Advanced Adaptive Test for Optimized Semiconductor Operations
EXECUTIVE SUMMARY

Throughout much of the history of semiconductor test, there has been a race to add greater performance at ever greater cost to the user. This trend was driven by the seemingly ever-increasing datarates and digital complexity of the devices to be tested. Subsequent to the 2001 industry slow-down, this trend took a step function towards reversal, largely on the growing adoption of techniques like DFT (design for testability) and BIST (Built in Self Test).

Still test costs persist in being a target of every capital budget cut. “Reducing the Cost of Test” has become not only a corporate mantra but an industry-wide cry. So committed to achievement of reduced cost of test are some companies that they are simply reducing the tests being run; they are sacrificing reliability for cost of test.

The next logical step-function – and one that is a likely outcome of the current global financial crisis – is the broad adoption of techniques that will capitalize on the wealth of data in the supply chain and transform it to actionable information to reduce the cost of test through operational optimization. Implementation requires a robust IT infrastructure and advanced software knowledgeable of the process.

Advanced Adaptive Test holds the promise of managing the trade-offs between test time (cost), yield and reliability.
**WHAT IS “ADVANCED ADAPTIVE TEST”?**

As semiconductor devices have become a ubiquitous part of our everyday lives, the semiconductor industry has entered a phase where the consumers’ demand for quality and cost are driving fundamental changes in operations. Those operations – once focused on performance alone – are now focused more on efficiency and repeatability to deliver the highest possible quality at the lowest possible cost. In test, the focus is now shifting towards optimized use of expensive capital equipment and human resources via sophisticated software tools.

In its Summer, 2008 session, the International Technology Roadmap for Semiconductors (ITRS) identified the need for Adaptive Testing techniques in order to reduce the overall cost of test\(^1\). This step is likely to bring enhanced focus to an issue that must achieve redefinition and broader adoption. Redefinition is required to move the focus from that of merely reducing test time (TTR) to the more holistic issue of optimizing global test operations for yield, productivity and efficiency.

For Adaptive Test to play a meaningful role as part of an integrated test strategy, an approach that accommodates & enables the complex, distributed and multi-enterprise semiconductor value chain has been required. Such an approach demands innovative software, robust IT infrastructure and a far more advanced approach to Adaptive Test. It is with these capabilities and requirements in mind that Optimal Test has introduced its Advanced Adaptive Test techniques to market; this is “second generation” Adaptive Test.

Essentially, Optimal Test’s Advanced Adaptive Test technique uses everything that is known about the device under test (DUT) – wafer map, lot, product and process – and combines current test results with historic data that is automatically fed forward from prior design, fab and test processes. With Advanced Adaptive Test, the focus is

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\(^1\) Source: ITRS Roadmap: public.itrs.net
not on test time reduction (TTR) alone but rather on reducing the overall Cost of test (CoT) through improved yield, repeatability and quality. In reality, with Advanced Adaptive Test, tests can be dynamically inserted at the detection of an excursion – and against designer-defined rules – to insure the quality of the delivered DUT. Using this data on a per-die basis is what propels Advanced Adaptive Testing beyond test time reduction and to greater overall semiconductor operational efficiency. It delivers more aggressive Cost of Test reduction in a more controlled manner than classical, previous-generation TTR.

The Optimal Test suite of solutions permits Advanced Adaptive Testing to be done in real time and “near time” across the multi-enterprise or distributed supply chain. It can also be done off-line in a post-processing model.

THE TEST PROGRAM & ENTERPRISE DATA

Advanced Adaptive Test is best achieved through the enablement of dynamic changes to the test program. This implies the pre-determination of criteria against which these changes are effected. Test or Yield Engineers establish a decision tree that articulates what changes are permissible in a test step based on historical test data and device design information. These criteria are built into a “rules set” at the time of test program development (or later, as required). These criteria then trigger dynamic test program or test flow/strategy modifications either in real time or in near time to accommodate either more robust testing or reduced testing. As stated above, all relevant information about the device, the wafer and the lot is brought to bear to formulate a composite view; this enables the optimal decision-making regarding the number of tests, the testing sequence, and/or test limits to be determined dynamically and automatically.

Dynamic changes can be made to test programs as a result of statistical analysis of a large number of devices; the following are examples of such changes that can be made to minimize test times:
• Skipping tests where statistics imply it is improbable (at a level to be set by the engineer) that the specific test will fail;
• Enabling a reduced set of tests that have been proven adequate to detect faults as proven by statistics;
• Skipping a test when another test or combination of tests has been proven to be adequate;
• Enabling statistical sampling on certain tests that are failing with a frequency below a certain threshold, typically tied to ppm failure criteria;
• Enabling tests at a single Vdd level;
• Reducing or eliminating “hold time” tests that check the period of time an input must be held after a clock;
• Reducing the number of patterns: IDDQ patterns, stuck-at patterns, or timing-related patterns;
• Reordering tests such that those that are shown to be statistically the most likely to fail are executed first;
• Using fab data: e.g., More metal shorts imply that IDDQ tests should be executed early in the testing sequence in order to rapidly detect shorts;
• Using results from neighboring die on a wafer to reduce testing on the current die;
• Data logging only die locations that are shown to be valuable for yield and/or reliability learning.

In order to fully enable all of the features of Advanced Adaptive Test, it is necessary to draw on a network that spans the semiconductor value chain from design through fab, assembly/test and shipment. This permits the test management software to draw on the data from design models, photolithography, defect inspection and metrology, parametric test, in-line and end-of-line test, the ECID database and from prior test insertions. It also permits the data feed back from test to critical design and fab processes. For example, data fed forward from parametric test results can show which areas of the wafer are likely to pass or fail...
die/device can be tested with a unique test suite if the data so dictates.

Maximizing Advanced Adaptive Test benefits requires feed-forward of the data from all prior operations to the current test insertion. Further, the infrastructure must support the utmost efficiency in data warehousing, data integrity and production throughput. At each test step – wafer and final – Advanced Adaptive Test must also be fully integrated with all types of test cells with an external standard interface that makes variations in tester or peripheral types and data formats transparent to the analytical tools.

Access to these test cells must be in “near time” regardless of geographic location or to which enterprise in the supply chain is operating the test cell.

The IT infrastructure – network, servers and software – must have the power to manage large quantities of data coming from these testers and provide critical input for the Advanced Adaptive Testing. The data capture must be done in real time with automated decision-making. This automated decision-making calls for enhanced analytical capabilities in the software. Only in such a model can Advanced Adaptive Testing be delivered across the multi-enterprise supply chain of a fabless semiconductor company or the globally dispersed operations of an Integrated Device Manufacturer.

**ROBUST RULES & RULES ENGINE**

The purpose of Advanced Adaptive Test is to deliver an optimized overall test operation; therefore, its scope is not limited to the individual die/device under test. In order to achieve sustainably improved test operations, there must be visibility to the test results of all the die across the wafer, across all the wafers in the lot and finally across all of the packaged parts at final test. These three dimensional results can be used to determine the optimized testing and data collection/archiving strategy for each die. They can also identify systematic fails versus random. Some statistical analysis can be performed in real
time; other statistical analysis can be post-processed – and
decisions driven – off line. Real time analysis can
determine the optimal die location for yield learning via
data collection

Fabs, foundries and OSATs today are buried under
mountains of data generated from test operations. Often,
there is too much data – due to lack of automatically
imposed rigor in the culling of data – to permit effective
analysis; much of the data collected is never used due to
size, complexity and lack of integrity of that data. Thus,
the collection of data is also required to be adaptive – with
automated rules guiding the collection only of actionable
data on a by-die basis and in real time. This results in the
need for a new kind of test management solution that
leverages Advanced Adaptive Testing and uses “smart”
data logging with minimum impact on the efficiency of test
operations throughput.

Customization at the test suite level requires discipline and
control monitors to be built into the process. This
discipline begins as change in the manner in which the test
program is released to production. An adaptive rule set is
created for each product. These test rules provide real
time control and management needed during testing. The
rules creation can be automated using a test rule
generator, which is part of the test management solution
suite. A simulation of the rules is performed which
imposes the conditions required to enact the modified test
program and simulate the results in terms of test time,
test quality/coverage and potential impact to yield. This
simulation of the Advanced Adaptive Test scenario ideally
utilizes actual historical test data.

In production, this rule set will be used with the current
test data being collected to optimize the test being
executed. The appropriate modified version of the test
program is then automatically executed when the
predetermined criteria are met. This allows running a
customized test suite for each die if warranted and
optimizes the test operations for quality, yield and test
time.

Often there is too much data to permit effective analysis; much
of the data collected is never used due to size, complexity and
the lack of integrity of that data.
**Baseline Die and Advanced Adaptive Test**

Achieving optimized test operations efficiency is at the heart of adaptive testing; often, this results in test time reduction through the use of various techniques. Statistical sampling plans identify tests that aren’t required on all devices. Once general sampling occurs, a statistical sampling plan can be executed on a chip-by-chip basis as testing progresses. This process dynamically adapts to the unique characteristics of a device or group of devices with a reduced version of the test program. An initial group of tests may be skipped on a specific die, and then as more die are tested, the results may lead to omitting further tests. In some cases, the tests are modified but not skipped completely. For instance, a test can be shortened by running fewer patterns. To maintain effective quality control, baseline die on each wafer are always tested with the full test suite. An automated test management software solution with real-time decision-making is required to handle the variations in customizing the test program on a chip-by-chip basis. As mentioned above, there are various data sources from design and fabrication that can further optimize adaptive testing. The key is having a comprehensive software tool set running on a real-time, integrated infrastructure.

Baseline die – chips that are specifically selected to be tested using the full (or even an enhanced) test program on each wafer – are instrumental in the success of Advanced Adaptive Testing. The selection of baseline die is based on a combination of criteria: to provide coverage of different physical area on the wafer, to cover various die locations within the lithography stepping pattern, or (if multi-die contacting is being used) to mark the different positions of the probe pattern. The objective is to select positions on the wafer that will optimize process control and yield/reliability learning as a result of applying Advanced Adaptive Test techniques. These die will provide a good representative foundation for the status of the fab and test processes for a given product or family of products. As was stated, sometimes even enhanced
testing is done on these baseline die for characterization or reliability stressing purposes.

To reiterate, the key objectives of baseline die as a part of Advanced Adaptive Testing are to facilitate yield and reliability learning while optimizing test operations. To assist with Advanced Adaptive Testing, these baseline die can be tested first so the results can be used in conjunction with test rules to make real-time adaptive changes to the test program. At final test, specific units are selected within each lot to be baseline units and to provide similar benefits as described for wafer test.

A well managed adaptive test strategy that can be customized on the fly delivers up to 50% test time reduction with zero compromise to product yield. It is important to note rules fully support the return to full testing upon the detection of any drift or trend away from predetermined results. The baseline die are valuable not only as process control and yield learning tools but also as a monitor of test cell performance.

**Better Yield, Reliability and Quality, Too**

Advanced Adaptive Test may mean adding tests to the program. While this may increase test times – and therefore costs – on some die, the payback through yield and reliability learning can be substantial. The adage “time is money” is nowhere more true than in the continuous processing environment of semiconductor fabrication. In this environment, rapid, closed-loop learning is essential.
continuous processing environment of semiconductor fabrication. In this environment, rapid, closed-loop learning, where test results coupled with diagnostics, provide precise direction for physical failure analysis (PFA). The test rules developed can also be used to select “die of interest” or die that exhibit specific fail signatures which allow the diagnostics to isolate root cause. This significantly reduces the cycle time in performing the PFA to identify the specific process defect. The fab can react to trends in the data coming off the testers that may indicate a shift in the process. This shortened “time to actionable data” is critical to improve the process yield and reduce the amount of product that may have the same defect.

More subtle defects may require off-line post-processing to identify the failure mode. For instance, analyzing a group of the failing chips by comparing test results across the wafer as well as in the z-axis across all wafers in the lot will enable the discovery of systematic faults resulting from a process problem or design/process interaction.

Without this capability, these systematic fails would be identified as random fails and no action would be taken.

Quality and reliability improvements are also benefits of Advanced Adaptive Test. For instance, additional reliability screens can be added to improve the reliability level for such markets as automotive. Parts Average Testing (PAT) may be employed to identify outliers that will be reliability exposures for the manufacturer. While these tests add to the test time, Advanced Adaptive Test can minimize the impact by using adaptive test limits – automatically and in real time adapted to the neighbourhood of the device – to detect reliability outliers. That is, the limits to determine an outlier are dynamically and automatically adjusted based on the distribution of the good die in the lot. This results in faster and more accurate outlier detection and management. In some cases, the reliability analysis work is done by using off-line post-processing techniques and the devices are re-binned as required. For example, statistical analysis of the test results can be performed to produce reliability predictions of each device. This can have a very significant
economic benefit as it may lead to reducing or eliminating burn-in. At a minimum, it allows segmenting, or “binning”, the tested product by reliability levels to meet requirements of specialized markets such as medical.

**TIME-TO-ACTIONABLE DATA FOR CRITICAL DECISION-MAKING**

The appropriate IT infrastructure between design, foundry and test is essential to decision-making support; without it, it is not possible to truly reap the benefits of Advanced Adaptive Testing. Data from the design models can assist in determining the type of failures likely to be seen on a given product. This information can be used to modify the program at test. Examples of design model projections that are useful at test include: yield, IDDQ ranges, stuck-at fault test pattern failures, timing-related failures and voltage stress failures. These projections give indicators to the amount of fall-out to be expected from each type of test. These can be used in conjunction with measurements taken in-line such as: number of open vias, metal/poly shorts/opens and transistor $L_{eff}/V_T$. This data in total will give a reasonable prediction of expected fall-out for a given set of tests. For voltage stress failures, $L_{eff}/V_T$ correlates to product speed and is a predictor of IDDQ. The design model projections, fab data and recent test results allow adaptive test to tailor a test sequence, modify the number of tests or dynamically modify test limits. The more data that is accessible, the more Advanced Adaptive Test can do to optimize the test suite.

While wafer sort is one obvious test step where Advanced Adaptive Test can have a substantial economic impact, it is by no means the only place where benefits can be reaped. Final test – that is, package test – benefits from many of the same techniques as previously discussed. Each packaged device can be exposed to a unique test suite as a result of data that is fed forward from previous test steps. Especially in a flow where wafer level die identification is implemented, final test benefits from the capabilities of Advanced Adaptive Test. The source of this data may be one or more of the following:

- Data from previous insertions;
Knowledge as a result of post analysis from an earlier insertion;
Data from recently tested ICs from the same lot.

This information can be used at final test to disable or add test steps or to modify the test flow. Utilizing this data can provide substantial quality, yield and cost advantages. Test time reduction opportunities result from reducing the test content, changing test limits or performing a more efficient search for outliers.

**SUMMARY**

Advanced Adaptive Test has much greater potential in semiconductor manufacturing than has been realized to date. Reaping the full benefits – reduced cost of test, improved yield and quality and yield/reliability learning – requires a robust IT infrastructure that leverages data across your distributed supply chain. The return on investment associated with implementing such a robust and holistic approach to Advanced Adaptive Testing is substantial; even 1 percentage point of yield readily justifies the investment.

In today’s deep submicron environment, systematic defects are not only more prevalent but also more difficult to detect. However, the potential exists to overlay and mine the data to find the signatures of various systematic defects. To close the loop requires that your test management solution insure data feedback to the fab and design processes that will accelerate yield learning and enhance design models. That is the promise of the Optimal Test architecture and approach.

Adaptive test manages the trade-offs between test time, yield and reliability. Companies utilizing the appropriate IT infrastructure, database and software analysis tools are enjoying substantial ROI with very short-term payback. Are you fully optimizing your test operations by leveraging all available data and knowledge with a seamless, multi-enterprise Advanced Adaptive Test solution?

**INTERESTED IN LEARNING MORE?**

Optimal Test has solutions for Global Test Operations that include Advanced Adaptive Testing for both real-time and near-time applications. The Early Detection Solution is a proven solution for multi-enterprise fabless device manufacturers whose supply chains include foundries and OSATs as well as for globally dispersed Integrated Device Manufacturers. For more information, contact Optimal Test through any of the global toll free numbers listed in the box below.