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

Increasing Technical Capability

Current/Low Density ↔ Small/High Density

Key Classes of Materials
- Polymide
- Epoxy

Figure Courtesy of Dr. Reza Ghaffarian NASA JPL
Polyimide Cracking in a Die Stack
Differential Thermal Expansion Drives Stresses

Opportunity

\[ \Delta T = 95^\circ C \]

Landsat 8

\[ \Delta T = 15^\circ C \]

Epoxy Molding Compound

Polyimide

Silicon Die \( \alpha = 3 \text{ppm/}^\circ C \)
Key Concepts in Fracture Mechanics

• Crack Opening Mode
• Stress Intensity, \( K \)
• Paris Law
Elements of Crack Propagation

\[ K = \alpha \left( \frac{a}{W} \right) \cdot \sigma \cdot \sqrt{\pi a} \]

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

Paris Law

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

Paris Law Exponent for Polyimide

\[ 3.3 \leq m \leq 5.3 \]

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

\[
(\sigma_{eq} \cdot r_p)^{1.095} \cdot N^{0.4497} = t \cdot W
\]

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

\[ G = \frac{1}{E_1} + \frac{1}{E_2} \left( \frac{K}{2 \cosh^2(\pi \varepsilon)} \right)^2 \]

\[ \Delta G \propto \Delta K^2 \propto \Delta \sigma^2 \]

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

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

Micromechanical Fracture Test
Epoxy Bonded PI on SiN

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

![Interfacial Delamination Image]

Epoxy

Polyimide Coated Active Si Structure

Courtesy Ahmed Amin GSFC
Threshold Values

Paris Law

\[
\frac{da}{dn} = Kc \cdot \log \Delta K
\]

\[
K_{th} \approx 1.1 \cdot \sigma_{th} \cdot \sqrt{\pi a}
\]

\[
\sigma_{th} = E_1 \Delta \alpha \Delta T
\]

\[
K_{th} \geq K_{Ith}
\]

\[
K_{th} = 0.1 \text{ MPa mm}^{1/2}
\]
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