White Paper

Using TetraMAX® Physical Diagnostics for Advanced Yield Analysis

Improving Defect Isolation with Layout Data

January 2010

Cy Hay
Product Manager,
Synopsys

Introduction

Scan-based DFT is now the standard digital logic testing methodology used on almost all SoC designs. It enables a highly automated approach to implementing testable designs and generating test patterns, while providing predictable, high fault coverage and scalable test cost. More recently, products such as TetraMAX DSMTest and DFTMAX are widely used for testing for complex fault models, at-speed testing and scan compression, and these are all built on the foundation of scan-based DFT. Thus it is universally accepted that even the largest and most complex designs can be manufactured and tested with a high degree of confidence that defective devices will be rejected before they are packaged and shipped to system-level manufacturers.

Scan-based DFT provides another equally significant benefit, though less broadly adopted. This same infrastructure enables a highly automated and accurate process for not only identification of defective devices, but also for identifying the specific location of the processing defects which caused it to fail. While the most basic goal of delivering fully functional parts only requires stop-on-first-failure testing, further testing of failing devices and diagnostics can provide useful, detailed information as to *why* the part failed. For individual devices, this information may seem random and might not be actionable. However, when this data is collected and analyzed over a significant volume of failing parts, systematic issues causing lower manufacturing yields can be statistically separated from the “noise” of random defects by the companion Yield Explorer product. Correlating the defect locations from a large number of devices, prioritizing those with the highest yield impact, and taking immediate corrective action has potentially enormous cost benefits by enabling faster time to market when new designs are being ramped up in manufacturing. This approach is known as volume diagnostics, and can also be used to help identify the root cause of spurious process excursions, and to make continuous yield improvements which increase long-term manufacturing efficiency.

This white paper introduces recent advances in TetraMAX diagnostics which improve the accuracy of defect isolation by incorporating physical layout data, in addition to logic netlist information, in the diagnosis of individual failing parts. This paper also explains how physical diagnostics can improve the overall efficiency of volume diagnostics.

Understanding Scan Diagnostics and Stuck Fault Simulation

A key concept for scan diagnostics is the *defect signature*. This is the set of all failing and passing test pattern responses for a given defect at a specific location in the circuit. Isolating the location of a defect requires calculating the signatures of all defects and locations under consideration, and then comparing those signatures against the signature measured by the tester. If the signature from the tester matches a calculated defect signature, and if that defect signature is unique, scan diagnostics will successfully isolate the defect location.

Similar to ATPG, scan diagnostics begin with the stuck fault model of defects. And the underlying technology to calculate signatures is the high-performance fault simulation engine in TetraMAX also used for scan ATPG. So how do scan diagnostics use stuck fault simulation? ATPG targets a stuck fault by controlling the node to the opposite value and simultaneously propagating and observing that node value in at least one scan cell. Once a pattern is generated, fault simulation will mark stuck faults as detected based on this criteria, and detected faults no longer need to be targeted by ATPG nor fault simulated for additional detections. During diagnostics, fault signatures are calculated by re-simulating the ATPG patterns that were applied on the tester, and by not dropping detected faults during fault simulation (which is only done for runtime efficiency during ATPG.) The essential function then is to identify those faults from the entire ATPG fault population with a signature that most closely matches the measured defect signature from the failing device on the tester. These identified faults are called *fault candidates*.

Defect Mechanisms vs. Fault Models

For defect isolation, it is important to note that fault candidates do not have to be an exact model of the actual defect - they only need to match the responses measured by the tester better than all other possible faults. Consider that if a particular stuck fault is detected by a test pattern, then any defect at that same location will also cause a similar set of failures as long as the defect has been sensitized. Just as stuck fault ATPG patterns can detect many types of defects which have a more complex behavior than a single stuck fault, so too can diagnostics isolate many "non-ideal" defects using just the stuck fault model.

However, candidates taken only from the set of stuck faults may limit the accuracy and resolution of diagnostics in a number of cases:

- Stuck faults are modeled only on the pins of library cells. Defects within a complex cell or along a large net will be identified as fault candidates on the associated cell pins. This might not be precise enough for physical failure analysis, or to distinguish different defects that map to the same stuck fault candidates.
- Metal shorts usually behave like a bridging fault between two nets. If fault candidates are reported only as stuck faults, these candidates might appear as two independent defects, neither of which matches the failing signature from the tester.
- Complex defects that affect an entire cell or multiple nets in a routing channel might have significantly different signatures than any of the individual stuck faults associated with the defective cell or region.

Improving Diagnostics Accuracy with Physical Layout Data

Since defects occur in the physical environment, the greatest potential to improve diagnostics accuracy is to also consider the circuit layout (in addition to its logic behavior) when possible defects might have a different signature than the set of stuck faults. For diagnostics, the two most important defect types to consider here are metal shorts between two nets, and metal opens on large or high-fanout nets. The following figures show images of two common metal defects.

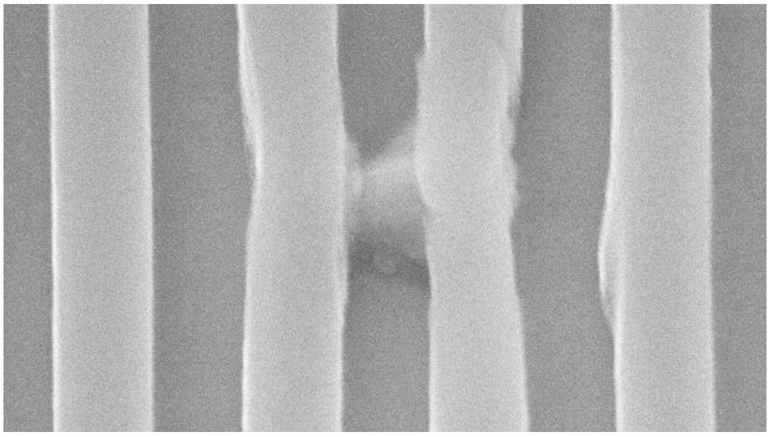

Figure 1: High resistance short causing a bridging fault

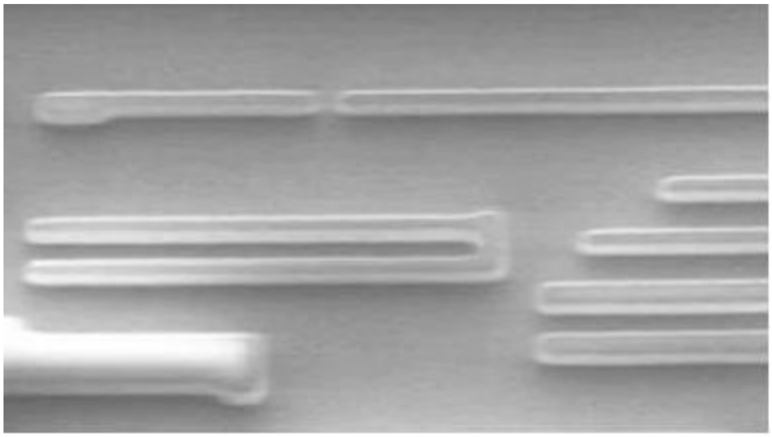

Figure 2: Broken line causing a net open fault

For metal shorts, it is important for diagnostics to recognize the signatures of bridging faults that could occur between two physically adjacent nets. At the same time, diagnostics should not consider several partially matching stuck fault signatures if those faults are physically separated. To achieve these objectives, several enhancements have been made to TetraMAX diagnostics. TetraMAX reads a list of adjacent net pairs in the design and uses those not only to target bridging faults during ATPG but also for diagnostics to distinguish between physically possible and impossible bridging fault candidates. Diagnostics also consider the signatures of the bridging faults associated with these net pairs, in addition to the signatures of the set of stuck faults, to identify the best fault candidates that match the tester response.

Many nets may extend across a relatively large area of silicon, and for defects on those it becomes important to isolate not only the failing net but also where on the net a defect appears to be. Metal opens at or near a cell pin (basically at the end of a net) will behave very similar to a stuck fault on the respective pin, and diagnostics will identify that fault as a candidate. However, metal opens occurring in the middle of a large net often do not behave the same as any of the fault signatures at the net endpoints. Wherever the net branches to different fanouts, there will be a unique signature for each branch. Similar to metal shorts, TetraMAX has also been enhanced to read the physical topology of each net in the design, and diagnostics will also consider the signatures of faults associated with each branch, or segment, of the overall net.

The following table shows the improvement in diagnostics accuracy when physical layout information is used. For this data, more than 20 circuits were characterized and hundreds of short and open defects were injected into the circuit model at random locations. The resulting simulation mismatches were diagnosed, and those results were compared with the actual location of the injected defect.

	Accuracy w/o physical data	Accuracy w/ physical data
Bridging faults	**87.6%**	**99.1%**
Net open faults	**<80%**	**99.0%**

Table 1: Accuracy improvements with physical net pairs and net topology

Using Physical Diagnostics to Improve Yield Analysis

With the improvements just described, TetraMAX can provide both higher diagnostics accuracy and better diagnostics resolution by incorporating additional data from physical layout. Such improvements not only help during the physical failure analysis of an individual failing die, they can also significantly improve the effectiveness of volume diagnostics. For volume diagnostics, fault candidates from many failing die will be correlated and analyzed. To clearly distinguish the systematic yield issues from random defects, fault candidates with “good” signature matches need to be strongly separated from other fault candidates with “poor” signature matches. If critical yield issues are causing defects with signatures unique to metal shorts or metal opens, volume diagnostics will be less efficient if only stuck fault candidates are considered, as they might not correlate with the actual defect location and behavior.

Summary

Scan diagnostics and yield analysis are now required tools for achieving high manufacturing yields. As yield ramp and managing process yields become increasingly difficult with today’s most advanced processing geometries, both better automation and better predictability are required to address yield issues in a cost effective manner. TetraMAX physical diagnostics provide a significant improvement to the accuracy of defect isolation and to Yield Explorer volume diagnostics.

SYNOPSYS® Predictable Success Synopsys, Inc. · 700 · East Middlefield Road · Mountain View, CA 94043 · www.synopsys.com