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In-situ characterization of interface delamination by a new miniature mixed-mode bending setup

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ABSTRACT

The demands by the semiconductors industry for high levels of integration, lower costs and a growing need for complete system solutions has led to the emergence of "System In Package" (SIP) solutions in which "the package is the system". Since SIP-microsystems have multiple thin and stacked layers manufactured using different processes and materials, internal (intrinsic and/or thermal) mismatch stresses are almost always present, making interface delamination a primary failure mechanism. However, no effective methodologies are currently available for the proper characterization of interfacial fracture toughness in SIPs. In addition it is necessary to characterize interfaces in these systems over complete range of mode angles since the interface fracture toughness varies with mode angle. As a consequence, the industry is still heavily depending on trial-error methods for product/process development. Consequently, a strong demand exists for a generic and accurate mixed-mode bending (MMB) delamination setup that yields interface properties over the full range of mode mixity. Therefore, this work presents a generic technique to characterize interfacial properties and failure behavior over full range of mode mixity for complex multi-layer systems with a broad range of interfaces in terms of elastic mismatches with a particular emphasis on SIP-microsystems.

A number of experimental techniques have been developed to measure specific interfacial properties such as the fracture toughness. Fracture toughness diagnostics reported in the literature include the well-known double cantilever beam test for pure mode-I loading [1] and end notch flexure test for measuring pure mode-II loading [2], whereas the mixed-mode bending (MMB) setup [3, 4, 5] yields the fracture toughness over a much larger range of mode mixity. A primary difficulty for all of these delamination experiments, however, is the exact crack tip location, which is needed to calculate the fracture toughness. Moreover, additional interfacial properties, such as the crack growth rate or the crack opening profile, will be very useful for the accurate calibration of numerical models that are used to predict interface delamination in complex microsystems. Therefore, detailed in-situ characterization of the delamination experiment is crucial to pin-point the crack tip location and obtain more insight of the fracture process occurring at the crack.

This work improves on existing MMB setups by realizing an advanced miniature MMB setup that: is specially designed to minimize all non-linearities, such as friction, hysteresis, the influence of gravity, and geometrical non-linearities; yields the fracture toughness over the complete range of mode mixities; and, above all, has sufficiently small dimensions to fit in a scanning electron microscope and under an optical microscope for detailed real-time crack tip analysis, allowing, e.g., for local strain measurements using digital image correlation. The setup performance and its calibration procedure were verified from detailed finite elements simulations and various delamination tests on specially-designed test samples. Moreover, an analytical formulation was constructed to describe the applied loading configuration. Finally, proof of principle of the setup is demonstrated from the detailed characterization of several industrially-relevant bimaterial interfaces.

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