On-wafer Reliability Testing – Back to the Future

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IF there is one grand truth in the semiconductor industry it is this: Simple device scaling to achieve performance gains is dead.

You might say that the lithography cow has been milked. Performance gains at future technology nodes will no longer come from simply shrinking devices by ratcheting down wavelengths.

As fabs race to stay on the Moore's Law curve, they can no longer count on performance gains from device scaling. As a result, they are introducing new materials at mind-numbing rates. Incremental performance gains from these new material systems began to surpass those from litho technology at the 90nm node. However, newer materials are often electrically unstable and/or unpredictable. This drives the need for a larger volume of reliability testing and at more points in the development cycle.

Consequently, more expensive and riskier R&D must occur far earlier in the lifecycle of a new technology node. This is evidenced by recent consolidation of R&D at industry consortia and smaller IDMs. Evidence that integrating new materials and devices is more challenging than expected is seen in the plugged-up funnel of major new innovations. These include characterizing extremely low leakage and tunneling currents, Si and gate dielectric interface defects and related degradation, NBTI degradation and recovery mechanisms in PMOSFETs, and charge trapping in high-κ gate dielectrics.

The industry had walked down a similar path nearly 20 years ago. Back then, Si/SiO_2/polysilicon/Al materials were the new big frontier in materials science. Understanding the basic materials and their integration into a full process required substantial effort. Unfortunately, once that was solved, the industry largely neglected materials engineering because the Si/SiO_2/polysilicon/Al materials system is so well behaved. With two decades of stable Si/SiO_2/polysilicon/Al materials experience, the industry had little need for a large cadre of materials physicists or the infrastructure to train new ones. The industry's complacency resulted in the atrophying of the infrastructure needed to train the new materials scientists who are required to overcome the next wave of emerging materials challenges.

Today, there is a lack of skilled scientists who can develop new material systems, expand reliability test methodologies, and interpret the huge volume of data this entails. Unfortunately, we don't have the luxury of waiting for the redevelopment of a materials physicist infrastructure – Moore's Law is calling us back to the future.

In addition to the materials science juggernaut, device voltage scaling driven by low-power mobile devices compounds the industry's problems. The ability of even the well-behaved Si/SiO_2/polysilicon/Al materials system to deliver stable DC operating points like threshold voltage over extended product lifetimes is becoming more difficult, let alone with the new electrically-unstable materials systems.

This decades-long complacency driven by the stability of the Si/SiO_2/polysilicon/Al materials systems leads to an inefficient testing model. Some reliability testing is done in R&D and process development, and then little or none is performed during the process integration and volume wafer production phases. It is then ramped up again when dies are packaged.

The net result of the materials changes and voltage scaling are twofold. First, there will need to be increased reliability testing done in R&D, process development, and technology development. The results will be more difficult to analyze due to the physics of the new materials. A lack of materials engineers means that those facilities will need to rely on test suppliers not just for measurement boxes but for physics and materials expertise to interpret results. Ultimately, this will call for a wider breadth of new test instrumentation.

To stay competitive, fabs will have to increasingly rely more on suppliers who have in-depth expertise, not just in instrumentation and measurements, but also in material behavior. Such suppliers can rapidly develop new test methodologies and equipment, help integrate testing throughout the entire development cycle – from R&D to volume production, and extract actionable information and knowledge from obtained data. This is the paradigm required for fabs to quickly ramp new processes to acceptable yields and profitability.

In addition, reliability testing done mostly at the package level will need to move upstream to volume production and be performed on-wafer both in-line and end-of-line. Speed requirements of 100× faster testing than is currently available are also pushing the envelope. Right now, it is unclear if this is an extension of existing electrical testers, or if new toolsets will be needed in the fab.

Either way, reliability testing is set for a major shake up. Surviving and prospering depends on your company's ability to change and keep up with the times. KEITHLEY

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