APPLICATION NOTE

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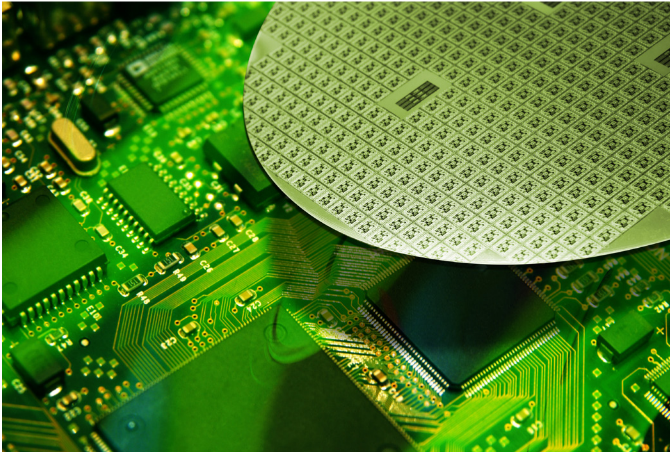
Industry Solutions: Semiconductor Packaging



Semiconductor Research

Hysitron's line of **PicoIndenter**® nanomechanical test instruments have become powerful *in-situ* characterization tools for researchers within the semiconductor and semiconductor packaging industries. Recent advances in this field, including the trend toward 3D integration, offer the promise of a significantly higher density of devices within a smaller overall package, along with numerous improvements in overall performance. However, investigation of these wafer-on-wafer systems has revealed a host of micro and nanomechanical hurdles that must be overcome.

CTE Mismatch in TSV

In-situ nanomechanical testing offers a number of advantages for characterization of three-dimensional integrated circuits (3D IC). Due to mismatches in coefficients of thermal expansion (CTE), temperature cycling in through-silicon via (TSV) connections results in highly non-uniform stress distributions. This has been found to impact reliability and can lead directly to mechanical failure through TSV extrusion, delamination, and/or cracking in the silicon substrate. Hysitron's **PicoIndenter** products offer a direct means for studying these phenomena at the micro and nanoscale by enabling researchers to apply stress to a specific structure while observing the subsequent mode of deformation in real-time. Temperature dependence can also be further investigated using PicoIndenter instruments equipped with the MEMS heating option which enables sample heating up to 400°C, giving the user a direct method for reproducing and investigating the effects of CTE mismatch.

Cu Grain Size and EBSD

In addition to complications related to CTE mismatch, temperature cycling within TSV interconnects alters the microstructure of the copper and influences grain size. PicoIndenter instruments are used to measure corresponding changes in mechanical strength while other capabilities of the SEM such as electron backscatter diffraction (EBSD) can be utilized to monitor temperature-dependent grain orientation. Through these complementary techniques a complete characterization of these materials is facilitated without the specimen ever leaving the SEM chamber. Materials that are prone to oxidization, such as the Cu interconnects within the TSV, can be tested in a pristine state without exposure to O_2.

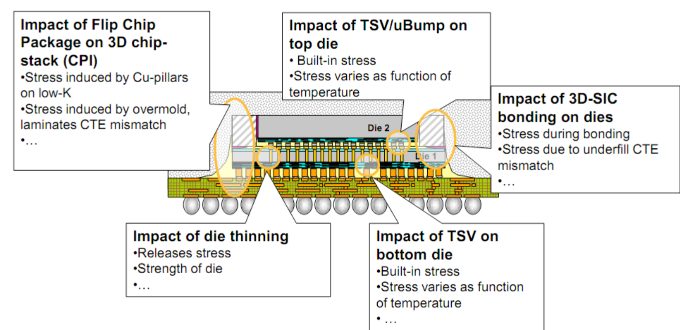


Figure 1: Stress-related concerns for 3D IC packaging.
Image courtesy of IMEC.

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Keep Out Zone

The force/displacement curve resulting from quantitative nanoindentation testing can be correlated with the residual stress of the small volume of material beneath the indenter. For semiconductor packaging, this capability can be used to determine the extent of the keep-out zone surrounding TSV interconnects. Real-time images obtained from the microscope enable the user to align the probe with high spatial resolution onto the regions of interest and confirm correct placement following the test. In the SEM, automated grids of indents can also be performed to accurately map the properties of larger regions.

Interfacial Delamination

On focused ion beam (FIB) systems, milling of the 3D IC structure can be accomplished to simplify the sample geometry and isolate a given component or interface for mechanical testing. The role of impurities at these interfaces can also be studied for a more complete understanding of interfacial debonding.

Underfill Properties

Underfill materials can become brittle when subject to normal working temperatures in electronic packages. The evaluation of this transition from ductile to brittle as a function of temperature and proximity to metals or the heat source can be evaluated by the precise tip placement and sensitivity of the Hysitron PicoIndenter instruments.

PI 95 TEM PicoIndenter® Instruments

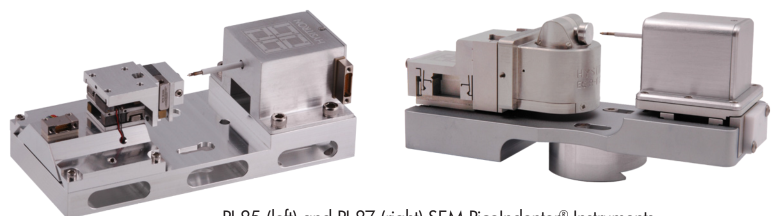
PicoIndenter Overview

Hysitron's *in-situ* product line features the **PI 95 TEM PicoIndenter**, the **PI 85 SEM PicoIndenter**, and the **PI 87 SEM PicoIndenter**. Standard testing modes include indentation, compression, bend, and tensile. On the **PI 95** and **PI 85**, sample heating up to 400°C and simultaneous electrical characterization can also be added for an even more robust determination of mechanical properties.

The **PI 87 PicoIndenter**, in comparison to the **PI 85**, features two additional degrees of freedom (rotation and tilt) for sample positioning. This enables users the freedom to align the sample to an ion beam or various detectors (EBSD, EDS, WDS, etc) for advanced analysis. Mechanical stresses induced by this system, in conjunction with subsequent seamless EBSD mapping, can be used for a thorough examination of the stress/strain relationship as well as stress-induced failure modes.

Semiconductor Applications

- Residual stresses and mechanical failure resulting from CTE mismatch
- Hardness and elastic modulus of low κ films
- Phase transformations, electrical properties, and crystallographic orientation of Si substrates
- Temperature- and size-dependent properties of lead free solders
- Cu grain structure and temperature influence in TSVs
- Role of impurities on interfacial strength



PI 85 (left) and PI 87 (right) SEM PicoIndenter® Instruments

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