◆ Application Paper

Quality and Productivity Improvement by Clustering Product Database Information in Semiconductor Testing Floor

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Abstract

The testing processes for VLSI finished devices are considerably complex because they require different types of ATE to be linked together. Due to the interaction effect between two or more linked ATEs, it is difficult to trace down the cause of the unexpected longer ATE setup time and random yields, which frequently occur in the VLSI circuit-testing laboratory.

The goal of this paper is to develop and demonstrate the methodology designed to eliminate the possible interaction factors that might affect the random yields and/or unexpected longer setup time as well as increase the productivity. The statistical method such as design of experiment or multivariate analysis cannot be applied to the final testing floor here directly due to the environmental constraints. Expanded product data information (PDI) is constructed by combining product data information and ATE control information. An architecture utilizing expanded PDI is designed, which enables the engineer to conduct statistical approach investigation and reduce the setup time, as well as increase yield.

Key words: ATE, Database, Expanded Product Data Information, VLSI circuit, Yield

1. Introduction

The semiconductor manufacturing process is so complex that it cannot be described within limited contents. Uzsoy *et al.* [4] described the overall semiconductorm anufacturing processes focused on the production and scheduling. A scheme ofsemiconduct or manufacturing, whose process is VLSI circuit technology, is shown in Figure 1.

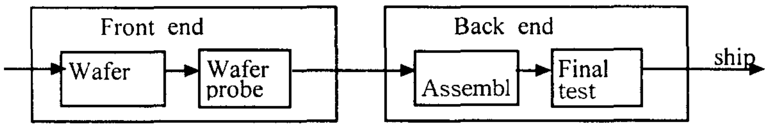

Figure 1 Scheme of semiconductor manufacturing process

With raw materials such as silicon or germanium, wafer fabrication, which is the most technically complex process (e.g., epitaxial growth, impurity diffusion, oxide deposition and metalization), forms semiconductor devices on the wafer. In probe, a metal probe is used to make electrical contact with each of the semiconductor devices bonding pads. Upon a completion of the wafer probe test, finished wafer that meets the specifications is separated into individual dice for assembly and packaging. Together wafer fabrication and probe processes are, in a slang term, called the Front

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end. The Back-end refers to the assembly and testing processes. Since wafer probe tested die itself is useless on its own, circuits need to be placed into packages for accessibility. Packages can be categorized based on a number of different ways: basic shape, packaging materials involved, the way they are assembled, or whether they have an internal cavity.

Before products are sent to customers, final testing such as burn-in, reliability, and quality assurance are conducted, and then they are delivered to the finished device screening (100% test) process, where batches of semiconductor devices of different sizes and types must be verified for adherence to product specifications.

1.1 Final device screening

The purpose of the final device screening is to make sure that all devices met product specification. A linked set of different ATE is used to test functionality of each batch of product devices, hereafter called DUT (Device Under Test), during the screening process. An example of the linked ATE setup for a particular type of DUT is depicted in Figure 2.

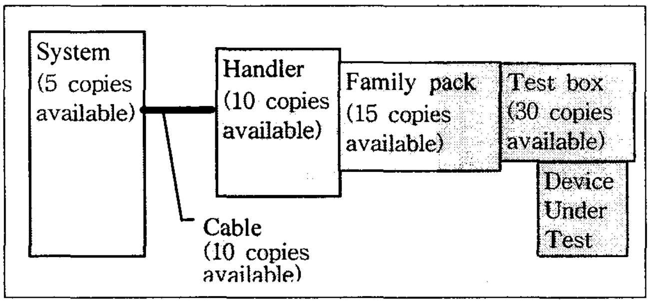

Figure 2. Example of a set of five linked test equipment for the screen process

As shown in Figure 2, copies of test equipment, e.g., system_1,..., system_5, are available in order to test similar or same types of batch products simultaneously. Therefore, different linked sets of ATE could be used for the same type of product device screen process and thus the possible combinations of the linked ATE setup are numerous.

The actual screening process is not conducted until the correlation units have passed the ETS (Electrical Test Specification for Reliability) whose typical test numbers are shown below. The passage or failure of DUT is a Go-No-Go test: if any one of the functions falls outside of specifications, then the DUT cannot pass the ETS.

Test #1 5.00 V

Test #2 2.3 mA

Test #3 < 1.5 nA

Test #4 > 20 nS

Test #5 25 MHz

Test #6 50 dB

....

Upon finish of the screening process, product data information such as type of product, yield, date, wafer number, and lot number are logged in the database. Table 1 shows an example of product data information stored in the product database. Any product which fails to meet ETS is sent to the bench lab for failure analysis.

Table 1. Example of product data information

Product	Yield (%) (out/in)	Date	Wafer No.	Lot No.
ABC334	74.56(85/114)	920707	J334128	A93234

1.2 ATE setup time and random yields

In this section, two types of problems are discussed: Unexpected longer ATE setup time and lower yields. The solution approaches to these problems are limited by the environmental constraints, which will be described later.

Yield, one of the major concerns in a manufacturing environment especially if the unit cost is high as in expensive VLSI circuits, is directly related to the companys profit and also is an indicator of the process quality. Throughout the VLSI manufacturing process, the yield is calculated wherever a lot acceptance sampling is performed, and then evaluated by the upper managers. In the final product screen process, it turns out that factors affecting the random yields are due to the interaction effect between ATE. As an example, the yield for the ABC545 product device under a set of linked ATE, e.g., S1--C3--H2--F4--T2, is 95 % and for the same product device under a different set of linked ATE, e.g., S3--C2--H1--F4--T2, is 55%.

From the statistical analysis point of view, the yield is considered to be a dependent (response) variable, and the independent variables (factors associated with the yield) are a set of ATE and product devices. The effect of operator is negligible since no particular skill is required for the screen process. There are five independent variables (assuming that the product device is constant) such as System, Cable, Handler, Family_pack, Test_box. A possible factor causing a lower yield might be one of the independent variables (e.g., one of the testing equipments) or a combination of two or more, up to five independent variables. It is known that a total variation is expressed as sum of product variation and measurement variation, which is shown in equation (1).

$$\sigma^2_{\text{total}} = \sigma^2_{\text{product}} + \sigma^2_{\text{measurement}} \quad (1)$$

Because the correctness of the ATE setup is verified using correlation units, it may mislead the engineer or analyst to jump to a conclusion that these ATE setup are reliable (normal measurement variation) if the correlation units are passed ETS.

However, there are a number of possible situations even though the correlation units are passed ETS. One of the possible situations might be the mean value of the critical testing functions (critical performance characteristics or response variable, say i) of correlation unit shifted to the upper or lower specification limit, e.g., E[Yi] is close to the USL or LSL, regardless of the variance. Another situation could be that variances of the critical variable, Var[Yi], are widely spread out within the specification regardless the mean value. Whichever the cases are, it will cause a serious random yield with a batch of product devices. See Montgomery [2] for details of quality process control.

The other major problem in final device screening laboratory is unexpected longer ATE setup time. The time study shows that time required for a proper ATE setup ranges from 5 minutes to 251 minutes for the same type of DUT. As a results, unexpected setup time caused not only a scheduling problem for its own products due date but also the other batches on the queue because numbers of other batches of product are blocked by a current batch of product. Benefits from solving this problem includes increased productivity of the operator and test engineers, reduced throughput time, and higher utilization of the test equipments.

2. Statistical approach

Statistical approaches are widely used for the on-off-line quality control and also useful techniques for the study of measurement variation [1, 3]. Montgomery [4, 5] explained basic statistical approach for on-line gauge capability study and demonstrated the number of factorial design methods for gauge capability analysis, in which two and three factor random effect models are illustrated. Tsai [6] demonstrated how statistical approach could be applied for gauge repeatability and reproducibility analysis for the rubber measurement systems in order to compute the component variance and interactions of each others, where two factors (operator and part) with random effect model is used.

For example, three factors (e.g., operator, device, and a set of five test equipments) random effects model might be written as equation (2).

$$mXijkl = \mu + Oi + Dj + ODij + Tk + (OT)ik + (DT)jk + (ODT)ijk + Rl(ijk) \quad \begin{Bmatrix} i = 1,\ldots,a; \\ j = 1,\ldots,b; \\ k = 1,\ldots,c; \\ l = 1,\ldots,d \end{Bmatrix} \qquad (2)$$

Where, *mXijkl* is the *lth* measurement made with ATE test set *k* by operator *i* on product device *j* for *mth* function (*mth* response variable or *mth* test function which varies depending on device type), is an overall mean that is common to all observations, *Oi*, *Dj*, *ODij*, *Tk*, *(OT)ik*, *(DT)jk*, *(ODT)ijk*, and *Rl(ijk)* are random variables representing the effects of the operator, device, device by operator, set of test equipment, operator with set of test equipment, device with set of test equipment, device by operator with set of test equipment, replication measurement respectively.

In practice, it is common that higher order interactions, e.g., interaction effect between three or more factors, are negligible. However, results of experimentation, as stated before, revealed that existence of interaction effects between three or more test equipments, which should be investigated as one of the steps in factorial design. Thus, subjects in this paper are tracing the interaction factors (if possible) and/or eliminating those factors thereby it will reduce setup time and/or improve yield.

Under this situation, there are five factors (types of test equipment) with each different level because of the different number of copies for each type of test equipment. It can be designed as five factor mixed level model. Since these test equipments are considered to be unique, interpolation of the response is not meaningful. When there are too many factors and too many levels, fractional factorial design would be appropriate to reduce the number of treatment under assumption that higher order interactions effects are negligible. Considering all these, factorial design model becomes very complex experiments, even though complexity was not a main reason to search other approach.

The physical and economic constraints exist in this environment. For instance, each individual ATE is calibrated and/or inspected according to its own scheduled time interval. Therefore, once ATE is calibrated, experimental results associate with that test equipment are no longer valid.

2. 1 Constraints

As stated before, all testing equipment must be calibrated. The calibration of the different type of testing equipment is scheduled at different time interval basis. As an example, the system type testing equipment is inspected at everyday basis interval and is calibrated monthly basis interval while the test box equipment is not inspected but calibrated every three-month interval. Further, the final product screening process operates twenty-four hours with three shifts in which interruption of screen process is not allowed. Summary of constraints in this environment are:

(i) The method should not interrupt the normal testing operation.

(ii) The testing laboratory operates twenty-four hours with three shifts.

(iii) Each individual ATE is calibrated and/or inspected according to its own scheduled time interval.

(iv) Expenditure for new test equipment is not allowed.

Due to those environmental constraints, solution approach is somewhat limited. The objective of this paper is to eliminate the possible ATE that causes lower or upper skewed signal or reduce the abnormal variation while satisfying the above four environmental constraints.

3. Expansion of product data information

Since the statistical approach cannot be applied, one of the solution approaches could be based on the use of product data information. An expanded product data information is constructed by creating more fields in a record, called ATE control information, and adding this ATE control information to the existing product data information. Thus, a record for each batch of product device has all product activity informations, e.g., a set of linked test equipments, lot number, wafer number, and operator. These informations are used for the future selection of test equipment and analysis of interaction effect. An example of ATE control information is shown in Table 2, and existing (current) product data information can be found from the Table 1. The result of expanded product data information table is shown in Table 3.

Table 2. Example of ATE control information

System	Cable	Handler	Family pack	Test box	Operator	Setup ime (min)
2	52	1002	140	302	92001	14

Table 3. An example of expanded product data information

System	Cable	Handler	Family pack	Test box	Operator	Yield	Date	Wafer No.	Lot No.	Setup Time
2	52	1002	140	302	92001	93.43	920707	4322	A92J13	15

Practically applicable method developed, while satisfying the aforementioned constraints, is to classify each type of product device into two groups according to its yields: high yield group and low yield group (see Table 4). After the screen process, for each batch of product device, the expanded product data information (PDI) is stored in the database in accordance with grouping criterion. Grouping criterion is a method to decide if a resulted yield should be classified in high yield group or not, which is determined by managers using history yield. Since all measurement systems should be calibrated based on scheduled interval time, if any particular testing equipment is calibrated then it should be considered as a new born equipment therefore a record which contains this calibrated equipment should be removed from the database.

Table 4. Example of Expanded Product Data Information in High Yield Group

System	Cable	Handler	Family pack	Test box	Operator	Yield	Date	Wafer No.	Lot No.	Setup time
2	52	1002	140	302	92001	93.43	920707	4322	A92J13	15
5	51	1001	141	302	91007	91.87	920707	4322	B92H19	19
2	52	1002	143	307	92003	98.21	920707	4508	A92H18	21
2	52	1002	143	308	92003	98.21	920707	4508	A92H18	17

4. Applications of EPDI (Expanded Product Data Information)

ATE selection module, which utilizes the expanded PDI database, is designed (see Appendix 1) and developed in order to reduce the ATE setup time and increase the productivity as well as the yields by eliminating the chances of selecting unreliable a set of ATE. The overall procedure to select a set of ATE is as follows.

Since the history information related to yield for each different type of product are available, a set of test equipment (ATE) that produced high yield will be used for current screen process as long as they are available. For example, the first record in Table 4, a set of linked ATE (System_2--Handler_1002--cable_52--Family pack_140--Test box_302) that had produced high yield previously, will be used for the next batch of product device screen process if this particular a set of ATE is available. The ATE selection algorithm can be described as below.

Algorithm

```
Step 1. Query product type in high yield group
        go to step 2
Step 2. Do i = 1 to last record in high yield group
        If all five test equipments is available in a record
                then, select a record : a set of ATE -> exit
        else
                go to step 3
Step 3. Select available ATE until the last record
        If a set of ATE complete
                go to Step 4
        else
                a set of ATE is not available    -> exit
Step 4. Query product type in low yield group
        go to step 5
Step 5. Do i = 1 to last record in low yield group
        If a set of ATE is match to a record
                then, analysis and go to Step 3
        else
                a set of ATE complete -> exit
```

Once a construction of a set of ATE from the high yield group is complete, it checks if this a set of ATE experienced low yield in history. It can be done by searching a record in low yield group. If any record from the low yield group matches to the selected a set of ATE, then investigation can be conducted followed by a selection of other test equipment from the high yield group in order to avoid this undesired match.

Analysis module (see Appendix 1) is designed and developed to assist in order to classify PDI, after the screen process, into either low yield group or high yield group. The below four rules are applied for the classification purpose.

Rule 1. If a set of ATE matches to a record in high yield group and current yield is high, then the current expanded PDI will be stored in high yield group.

Rule 2. If a set of ATE matches to a record in high yield group and the yield is low, then a current expanded PDI will be stored in high yield group. The low yield is due to the current batch of product device therefore, current expanded PDI will be stored in high yield group.

Rule 3. If a set of ATE does not matches to a record in high yield group and current yield is high, then a current expanded PDI will be stored in high yield group.

Rule 4. If a set of ATE does not matches to a record in high yield group and current yield is low, then a current expanded PDI will be stored in low yield group. Under the previous assumption, the possibility that cause of low yield is due to the batch is ruled out.

Table 5. Sample results with the previous and proposed PDI.

Device type	Previous DB		Proposed DB	
	(% yield)	(avg. setup time, unit: min.)	(% yield)	(avg. setup time, unit: min.)
LM 108	57	183	76	25
LM 207	72	126	85	61
......	....	...	...	...
NM 103	59	64	68	45

The effectiveness of this method is depending on the frequency of the same type of ATE used within the calibration time interval of ATE, therefore, introduction of a new product will not utilize expanded PDI. Application of the proposed PDI resulted in the following % yield improvement and average setup time reduction as shown in Table 5*.

5. Summary and conclusion

The screen processes for VLSI finished device are considerably complex, because it requires different types of test equipments to be linked to form a set of linked ATE in order to test a product device. Due to the interaction effect between two or more linked ATE, it is difficult to trace down the cause of the unexpected longer ATE setup time and random yields. The statistical approach could not be applied directly due to the environmental constraints. An architecture utilizing expanded product data information is designed, which enables to conduct statistical approach investigation, reduce the setup time, increase yield. The effectiveness of this method is depending on the frequency of the same type of ATE used within the calibration time interval of ATE, therefore introduction of a new product will not utilize expanded PDI.

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* The data provided in Table 5 are different from the real data due to the confidentiality..

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Appendix 1.

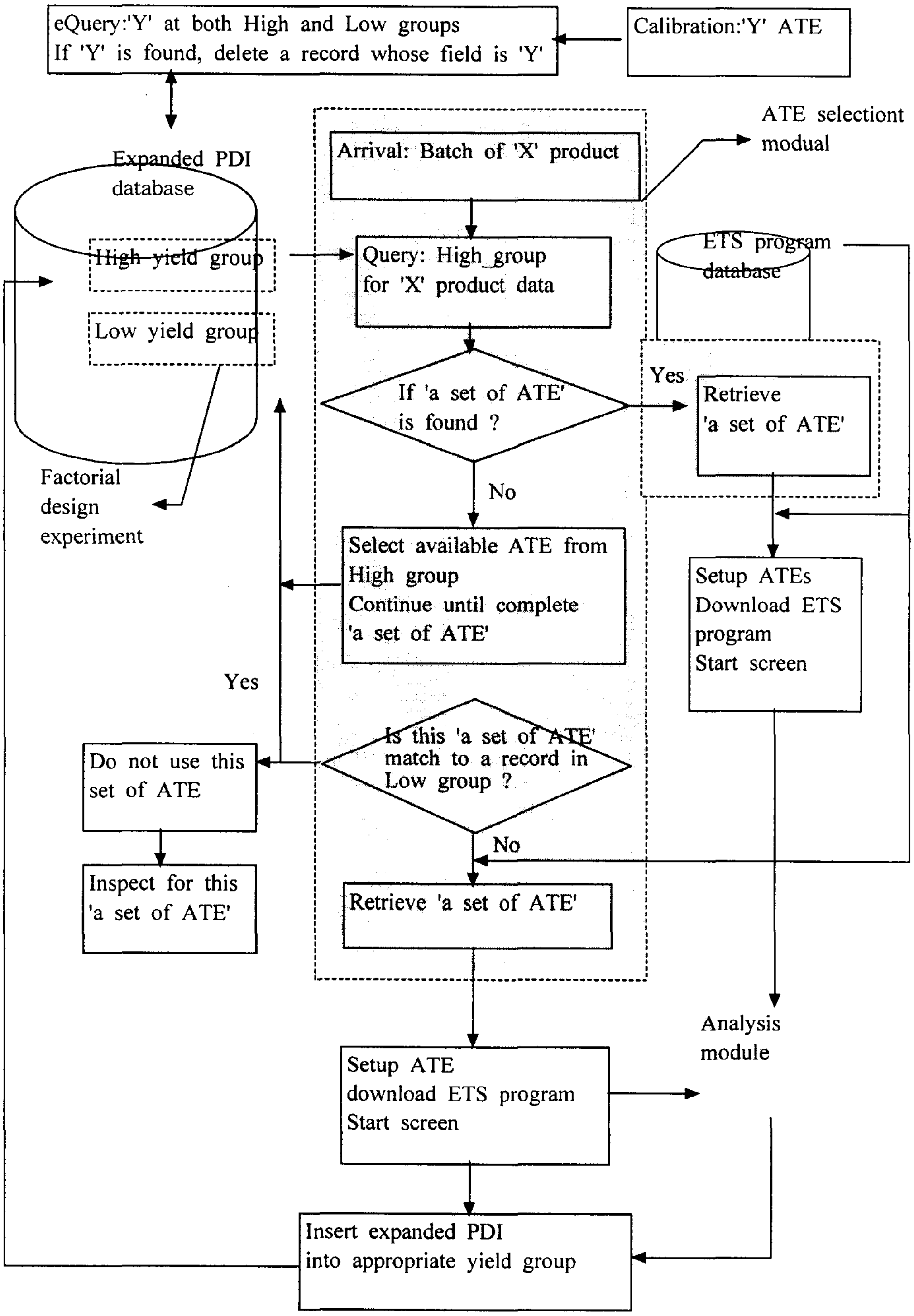

Figure 3. Information Flow Structure for the Use of Expanded PDI in Screen process