Applications of Fracture Mechanics to Accelerated Testing of Plastic Encapsulated Microelectronics

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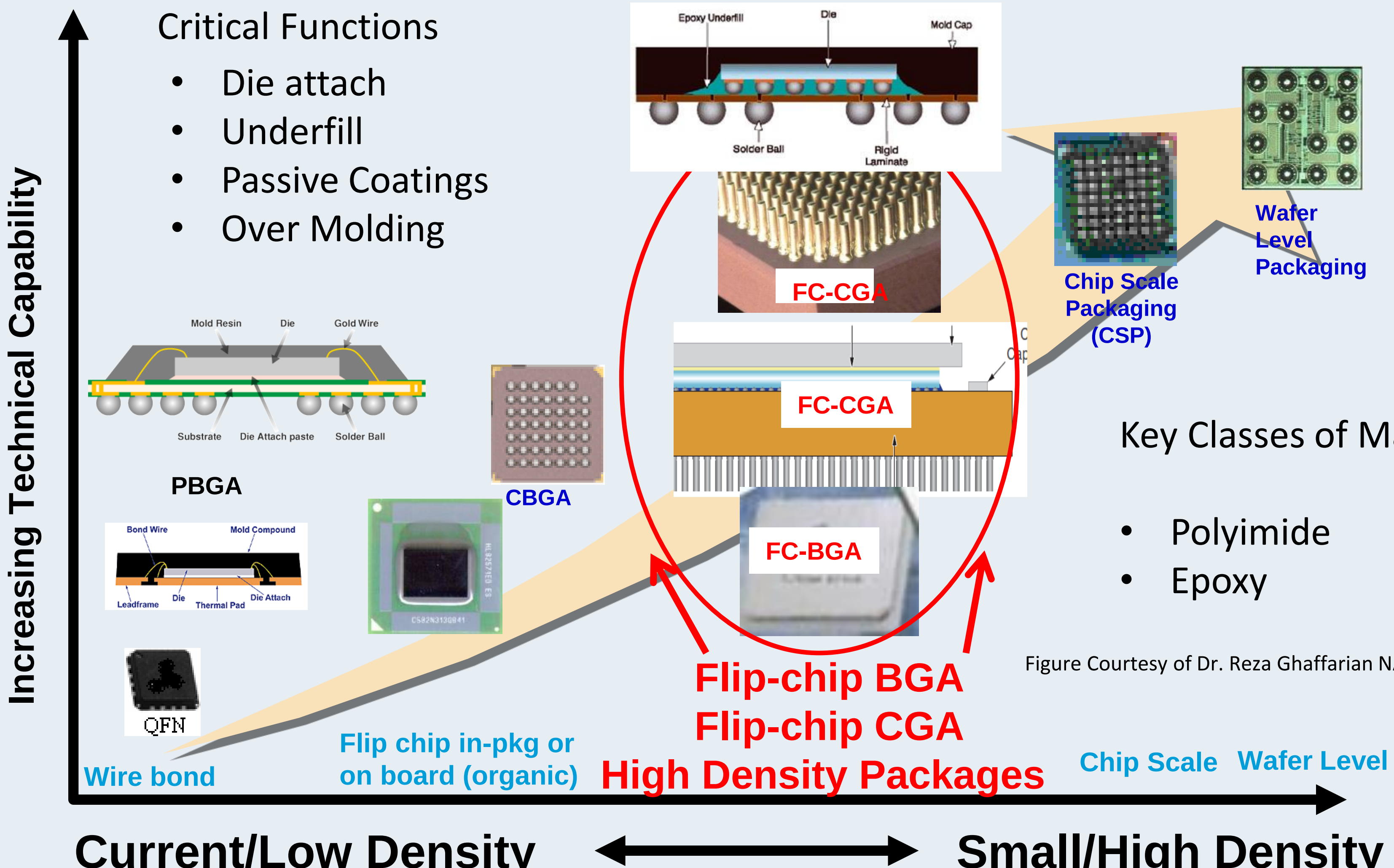
Advanced Packaging Depends on Polymers

Critical Functions

- Die attach
- Underfill
- Passive Coatings
- Over Molding

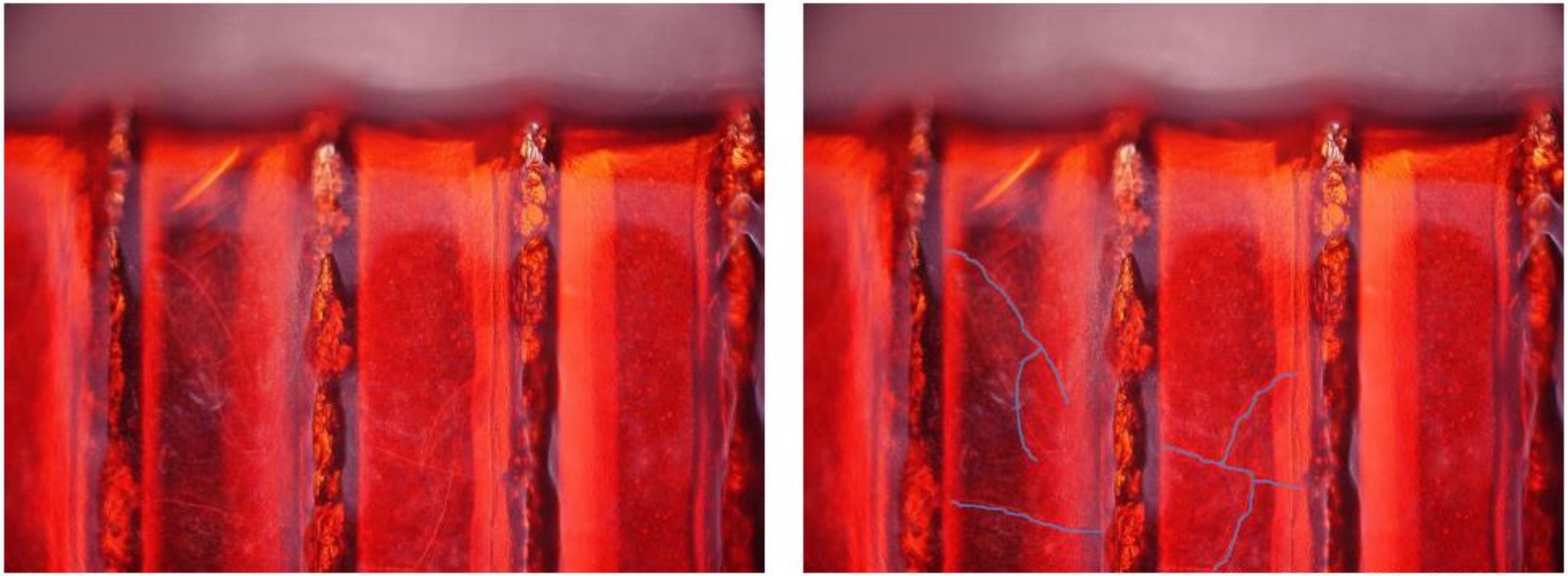


Key Classes of Materials

- Polyimide
- Epoxy

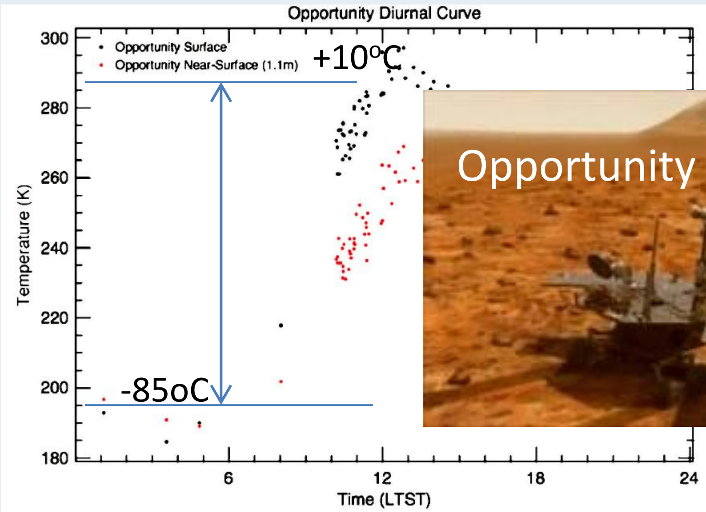
Figure Courtesy of Dr. Reza Ghaffarian NASA JPL

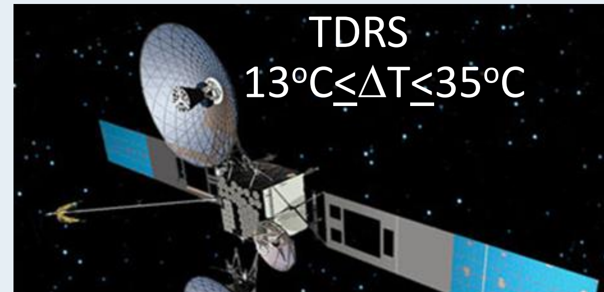
Polyimide Cracking in a Die Stack

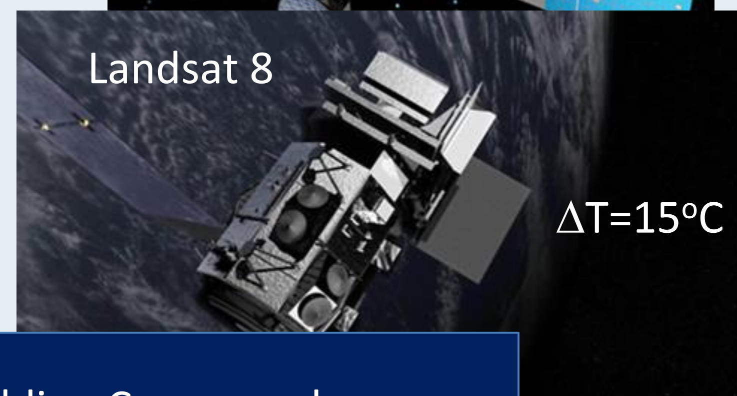


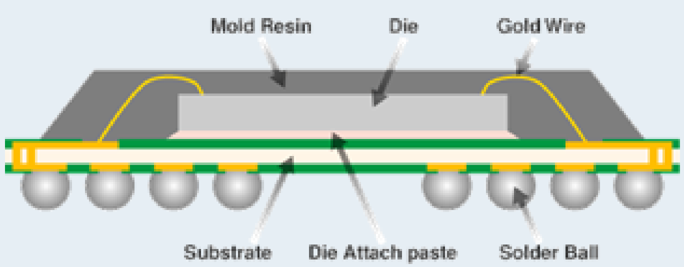
Courtesy of Ahmed Amin and Henning Leidecker
NASA GSFC

Differential Thermal Expansion Drives Stresses









Epoxy Molding Compound

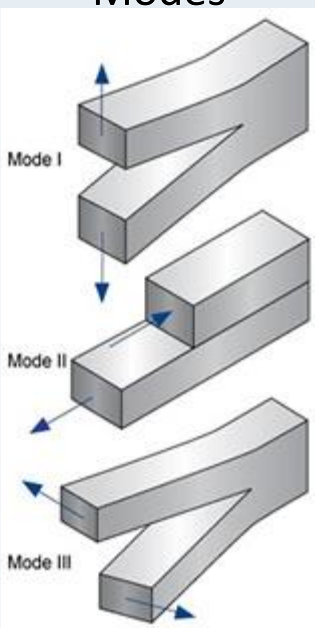
Polyimide

Silicon Die $\propto = 3ppm/°C$

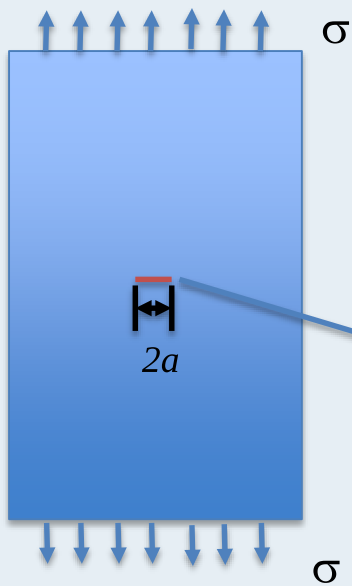
Key Concepts in Fracture Mechanics

- Crack Opening Mode
- Stress Intensity, K
- Paris Law

Opening Modes

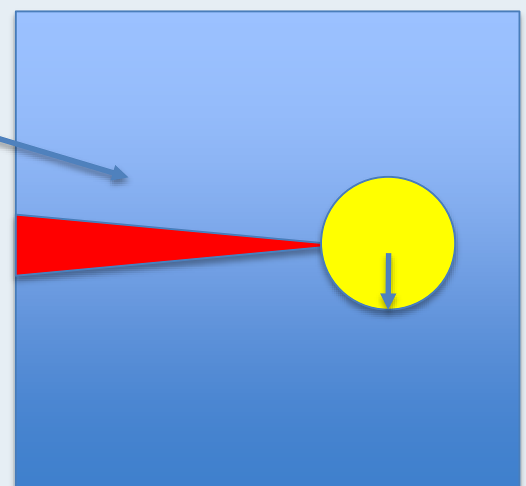


Stress Intensity

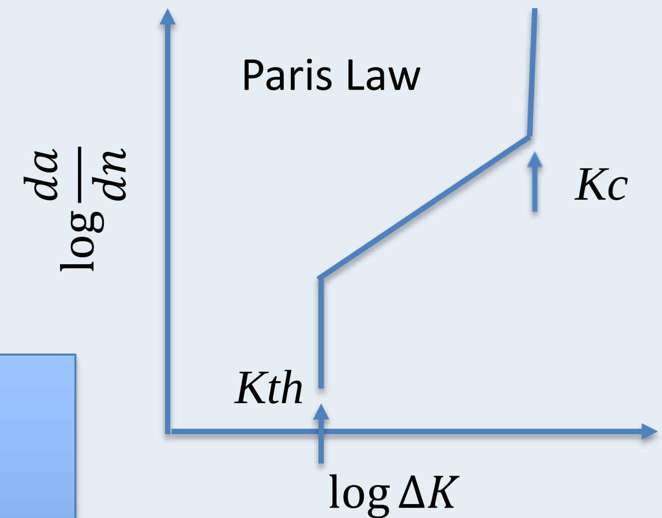


$$K = \alpha(\frac{a}{W}) \cdot \sigma \cdot \sqrt{\pi a}$$

Crack Tip Plastic Zone



$$rp \cong \frac{1}{6\pi} \cdot \left[\frac{K}{Sy}\right]^2$$



$$\frac{da}{dN} = A[\Delta K]^m$$

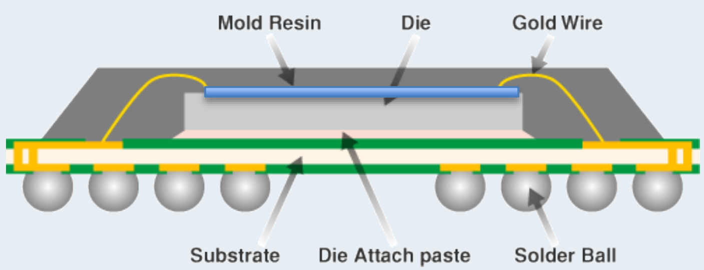
Paris Law Exponent for Polyimide

$$3.3 \le m \le 5.3$$

Notomi et. al. (1999)

Amagai Acceleration Factor

Spin-on Polyimide on Si Die
with Overmolded Epoxy



Complexities:

- Geometry
- Layered Structures
- Mixed Mode Crack Growth

Amagai Fatigue Prediction Model

$$(\sigma_{eq} \cdot rp)^{1.095} \cdot N^{0.4497} = t \cdot W$$

Amagai (1995)

$$N^{0.4497} \propto \frac{t \cdot W}{\Delta\sigma^{1.095}}$$

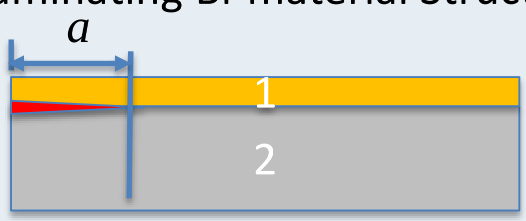
$$N \propto \Delta\sigma^{-0.2112}$$

$$\Delta\sigma \propto \Delta T$$

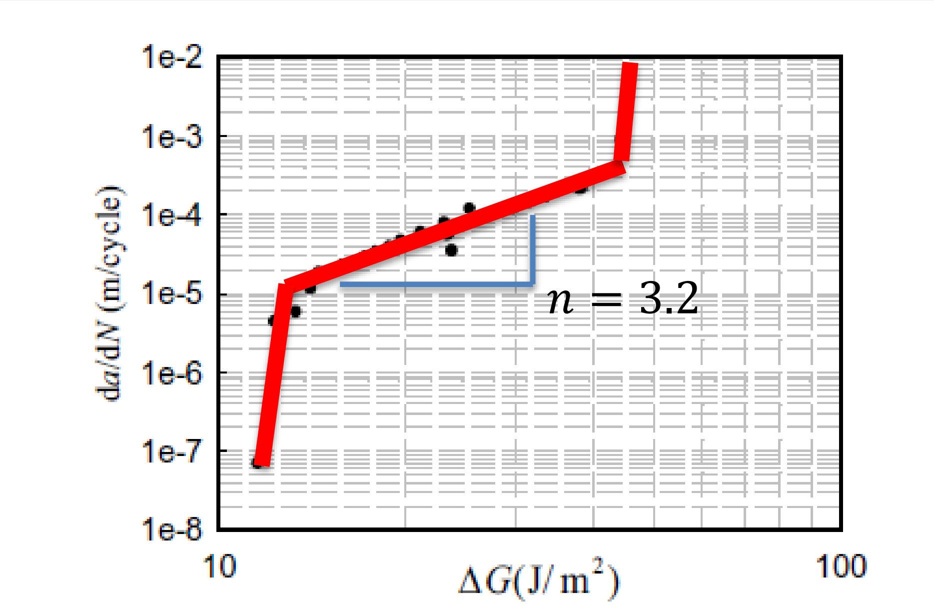
$$AF = \left(\frac{\Delta T_2}{\Delta T_1}\right)^{4.7}$$

Special Case: Interfacial Delamination

Delaminating Bi-material Structure



Micromechanical Fracture Test
Epoxy Bonded PI on SiN



(After Zhu et. al. 2010 w IEEE Permission)

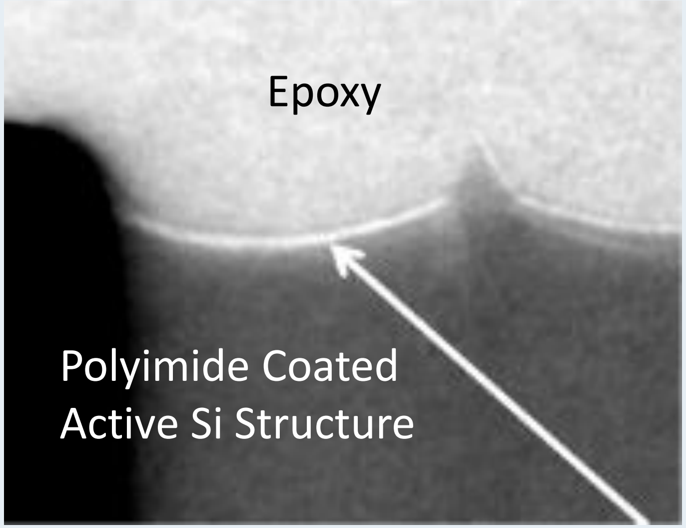
$$G = \frac{1/E_1 + 1/E_2}{2\cosh^2(\pi\varepsilon)} |K|^2$$

$$\Delta G \propto \Delta K^2 \propto \Delta\sigma^2$$

$$AF = \left(\frac{\Delta T_2}{\Delta T_1}\right)^{2n}$$

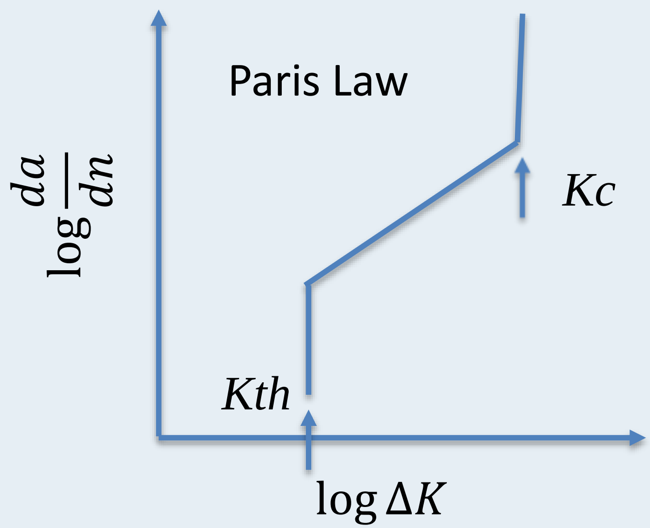
$$\frac{da}{dN} = C[\Delta G]^n$$

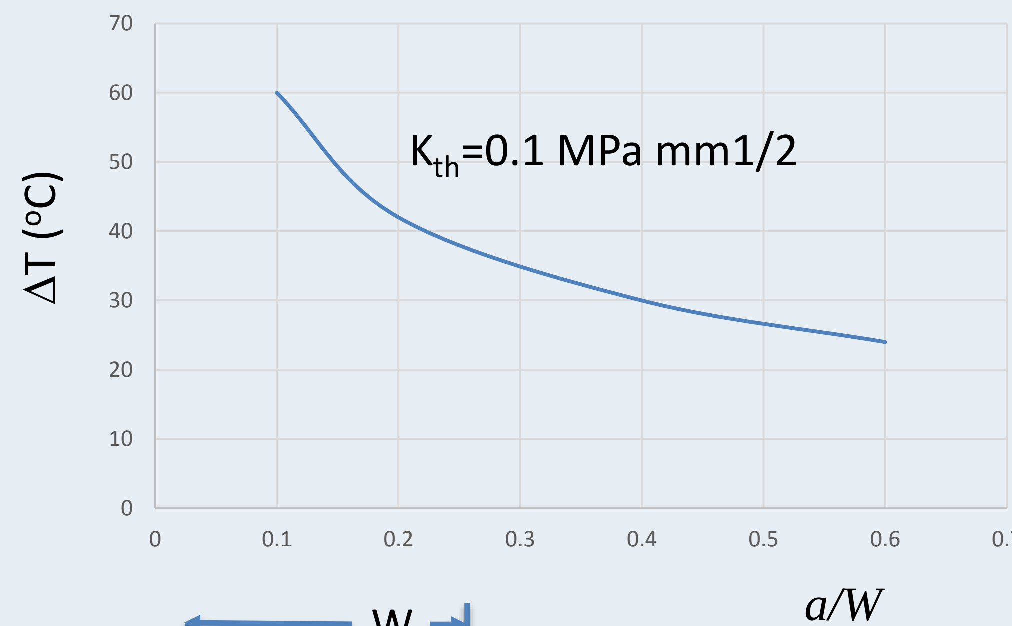
Interfacial Delamination

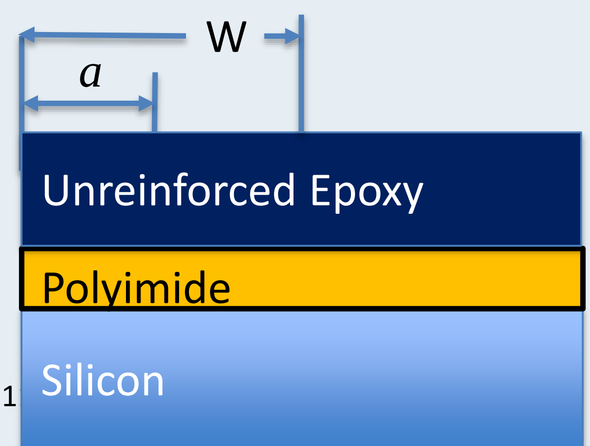


Courtesy Ahmed Amin GSFC

Threshold Values







$$\mathrm{K_{th}} \approx 1.1 \cdot \sigma_{th} \cdot \sqrt{\pi a}$$

$$\sigma_{th} = E_1 \Delta\alpha \Delta T$$

$$K_{th} \geq K_{Ith}$$

Conclusion

- Fracture mechanics provides a wealth of information for designing accelerated tests in polymer coated and encapsulated microelectronics
  - Acceleration factors for thermal cycling environments can be extracted
    - Delamination
    - Cracking
  - Materials performance and properties explicitly considered
  - Defects and defect interactions with structures can be modeled