Fracture and delamination response of semiconductors under humidity exposure

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1. Introduction

Semiconductor wafers are central to microelectronic devices, where the die within a wafer-level package consists of multiple semiconductor, polymeric, ceramic, and metallic layers serving distinct functions. These heterogeneous interfaces are highly susceptible to humidity-induced degradation, leading to interfacial weakening and delamination, which must be systematically investigated and mitigated. Adhesion reliability at polymer–semiconductor interfaces is critical in microelectronic packaging and multilayer device fabrication. Polyimide films are widely used as dielectric and passivation layers on silicon substrates.

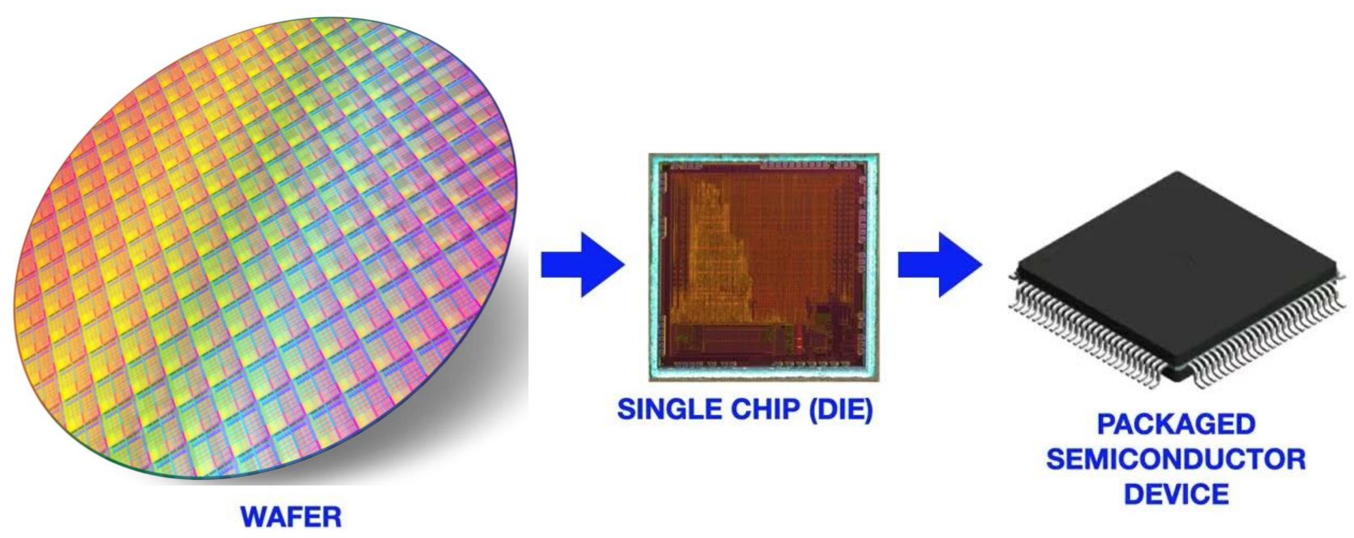

Figure 1. Semiconductors; from wafer to chip.

2. Methodology

One of the established methods for evaluating adhesion behavior is the 90° peel test, in which an adhesive film is peeled from the substrate at a fixed angle while the required force is recorded. This technique provides a quantitative measure of interfacial strength and is widely used to assess environmental effects, rate dependence, and failure mechanisms in bonded systems.

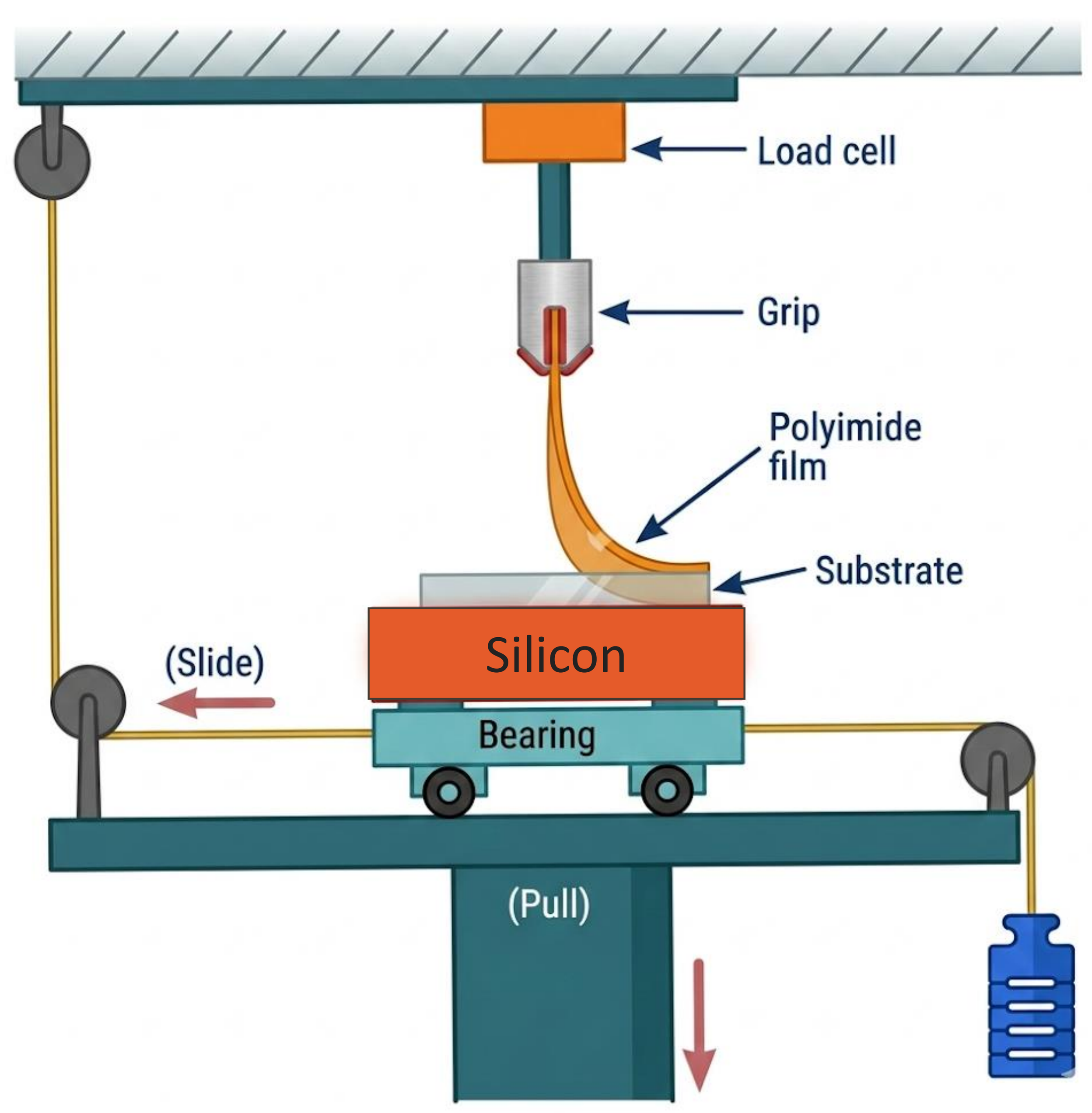

Figure 2. Schematic diagram of a 90° peeling apparatus

3. Humidity-Dependent Fracture Behavior

There is a non-monotonic relationship between peel strength and relative humidity, with adhesion initially decreasing as humidity rises, reaching a minimum at intermediate levels, and then increasing again under higher humidity conditions. This trend reflects the interplay of competing interfacial processes, where moisture influences both the energy required for crack propagation and the dominant failure mechanisms at the adhesive-substrate interface.

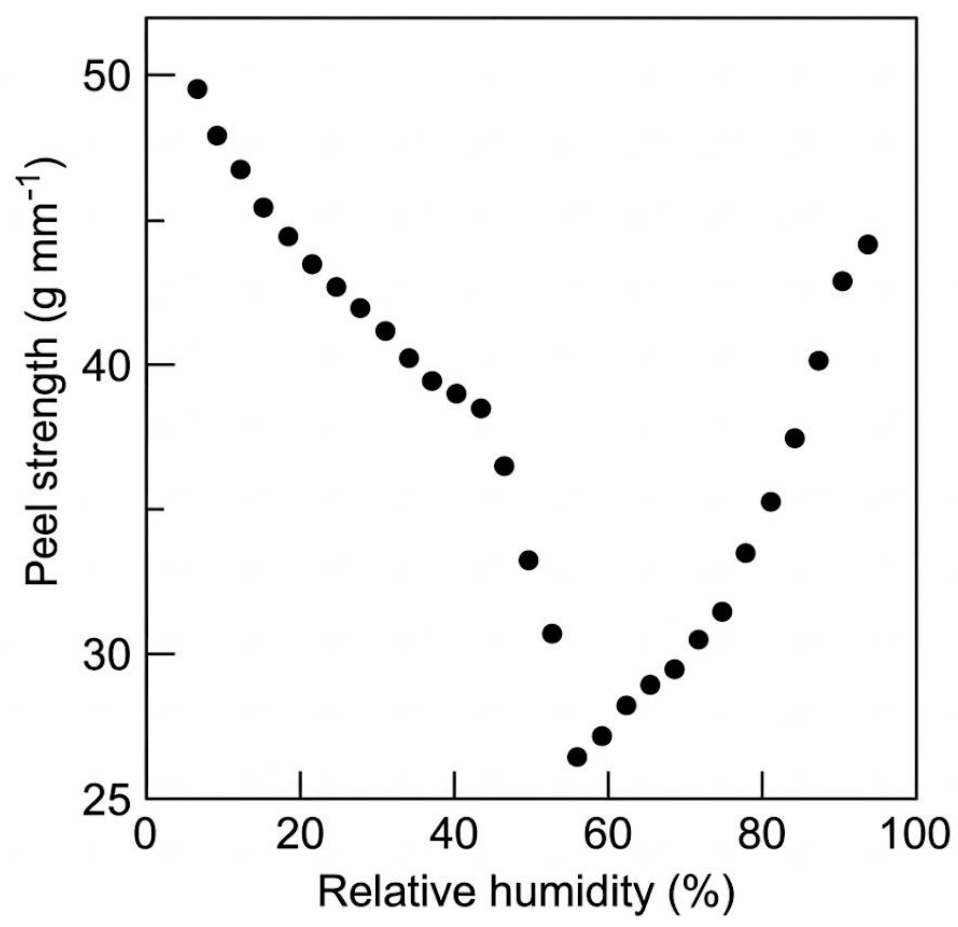

Figure 3. Peel strength of polyimide film as a function of relative humidity [1].

4. Mechanisms of Moisture-Induced Delamination

Interfacial Moisture affects adhesion through hydrolysis of interfacial bonds and adsorption at crack tips. At moderate humidity, water weakens interfacial interactions, reducing fracture resistance. At higher humidity, hydrogen bonding within weak boundary layers may temporarily increase apparent adhesion. Direct moisture attack at the peel crack tip is identified as the dominant degradation pathway. Figure 4-a illustrates the weak boundary layer concept, showing failure occurring near the polymer–silicon interface during peel-induced delamination. Figure 4-b schematically illustrates hydrogen bonding induced by water within the weak boundary layer of the polyimide.

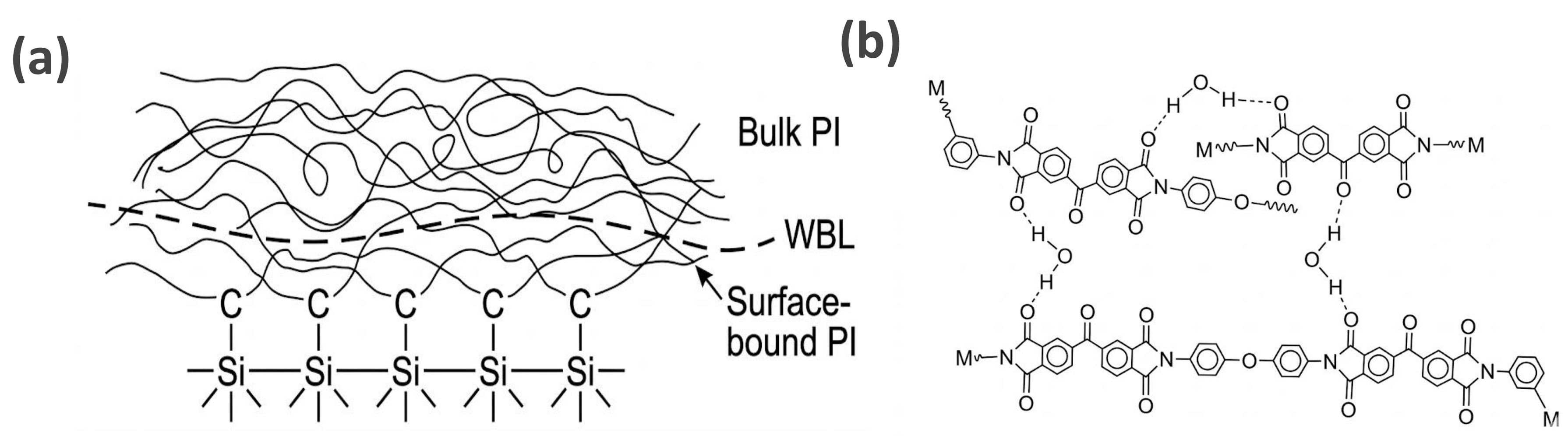

Figure 4. a) Weak boundary layer and interfacial failure zone, b) Moisture-induced hydrogen bonding at the interface [1].

5. Conclusion

Humidity significantly alters fracture and delamination behavior in semiconductor–polymer systems. Crack-tip moisture adsorption governs adhesion degradation, highlighting the importance of environmental control and interface engineering for reliable microelectronic device performance.

References

[1] Hu, D. C., & Chen, H. C. (1992). Humidity effect on polyimide film adhesion. *Journal of materials science*, *27*(19), 5262-5268.