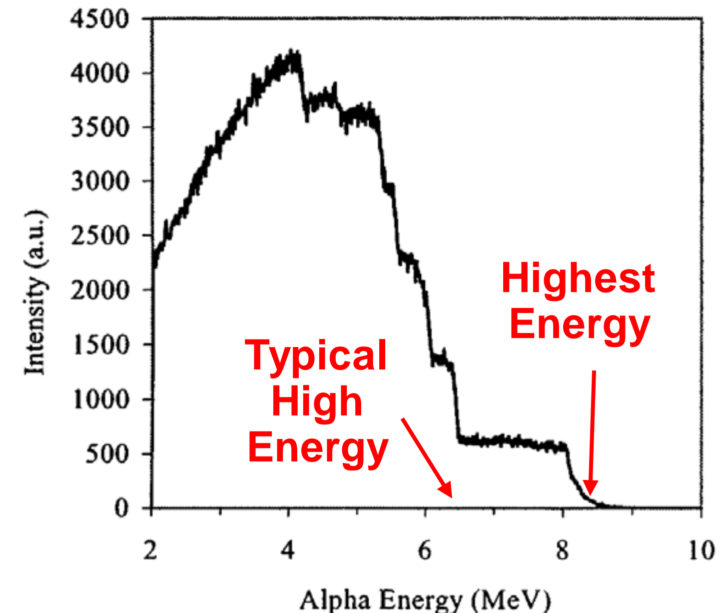
Alpha Range Simulation

- Assume alpha particles are emitted from the bump reflowed with pre-solder
- Two emission points for alpha particles will be simulated:
  - Directly under the UBM
  - On the bump



- Two emission energies for simulation
  - Typical energy = 6.4MeV
  - Highest energy = 8.9MeV



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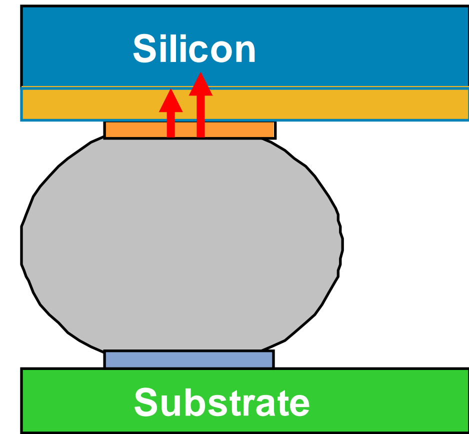
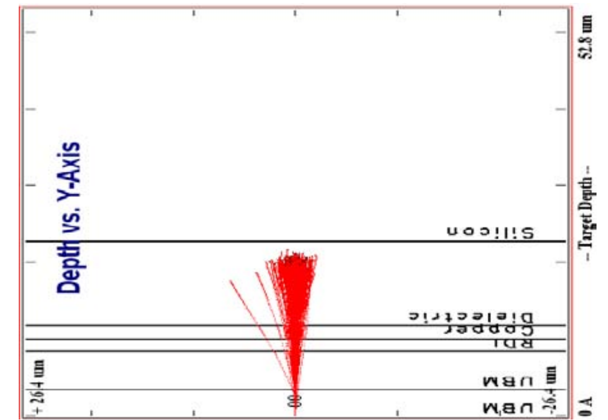
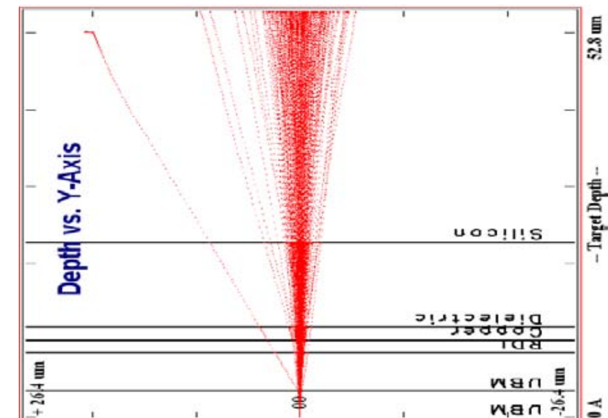
Scenario 1: Alpha Directly Under UBM

- Layers above active silicon
  - UBM
  - 9 layers of metallization at 50% metal density
- Results for 2 energy levels
  - 6.4 MeV alpha particles will unlikely reach the active silicon
  - 8.9 MeV alpha particles will likely reach the active silicon
  - Conclusion: Most alpha particles originating under the UBM will NOT cause soft errors.







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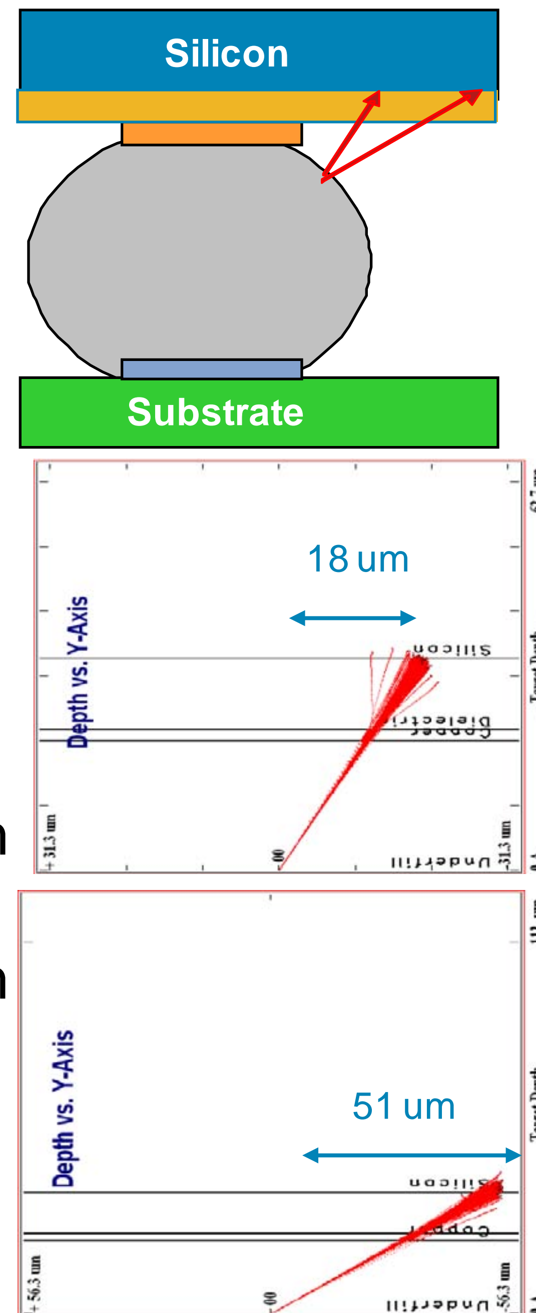
Scenario 2: Alpha from Solder Bump

- Layers above active silicon
  - 20 μm of underfill
  - 9 layers of metallization at 50% metal density
- Results for 2 different energies
  - 6.4MeV alpha particles will penetrate into the silicon with a max lateral range of 18 μm
  - 8.9MeV alpha particles will penetrate into the silicon with a max lateral range of 51 μm
  - Conclusion: Most alpha particles originating from the edge of the bump will likely cause soft errors.



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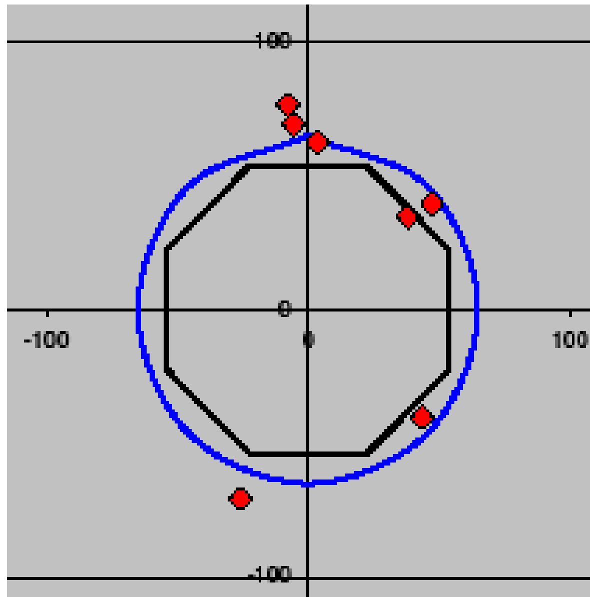
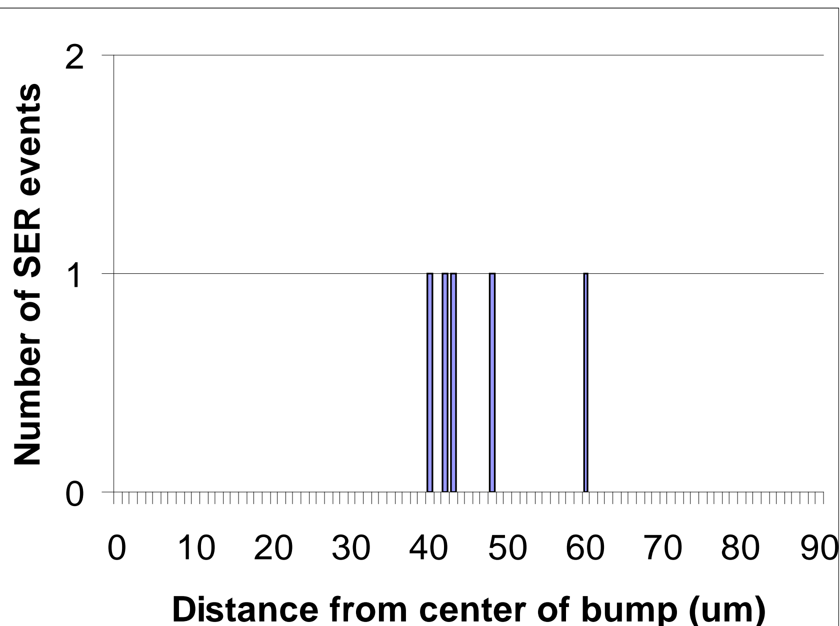
Soft Error Locations on Two Actual Devices



- Bit errors locations with ULA **eutectic solder** bump, uncontrolled alpha presolder
- Blue circle: outline of the UBM pad
- Red diamond: bit errors overlayed onto one solder bump



- Bit error locations with ULA **high Pb bump,** uncontrolled alpha presolder
- Bit errors are mapped with respect to the center of the bump
- All errors are located around the perimeters of the solder bumps

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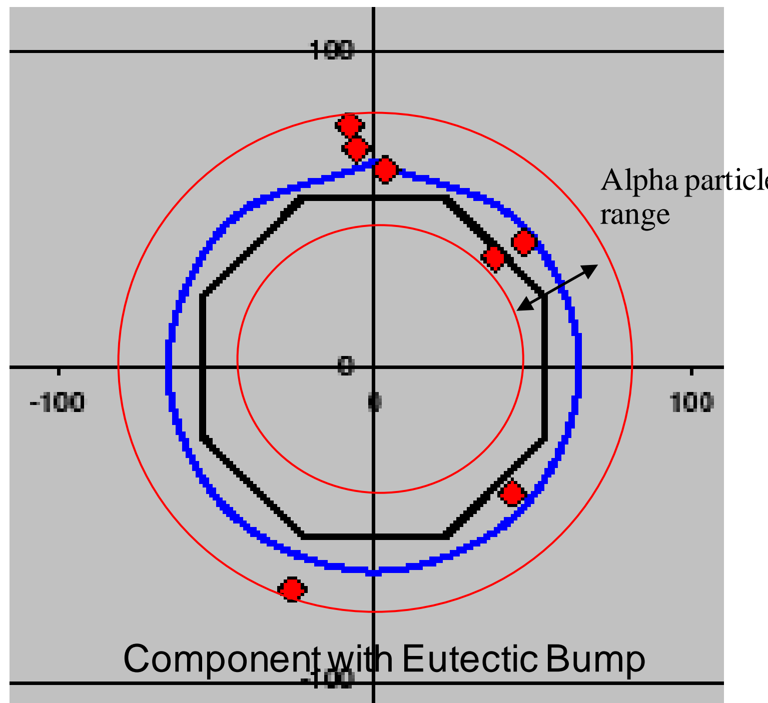
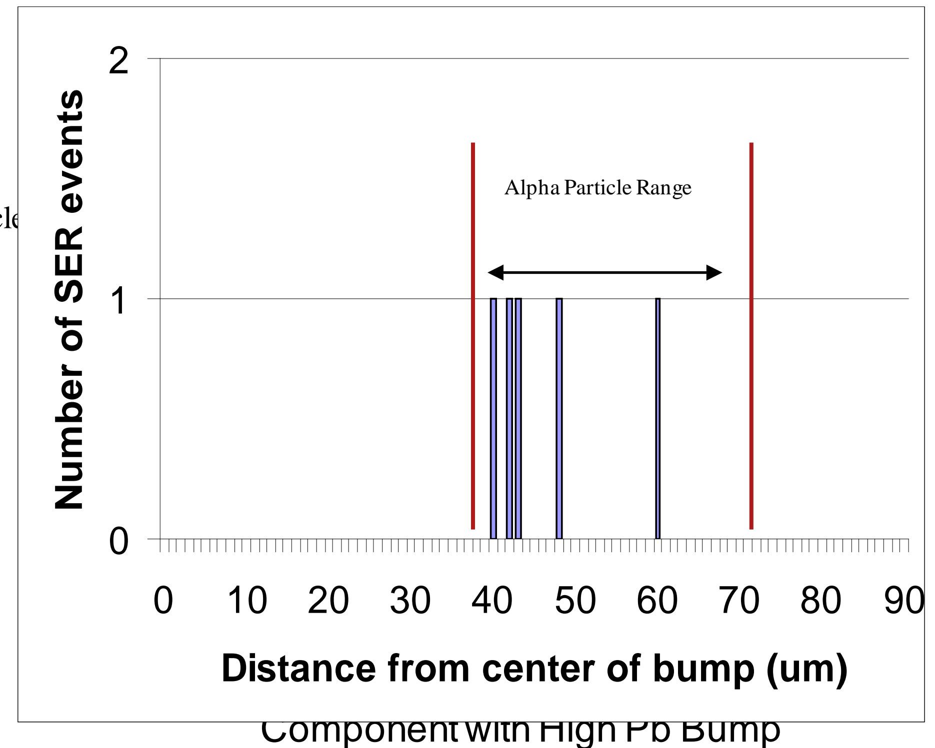
Simulated Range and Soft Error Location

- Most soft errors are within simulated range of typical high energy alpha particle





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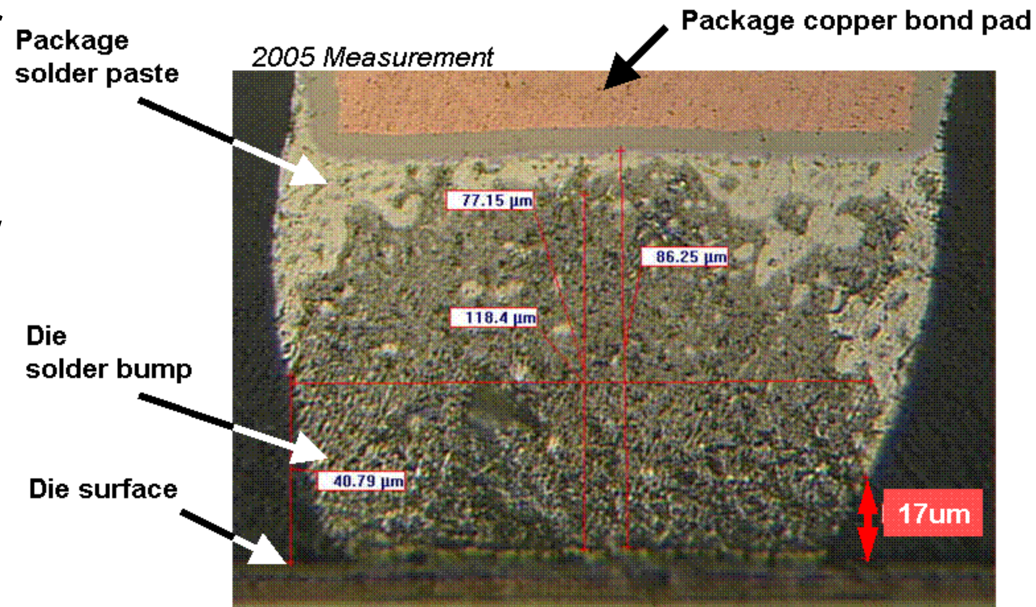
Uncontrolled Alpha Presolder Effect Soft Errors

- ULA eutectic bump with uncontrolled alpha eutectic presolder
  - Both solder melts and diffuse into each other
  - High alpha emitting presolder will end up near the silicon surface
- ULA high lead bump reflow with uncontrolled alpha eutectic presolder
  - Eutectic presolder melts and wicks along the sides of the bump
  - High alpha emitting presolder will reflow to near the silicon surface

Cross section of high lead bump reflowed with eutectic presolder



Eutectic solder after reflow is 17um from die surface

Note: die is on bottom

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ULA Presolder Effect on Soft Errors

- By converting to ULA pre-solder, a 50x reduction in soft error rate was achieved
- For flip chip components, alpha emissivity of all packaging materials must be controlled to reduce overall soft error rates

Pre-solder	Soft Error Rate
Un-controlled Alpha emissivity	503,000 FITs
ULA (<0.002 alpha/cm2/hr)	10,500 Fits

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Conclusion

- Simulations confirms soft error locations are within the range of Alpha particles emitted reflowed bump:

  All bit failure locations are an annulus around the bump

- Uncontrolled alpha emission eutectic presolder

  Reflows and mixes with eutectic bumps and cause Soft Errors

  Reflows around the sides of high lead solder bumps and cause Soft Errors

- System tests confirmed that replacing the uncontrolled alpha emission presolder with ULA presolder significantly reduces the soft error rate

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