

Adhesion at bi-material interfaces in microelectronic packaging: Joining mechanisms and failure modes

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1. Introduction

Bi-material interfaces are fundamental to microelectronic packaging because modern devices integrate semiconductors, metals, ceramics, and polymers within compact architectures. These dissimilar materials experience thermo-mechanical and environmental loads, generating interfacial stresses due to property mismatch. Since cracks often initiate at interfaces, their integrity directly governs device reliability, performance, and long-term durability. Strong adhesion between dissimilar materials prevents delamination, ensures load transfer, maintains electrical integrity, and enhances long-term reliability. Figure 1 shows an illustration of Flip-Chip package involving different bi-materials.

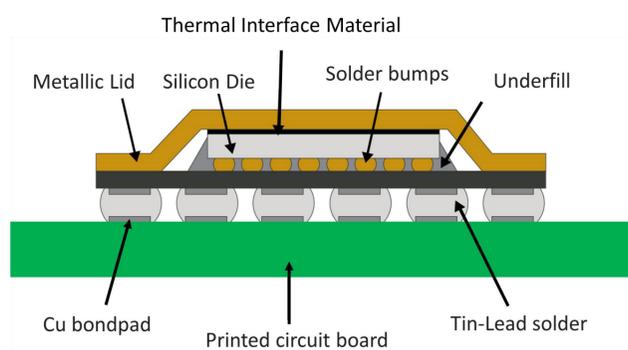


Figure 1. Cross-section of Flip-Chip package.

2. Joining mechanisms

Interfacial bonding in bi-material systems arises from combined chemical, physical, and mechanical mechanisms governed by material type, surface energy, compatibility, and processing (Figure 2). Metal/polymer systems rely on covalent, hydrogen, and van der Waals bonding plus interlocking; metal/metal interfaces involve diffusion and intermetallics; polymer/semiconductor systems form reaction layers; polymer/ceramic interfaces depending on surface treatment join by mechanical interlockings.

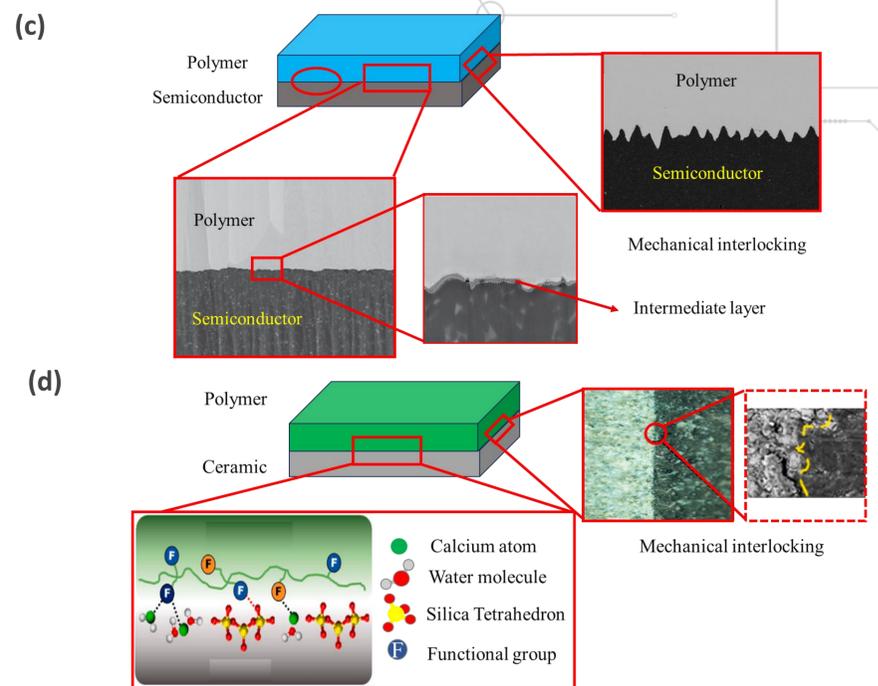
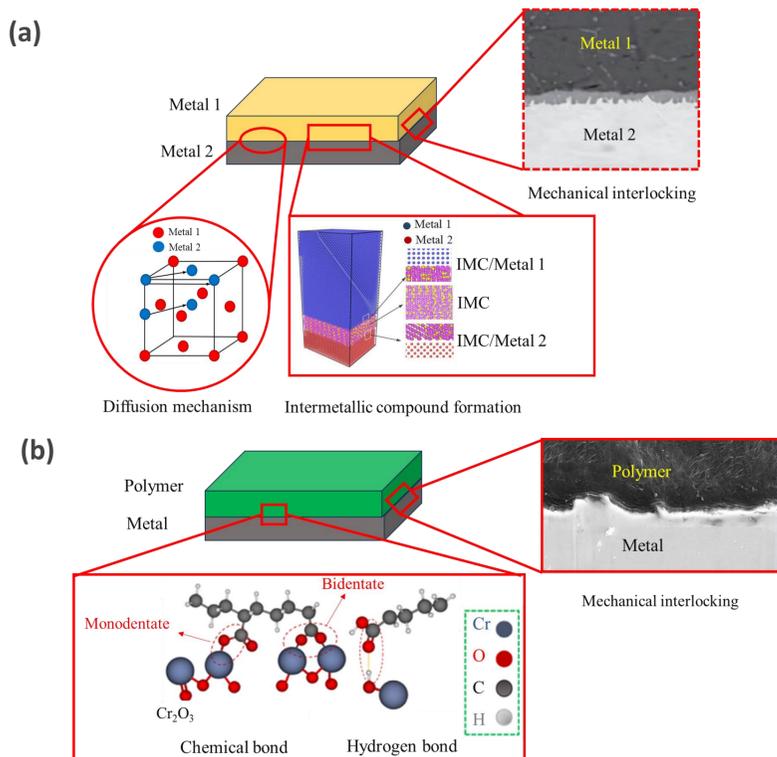


Figure 2. Bonding mechanisms at the interface of specific bi-materials; (a) metal/metal, (b) metal/polymer, (c) polymer/semiconductor, and (d) polymer/ceramic bi-materials

3. Failure modes

Interfacial delamination is a dominant failure mode in microelectronic packages, often triggering subsequent damage at both device and package levels. It typically initiates at material interfaces where thermal expansion mismatch, moisture swelling, elastic stiffness differences, and residual manufacturing stresses generate high mixed-mode stresses. Once initiated, crack propagation can degrade load transfer paths, reduce structural integrity, and ultimately compromise package reliability. Figure 3 shows examples of failures that originate from delaminating interfaces.

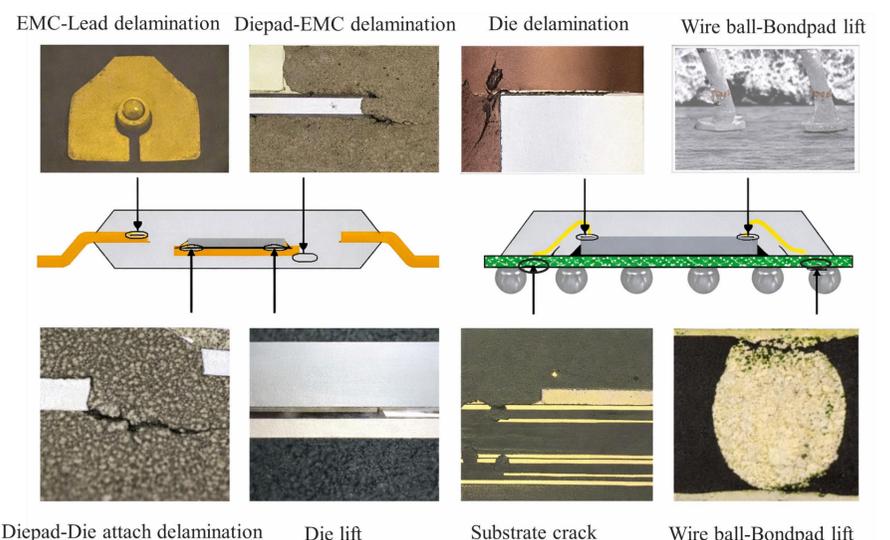


Figure 3. Failure modes for the leadframe-based (left) and substrate-based (right) packages.

4. Conclusion

Reliable microelectronic packaging depends on understanding interfacial joining mechanisms and predicting delamination-driven failures. Optimizing material selection, surface treatment, and interface design is essential to mitigate stress concentrations and ensure long-term structural and functional reliability.