



## **Signature Failure Analysis-Based Methodology for Customer Failure Analysis**

**SEMATECH** and the **SEMATECH logo** are registered service marks of SEMATECH, Inc.  
**International SEMATECH** and the **International SEMATECH logo** are registered service marks  
of International SEMATECH, Inc., a wholly-owned subsidiary of SEMATECH, Inc.

Product names and company names used in this publication are for identification purposes only  
and may be trademarks or service marks of their respective companies.

# Signature Failure Analysis-Based Methodology for Customer Failure Analysis

Technology Transfer # 00124038A-XFR  
International SEMATECH  
*December 15, 2000*

**Abstract:** This document proposes the implantation of Signature Failure Analysis (SFA) methodology to analyze semiconductor failures. The SFA methodology groups failure modes, based on initial analysis results, over the product's lifetime. It then compares new failures to established data and suggests corrective action for the most prevalent failures. This methodology has been effectively demonstrated in the semiconductor industry.

**Keywords:** Failure Analysis, Manufacturing

**Authors:** Dan Rubens, Donat Renaud, Len Gibbons, Greg Wolfe, Noel Durrant, Roger Newkirk, Tam Le, John Drummond

**Approvals:** Noel Durrant, Program Manager  
Dave Anderson, Director  
Dan McGowan, Technical Information Transfer Team Leader



## Table of Contents

1	EXECUTIVE SUMMARY .....	1
2	AUDIENCE .....	1
3	TERMINOLOGY.....	1
4	PURPOSE .....	1
5	SCOPE .....	1
6	PROCESS OF DEVELOPMENT.....	1
7	QUALITY MANAGEMENT SYSTEM REQUIREMENTS.....	2
8	BUSINESS AND INDUSTRY ENVIRONMENT.....	2
9	SIGNATURE FAILURE ANALYSIS METHODOLOGY .....	3
	STEP 1: INITIAL DISCOVERY .....	3
	STEP 2: INITIAL VERIFICATION.....	5
	STEP 3: TRIAGE.....	5
	STEP 4: CUSTOMER FAILURE ANALYSIS .....	6
	STEP 5: INTERNAL FAILURE ANALYSIS.....	7
	STEP 6: SIGNATURE FAILURE ANALYSIS DATABASE.....	8
	STEP 7: CONTINUOUS IMPROVEMENT PROGRAM .....	9
	STEP 8: SIGNATURE FAILURE ANALYSIS AND TRIAGE REPORTS .....	9
	STEP 9: CONTINUOUS IMPROVEMENT CUSTOMER REPORTS.....	10
10	SUMMARY .....	11
11	CONCLUSION.....	11

## List of Figures

Figure 1	Signature Failure Analysis Methodology.....	3
----------	---------------------------------------------	---

## **Acknowledgements**

Authors and Members of the Signature Analysis Team of the International SEMATECH Quality Council:

Dan Rubens	Conexant Systems, San Diego, CA, USA
Donat Renaud	IBM Corporation, Burlington VT, USA
Len Gibbons	Infineon Technologies, San Jose, CA, USA
Greg Wolfe	Intel Corporation, Phoenix, AZ, USA
Noel Durrant	Intel Corporation/International SEMATECH, Austin, TX, USA
Roger Newkirk	Motorola, Austin TX, USA
Tam Le	STMicroelectronics, Carrollton, TX USA
John Drummond	Texas Instruments, Inc., Richardson, TX, USA

## **1 EXECUTIVE SUMMARY**

Semiconductor failure analysis is usually performed assuming that each failure is an isolated case, and requires full analysis without regard to the history of the product line. This paper proposes implementing the Signature Failure Analysis (SFA) methodology. Using this methodology, failure modes are grouped based on initial analysis results, building a database over the life of a product. New reported failures are run through an initial analysis (or *triage procedure*), and the results are compared to historical data. The triage results are used as an indicator of the uniqueness of the failure and a basis for decision for further analysis. This methodology systematically focuses detailed analysis and corrective action on the most prevalent failures. Improving the producer's ability to focus on the most prevalent failure type enables faster feedback to customers and faster improvement cycles in the producer's factory. This methodology has been demonstrated to work effectively in the industry.

## **2 AUDIENCE**

International SEMATECH member companies, semiconductor manufacturing companies and their customers.

## **3 TERMINOLOGY**

- Supplier, Producer - a semiconductor manufacturing company
- Customer - customer(s) of semiconductor manufacturing companies
- Product - an integrated circuit or semiconductor device
- Failed or failing unit(s), customer return(s) - products reported as a failure by a customer

## **4 PURPOSE**

- Provide a descriptive framework of signature failure analysis methodology and its application to customer returns.
- Promote acceptance and confidence in the signature failure analysis based approach to semiconductor product customer returns management.
- Demonstrate how this methodology accelerates quality improvement as an integral part of a customer returns management program.
- Describe the benefits including prioritization processes, historical comparison capabilities, and optimum use of analysis resources.
- Inform the industry how Signature Failure Analysis methodology improves product quality.

## **5 SCOPE**

This methodology is proposed for consideration by International SEMATECH member companies, other semiconductor manufacturing companies and their customers. It may be applied to all semiconductor components. The focus is on integrated circuit failures returned from customers.

## **6 PROCESS OF DEVELOPMENT**

The International SEMATECH Signature Analysis Team was formed in 1999 under the auspices of the International SEMATECH Quality Council. Participating member companies were Conexant, IBM, Infineon, Intel, Motorola, STMicroelectronics, and Texas Instruments.

## 7 QUALITY MANAGEMENT SYSTEM REQUIREMENTS

A robust quality management system is the best foundation for implementation of the Signature Failure Analysis methodology. This foundation should include

- Factory quality management systems
- Statistical process control systems
- Materials management and defect containment systems
- Data management systems
- Customer quality feedback systems

The SFA methodology is synergistic with these systems and quality management standards such as ISO 9000 and its derivatives (e.g. QS9000). It is intended to utilize and augment these fundamental processes, and does not replace them or change their importance, significance or function.

## 8 BUSINESS AND INDUSTRY ENVIRONMENT

Maximizing efficiency and reducing cycle time are important elements of the overall failure analysis strategy. To support these objectives, suppliers often utilize the experience and knowledge gathered in previous failure analyses. The SFA methodology represents an opportunity to optimize the alignment of the customer's needs with the efficient use of analysis resources.

The current environment promotes an ever-growing conflict between product development and support demands versus the allocation of failure analysis resources. The increasing complexity of circuit designs and fabrication processes suggests that the amount of time to complete root cause analysis of nonconforming products continues to increase. The complexity issue includes

- Multimillion transistor integrated circuits
- Minimum features with critical dimensions shorter than the wavelength of visible light
- Six or more levels of interconnects
- New fabrication materials
- Integration of multiple designs in multichip modules (MCM)
- Systems on a chip (SOC)

A second issue is that failure analysis labs must deal with shorter product life cycles, compressing the time needed for problem resolution. There is also an overall increase in unit volume throughout the semiconductor industry and a wider diversity of products. These factors imply a corresponding increase in the number of devices, as well as the types of devices, requiring failure analysis.

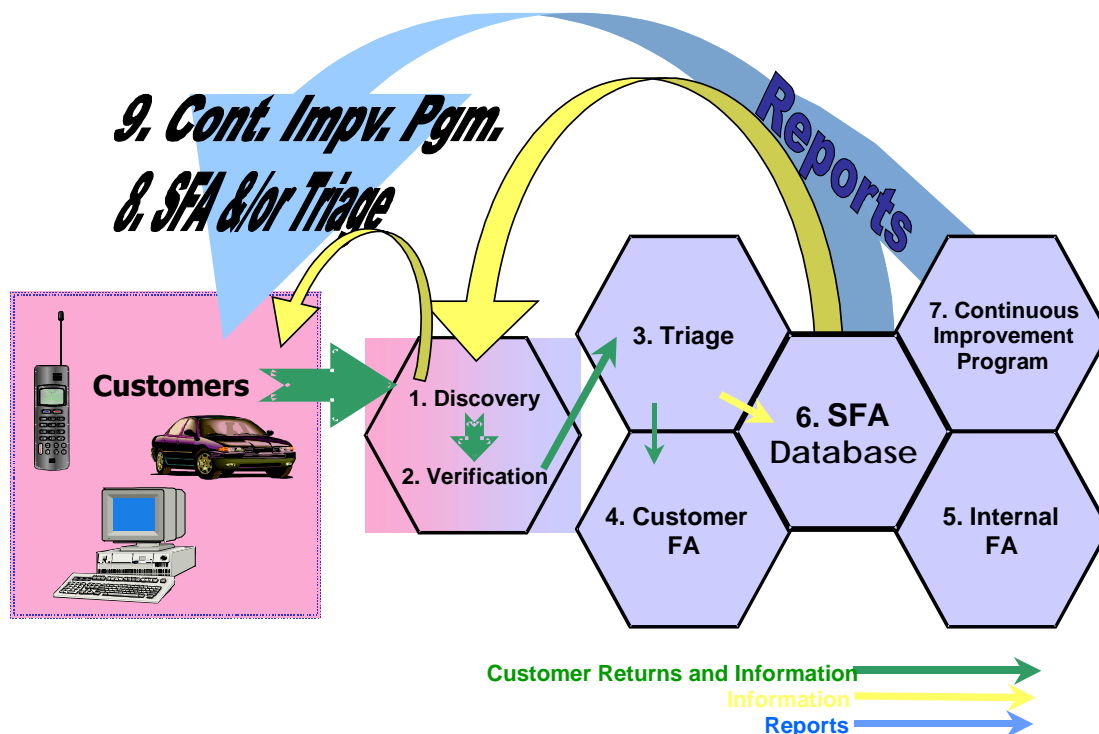
Third, the proliferation of worldwide production facilities, along with an expanded customer base, has helped foster a global business environment for semiconductor device suppliers. Globalization presents problems in the timely transport of failed devices to the appropriate analysis location.

Because of these issues, the practice of analyzing *everything that fails* is incompatible with the needs for shorter analysis cycle times and high value-added improvement activities. Alternative methodologies must be developed and implemented so that analysis resources may be utilized in the most efficient and effective manner. Reinforcing the analytical process (new tools and

techniques) is helpful but does *not* overcome these issues. The SFA methodology addresses these issues on the basis of lab input and maximizing the value of all the relevant product analysis done over the life cycle of the product.

## 9 SIGNATURE FAILURE ANALYSIS METHODOLOGY

The nine basic steps for the Signature Failure Analysis (SFA) methodology are shown in the flow diagram in Figure 1. These steps represent the information flow as well as product flow for the customer returns through the SFA methodology. The SFA methodology concept is to create a database containing the information on customer failure symptoms, initial verification characteristics at the supplier, and the actual failure mechanisms. This information is then applied to subsequent customer failures for rapid customer problem resolution. A supporting *Triage* procedure is used to make a decision on which customer returns are submitted for failure analysis. The analysis results are then used to guide and prioritize the supplier's continuous improvement program. Customers receive reports on the results of the SFA, Customer FA, Triage, and the Continuous Improvement Program actions/results. The following sections describe the details of each of these nine process steps.



**Figure 1 Signature Failure Analysis Methodology**

### STEP 1: INITIAL DISCOVERY

#### *DESCRIPTION*

A critical first step in the success of any analysis effort is the thorough discovery of the failure symptoms and the conditions during failure as observed and reported by the customer. Limited failure information on customer returns for analysis can lead to miscorrelation or a misdiagnosis of the “real” problem experienced by the customer. If the supplier is not able to replicate the

customer's reported failure mode due to insufficient information relating to the device environment/application during its failure, it may lead to suspect material being returned to the customer for additional validation and data gathering. Analysis efforts that end in miscorrelation or misdiagnosis only delay the opportunity to achieve the desired goal of permanent corrective action. It is imperative that as much applicable information as possible be gathered from the customer prior to the return of failed units to the supplier. Depending on the nature of the failure, the customer and supplier may agree to perform additional characterization at the customer site in an effort to assess conditions during failure and identify any possible marginality.

The primary benefit of a good discovery process is that the supplier can immediately focus on the customer reported failure mode and streamline the analysis approach to that area. A comprehensive discovery practice substantially improves the probability of correlation, reduces time to effective corrective action and minimizes ineffective use of analytical resources for both the customer and supplier caused by multiple attempts to achieve correlation.

A second benefit of comprehensive discovery is that the supplier can establish a correlation database between the customer reported symptoms for a given product family and the actual failure modes captured from the supplier's initial electrical / mechanical analysis results on customer returns. This correlation allows the supplier to prioritize their product improvement strategy and maximize the impact of reducing failures across the customer base.

#### *INITIAL DISCOVERY PROCESS*

The customer and supplier jointly determine what failure symptom data is provided with customer returns. This is normally a dialogue process resulting in the maximum information flow to the supplier. Examples of discovery question areas are:

- What is description of the failure mode?
- Is this a new application?
- When did the failure first present itself?
- What is the reported fail rate?
- What customer test(s) are failing? (non-functional, fails specific application code, etc.)
- Where in process did the failure occur? (manufacturing, in-circuit test, field, etc.)
- What are the environmental conditions during fail? (Voltage, Temp, Freq. , etc.)
- Does the failure repeat as environmental conditions are varied?
- Can the failure be replicated with consistent results?
  - (alternate tester, manufacturing line, swap to another board/module, etc.)
- If multiple units are involved, does the failure appear to be lot sensitive?
- Has the application undergone any changes in design, software, manufacturing process or material content?

If the supplier already has sufficient information from previous analysis results on the failure mode in question and its root cause (SFA Database), the supplier may be able to immediately provide the customer with the specific failure mechanism and its corrective actions. **In such cases, the customer request can be closed with the Discovery step alone.**

## STEP 2: INITIAL VERIFICATION

### *DESCRIPTION*

Initial Verification at the supplier is necessary to determine:

- How the failed unit performs on production test equipment
- If it meets the electrical/physical standards to which it was processed.

This information is used in the Triage procedure (Step 3) for Pareto ranking and signature failure analysis profile development.

### *INITIAL VERIFICATION PROCESS*

Based on the information captured in Initial Discovery, the supplier determines what type of verification testing is required on the customer return. The verification method may include such tests as

- Automatic test equipment verification
- Curve Tracer analysis
- Acoustic Microscopy Imaging
- Physical examination

## STEP 3: TRIAGE

### *DESCRIPTION*

*Triage* is a procedure to

- Manage the collection of data from customer returns in an organized manner,
- Categorize the electrical and visual mechanical failure modes (i.e. symptoms) on these failed units,
- Make decisions on what further actions are to be taken.

Triage establishes a formal process for managing the verification data on customer returns returned units for analysis and ensures rapid responses in areas of concern to minimize customer risk. This focuses the failure analysis and engineering resources on the best areas for improvement.

### *TRIAGE PROCEDURES*

Triage consists of four procedures.

*1. TRIAGE FAMILY DEFINITIONS:* Triage family definitions are initially established defining a set of data requirements for data collection and analysis. These data sets are used to establish relationships between customer failure modes, initial electrical verification results, and results of physical failure analysis. Care must be taken in selecting the family definitions so the data supports the analysis processes. Suppliers must establish their SFA families based on their products, technologies, etc. Family definition examples include:

- Technology (example 0.5 micron CMOS)
- Product Line (similar device types/part numbers/packages, etc.)
- Individual Device Type

The database is initialized with the supplier's internal Failure Analysis (FA) (Step 5) information obtained during the development of the new product/technology, such as:

- Technology and Process qualification
- Device Level Qualification
- Early Yield Analysis

2. *ESTABLISH FAILURE MODE PARETOS*: Data from the Initial Verification process is collected into Paretos of failure modes pertinent to the Triage Family Definitions above. These Paretos are dependent on the failure grouping process utilized in the electrical test and physical examination. Examples of individual Pareto categories include

- Speed failure
- Leakage failure
- Function failure
- Memory cell failure
- Bent lead
- Package delamination

3. *DECISION ON UNITS FOR CUSTOMER FAILURE ANALYSIS*: The data sets from Triage procedures 1 and 2 above are examined for several attributes that determine which customer returns should be processed through FA to obtain additional data on a Pareto category. Reasons for proceeding with FA on a failed unit include

- Unusual level of failures in a known Pareto category
- Emergence of a new Pareto category
- Evidence of a "maverick" lot or time based manufacturing event
- Re-verification of an SFA correlation previously established between a Pareto category and a specific failure mode (on a sample basis)

4. *CORRELATION OF FAILURE MODES WITH ROOT CAUSE*: The SFA Database contains results of FA on customer returns and internal FA results. The root causes from these FA sources are identified and compared to the failing device's symptom(s). When sufficient FAs have been completed to clearly identify the root cause of a particular electrical or physical symptom this known root cause is recorded in the SFA database. Any further customer returns with this failure mode or "signature" will have an established root cause and no additional FA is required.

These four procedures of Triage allow for the consistent collection and utilization of failure symptom information along with known root causes of those symptoms from failure analysis. The consistent application of this process ensures that units submitted to FA provide the maximum learning on product failures and maximum leverage of the semiconductor manufacturer's resources.

#### STEP 4: CUSTOMER FAILURE ANALYSIS

##### *DESCRIPTION*

The goal of Failure Analysis on customer returns is to discover the root cause of the reported failure. The clues obtained from the verification process are used to determine the most timely and effective method to discover the reported failure's root cause. A number of analytical

methods are utilized in FA to uncover the root causes associated with the reported failure symptoms.

#### *CUSTOMER FAILURE ANALYSIS PROCESS*

Following the verification of the reported failure, non-destructive tests and measurements are often used to gain more information to determine the root cause. Examples of non-destructive tests are

- High magnification optical inspection of the package leads and/or solder balls
- High magnification scanning electron microscope (SEM) inspection of the package, leads, and or solder balls
- Scanning Acoustic Microscopy Imaging
- Curve trace current/voltage measurements of pin leakage, shorts, or opens
- X-ray to inspect bond wires and leadframes
- Thermal films
- Photon emission
- Internal mechanical probing

If the root cause cannot be determined from the non-destructive tests, the failing unit may be subjected to destructive measures. Examples of destructive failure analysis processes include

- Focused ion beam cross sections
- Mechanically polished cross sections
- Removal of integrated circuit internal layers

All the tests and measurements performed during the failure analysis process are carefully documented with images and/or words in the failure analysis report. The results obtained are used to reinforce existing signatures or develop new signatures. The conclusion and the reported failure's most likely root cause are included in the report.

#### STEP 5: INTERNAL FAILURE ANALYSIS

##### *DESCRIPTION*

Semiconductor suppliers routinely perform Failure Analysis on failures from their internal operations. New semiconductor processes and package technologies are extensively tested and measured for reliability by semiconductor and package manufacturers. Semiconductor manufacturers constantly monitor reliability with ongoing tests and measurements, often based on production semiconductor devices. The failing devices from any of these sources are subjected to the same failure analysis performed on customer returned units described in Step 4 above. The results of these analyses are added to the SFA database. The internally generated failure analysis results can also be used to reinforce previously developed signature models. All of these are candidate data sources for the inclusion in the Signature Failure Analysis database.

## STEP 6: SIGNATURE FAILURE ANALYSIS DATABASE

### *DESCRIPTION*

The Signature Failure Analysis methodology requires establishing an SFA database. The SFA database contains critical historical information on previous product failures, including root cause and corrective actions for each known failure mechanism.

### *SIGNATURE FA DATABASE CONTENTS*

The SFA database is organized by family type, as explained by the Triage Family Definitions, and by failure modes within each unique family. As an example, a data set may contain the following essential information:

- Family Type
  - Technology
  - Product Line
  - Device type
- Failure Mode
  - Leakage
  - Physical damage (package)
  - Performance
  - Functional fail
  - Application sensitivity
  - Dependencies may include temperature, voltage, timing
- Initial Discovery data
- Root cause
  - Identify specific process levels, defect types, Foreign Material, etc.
  - Vintage issues (problem time period, specific tool issue)
- Corrective Action
  - Specific process fixes
  - Test coverage
  - Process Tool changes
  - Implementation date

### *SOURCE OF DATA*

The SFA database is normally created by the supplier during the early stages of product development, well before the product's general availability, and is maintained over the lifecycle of the product. As the product matures, the database is augmented with information from four major activities:

- Technology & Process Qualifications
- Product Qualifications
- Early Production or Ramp Yield Learning
- Customer returns

## *APPLICATION OF DATABASE*

The contents of the SFA database are reviewed in an attempt to match the failure mode of the failed unit with a known failure mechanism. This enables the correlation of Initial Verification results to known failure mechanisms. A successful correlation between a previously recorded failure mode and a recent failure implies a known root cause.

Conversely, a previously unreported failure mode may be discovered, which may prompt the need for further FA to understand root cause. Again, the decision to pursue additional FA during the Triage procedure weighs heavily on the data contained within the SFA database.

## STEP 7: CONTINUOUS IMPROVEMENT PROGRAM

### *DESCRIPTION*

Continuous improvement in product quality is a standard practice for semiconductor suppliers. In order to continuously improve manufacturing yields and product quality/reliability, semiconductor companies have formal improvement programs in their wafer fabs and assembly/test operations. These improvement programs integrate information from customer failures to

- Substantiate the internal failure data
- Identify any new failure mechanisms not previously detected

Normally each manufacturing site maintains these programs with action plans and metrics.

### *CONTINUOUS IMPROVEMENT PROGRAM PROCESS*

Information and data for continuous improvement come from multiple sources. First, as new technologies in package and silicon manufacturing are developed, process certification and capability data are analyzed and provide an early assessment of baseline quality and reliability performance. Second, new product and process qualification data provide an early assessment of a product's robustness and potential areas for improvements. Third, as the product and process matures, internal feedback from the producer's manufacturing and reliability monitors continues to identify improvement opportunity areas. All three of these life cycle stages identify areas for a Continuous Improvement Program to address. The information from Internal Failure Analysis (Step 5) generates the failure mechanism data for each of these (lifecycle) stages.

Finally, data from the analysis of customer returns provides the supplier with a complete picture to guide short and long-term improvement strategies. The Triage procedure (Step 3) directs the Customer Failure Analysis (Step 4) and provides the data to build the Pareto of failure modes. These Pareto's then provide the foundation for the Continuous Improvement programs.

## STEP 8: SIGNATURE FAILURE ANALYSIS AND TRIAGE REPORTS

### *DESCRIPTION - SIGNATURE FAILURE ANALYSIS REPORT*

The SFA Report correlates the knowledge in the SFA Database (known failure mechanisms) with the results of the Initial Verification (failure modes). The SFA Report contains sufficient information for the customer to understand the correlation of SFA to the Initial Verification, and what actions are already in place to address such failures.

The SFA Report contains the normal FA report information plus the following items

- The Initial Verification test results specifically on test parameters that are being correlated to a SFA failure mechanism. Physical exam results may also be used for creating this correlation.
- The Signature Failure Analysis conclusion from the SFA database with sufficient detail to demonstrate correlation of the Initial Verification results to the known failure mechanism.
- The existing corrective actions and schedules for the correlated failure mechanism should be provided as corrective action for the customer return.

**This information secures closure on the customer request for analysis.**

#### *DESCRIPTION - TRIAGE REPORT*

One outcome of the Triage procedure is that some customer returns fall into categories that have very low, even singular, levels of occurrence. In such cases, additional evaluation may not be warranted. A Triage Report provides feedback to the customer on the Initial Verification (Step 2) results. It also explains why no further action is taken on failures that do not represent a unique or significant situation. The justification is based on the known electrical signatures of the device type/family and known failure mechanisms.

The Triage Report contains the normal FA reference information plus

- Justification for not performing further analysis which could include
  - Low incidence of failure mode
  - No apparent manufacturing issue related to the failure
  - Previously discovered failure mode and mechanism
  - Corrective action, if already in place
- Documentation of the current Triage and Continuous Improvement (Step 7) focus areas related to the device type/family and their relative impact opportunity on the reliability and performance of that device type/family.
- Historical quality/reliability improvement trend for the device type/family.

Customer returns requiring no further analysis after Triage are typically archived. If additional failures are experienced with similar failure modes, they are pooled into a group for Triage action that could include further electrical analysis, sample failure analysis, etc.

#### STEP 9: CONTINUOUS IMPROVEMENT CUSTOMER REPORTS

##### *DESCRIPTION*

The Continuous Improvement Customer Report serves as a vehicle to provide the customer with an update of the supplier's progress in continuous quality improvement. The report highlights specific corrective actions that have been implemented or are planned for the future. The actions taken are measurable and data is provided in the form of charts, work plans, etc., that quantify the various areas of improvements.

##### *PROCESS*

The format and content of Continuous Improvement programs vary from fab to assembly and from manufacturer to manufacturer. They typically show the Pareto of failure mechanisms for a factory, the action plans in place, and the trend performance on key metrics. In wafer fabs, defect

density is normally the key metric with a Pareto of failure mechanisms causing the loss such as oxide defects, particles, alignment, etc. In assembly plants, process yields by stage such as bonding and molding are often tracked with Pareto analysis plus action plans for improvement.

## 10 SUMMARY

The Signature Failure Analysis methodology is a closed loop continuous improvement system that provides accelerated quality improvement in products when co-operatively used between a manufacturer and the semiconductor supplier. The SFA methodology provides

- *Discovery* - maximizes the information collection with the customer at first contact. The SFA response to failures can be applied at this point.
- *Initial Verification* - provides verification of failures and relation to reported failure modes
- *Triage* - procedures determining which units should be failure analyzed for root cause
- *Customer Failure Analysis & Internal Failure Analysis* - provides root cause information on customer returns and internal failures
- *SFA Database* - contains the failure analyses root causes with correlation to the initial verification failure modes and the customer reported symptoms
- *SFA & Triage Reports* - provide feedback to customers where SFA correlation exists or when the incidence of failures does not justify further analysis
- *Continuous Improvement Program* - the semiconductor supplier's program to utilize the Triage and FA information along with internal data to select actionable areas having the most significant impact on product quality and reliability.

## 11 CONCLUSION

The SFA methodology can yield timely and significant improvements in product performance when used jointly by semiconductor supplier and their customers. This methodology identifies the significant areas of improvement opportunity and focuses the supplier's resources (engineering and failure analysis) on these opportunity areas.

The Signature Failure Analysis methodology is currently being applied in a number of semiconductor markets including automotive, computer, printer, and telecom. The benefits of the SFA methodology are being seen with suppliers and their customers and the concept is gaining recognition for its effectiveness. The SFA methodology offers an optimum approach to achieve continuous improvement in quality that is efficient for the customer and the supplier.





**International SEMATECH Technology Transfer  
2706 Montopolis Drive  
Austin, TX 78741**

**<http://www.sematech.org>  
e-mail: [info@sematech.org](mailto:info@sematech.org)**