

Adhesion of Capillary Underfill Epoxies for Flip Chip Packaging

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Abstract:

Flip chip packaging is a popular means of compactly connecting silicon (Si) devices to their external circuitry. However, environmental factors can compromise the adhesive strength of capillary underfill epoxies used to seal and support the region between the devices and their substrates in such assemblies. In this study, methods of alleviating bisphenol-F (BPF) underfill epoxy delamination from Si through the addition of ductility-increasing flexibilizers and integration of organic-inorganic zirconium (Zr) hybrid layer sol-gels were explored. Double cantilever beam fracture mechanics tests used to quantify adhesive strength revealed that flexibilizers improve epoxy adhesion. Furthermore, through optimization of the hybrid layer preparation procedure, it was shown that while both stirring the sol-gel during aging and increasing the sol-gel cure time enhanced sol-gel adhesion, shorter sol-gel aging time most drastically improved upon the adhesion of hybrid layer-epoxy structures to silicon. These results, which identify flexibilizers and sol-gels as BPF adhesion promoters, will benefit the development of more reliable, high-performance microelectronics.

Introduction:

In flip chip packaging, Si devices are connected to their external circuitry with solder balls for space efficiency and reduced thermal resistance [1]. Underfill resins such as BPF-type epoxies can be deposited between the device and substrate to protect the device, enhance mechanical connectivity, and alleviate stresses from device-substrate thermal expansion mismatch [1]. However, standard processing and operating conditions of flip chip assemblies can introduce heat and moisture to the system, which accelerate epoxy delamination.

The addition of ductility-increasing flexibilizer functional groups to the epoxy matrix was investigated as one means of enhancing epoxy adhesion. Also explored were Zr sol-gels; graded hybrid films whose organic epoxy groups and inorganic Zr oxides covalently bind to organic epoxy surfaces and inorganic metal oxides on substrate surfaces, respectively (Figure 1). To determine BPF plus flexibilizer and hybrid layer (HL) effectiveness in improving upon BPF adhesion, their fracture energies, or the amount of energy per unit area required to propagate a crack through a material, were calculated using double cantilever beam fracture mechanics testing. The sol-gel preparation procedure was also optimized for coupling with BPF.

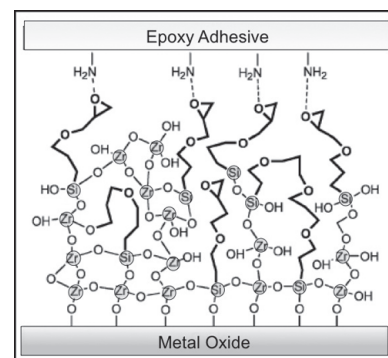


Figure 1: Network composition of the zirconium hybrid layer [2].

Experimental Procedure:

Double Cantilever Beam Specimen Fabrication and Testing (Figure 2). Pairs of rectangular Si substrates were sputtered with gold pre-cracks and bonded together with a 50 μm thick epoxy layer, either BPF or BPF with flexibilizers. Specimens were then cured at 165°C for two hours and sliced with a wafer saw into four identical beams. After loading tabs were attached, specimens were subjected to tensile testing, from which applied load and subsequent beam displacement values were obtained. Fracture energy of the epoxies sandwiched between the Si beams was then calculated from these values.

Sol-Gel Sample Preparation. Ether 3-glycidoxypropyl-trimethoxysilane (GPTMS) was homogeneously mixed with deionized water, while tetra n-propoxyzirconium (TPOZ) (70% in 1-propanol) and glacial acetic acid (GAA) were hand-swirled separately until cool to the touch. After the GPTMS/water was added to the TPOZ/GAA for a final 0.77:1 Zr/Si molar ratio and 3.75% volume GPTMS+TPOZ, the solution was aged at room temperature. Solutions were prepared with and without magnetic stirring during aging, as well as with variable aging times.

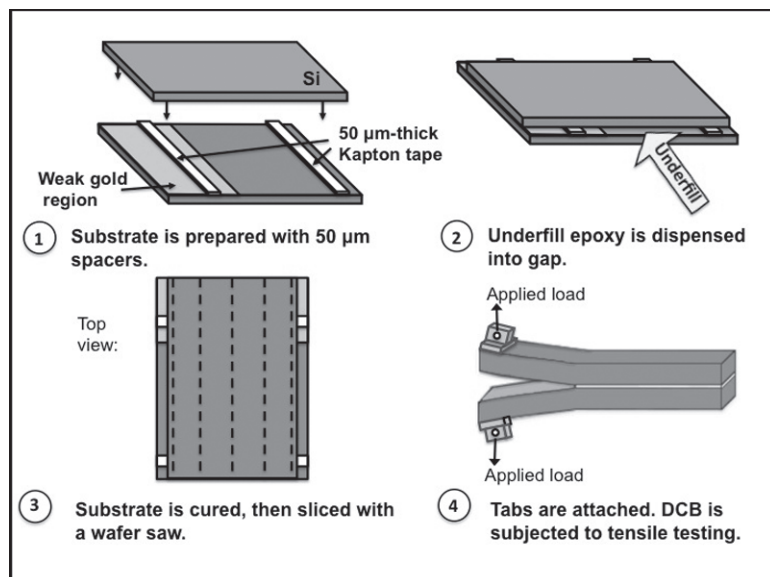


Figure 2: Double cantilever beam specimen fabrication and testing.

UV-ozone cleaned rectangular Si substrates were dip-coated into the sol-gel at 10 mm/sec and immediately withdrawn at 0.2 mm/sec. HL-coated pieces were then cured at 120°C for variable times and used to fabricate double cantilever beams with BPF underfill for tensile testing.

Results and Discussion:

Ductility-increasing flexibilizers increased BPF fracture energy (Figure 3a).

Stirring the HL during aging, and longer HL curing times, increased the HL fracture energy (Figure 3b), due to the sol-gel achieving a more condensed state with more network cross-linking.

Shorter sol-gel aging time drastically improved upon the fracture energy of BPF with HL (Figure 3c). The observed mixed-mode cohesive failure path within the BPF under shorter aging conditions explains this phenomenon, as more energy is required to plastically deform BPF than to delaminate BPF from substrates. Shorter HL aging time is thought to correlate with a shorter solution condensation time, thus leaving a fresher and higher-quality material for thin-film deposition onto Si substrates.

Summary and Future Work:

Both flexibilizers and Zr HLs improve BPF adhesion to Si. An optimized HL preparation procedure for coupling with BPF includes stirring while aging, longer curing times, and shorter aging times. Future work involves continued optimization of the Zr HL preparation process, such as optimizing cure temperature and determining the respective upper and lower limits on curing and aging times. Further characterization of the HL's physical and chemical properties is also necessary to more thoroughly understand its mechanism of fracture energy enhancement. Finally,

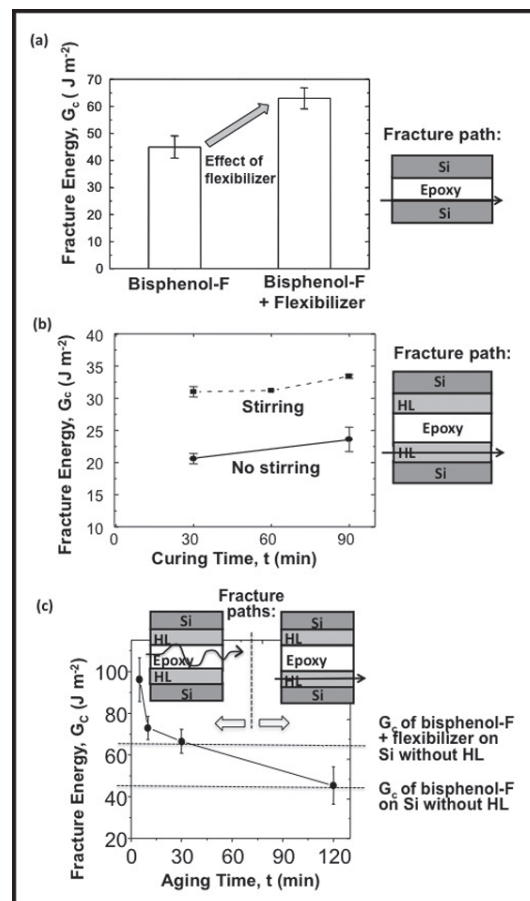


Figure 3: a) The effect of flexibilizers on BPF fracture energy. The effects of varying b) stirring presence and cure time, and c) aging time on HL fracture energy.

fracture mechanics testing of the HL under high humidity levels and temperatures will determine whether HL fracture energy enhancements can be sustained in harsher environmental conditions.

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