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An IoT Inspired Semiconductor Reliability Test System Integrated with Data-Mining Applications

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***Abstract*—Reliability assessment is a key step in ensuring the quality of a product. As semiconductor technology continues to evolve, the reliability test process also complicates, involving engineers and technical assistants responsible for different test tasks. In this paper, we propose a design of a comprehensive Reliability Management and Index System that integrates online test requests, database management and test data analysis. In addition, the resultant big data collected by the system inspire potential data-mining applications for new reliability data-analysis approaches.**

Keywords—Semiconductor reliability test; industrial 4.0; software system design; data mining; Bayesian reliability

I. Introduction

The concept of "Industry 4.0" was firstly proposed by Germany government in 2011 which refers to the 4th industrial revolution after mechanization, electrification and information revolution [1-2]. It mainly involves building a Cyber-Physical System (CPS) to realize a digital and intelligent factory, in order to promote manufacturing to become more digital, information-led, customized, and green. The implementation of Industry 4.0 is closely related to Internet of Things (IoT). IoT uses network devices to sense and collect data from the world around us. These data will then be shared across the Internet where it can be processed and utilized for various interesting purposes [1-4]. In the context of "Industry 4.0" and IoT revolution, modern manufacturing systems have become more intelligent. For instance, Emerson's recently released wirelessly monitored "Enardo 2000 emergency pressure relief vents (EPRVs)", combining its ability to monitor thousands of sensors in a process plant and turn the data from those sensors into useful information. Semiconductor industry, as one of the most sophisticated industry that involves hundreds of processing steps, is also in urgent need for "Industry 4.0". While intelligent wafer status tracing system and wireless sensor for equipment abnormity alarm system can already be seen in modern fabrication line, we still lack a comprehensive system designed for a laboratory testing environment with significantly smaller scale compared to the fabrication line.

Meanwhile, in the context of big-data era and continuous development of data storage technology, data-mining technique has seen its great applications in industries. For instance, FAW-Volkswagen Audi recently developed the "Audi Cloud Mirror"—a big data system that is used to make their marketing strategy and helps them lead the Chinese automobile market [5]. For semiconductor reliability testing, we also expect to make use of the organized test results for advanced applications. Each day we will receive hundreds of wafer for reliability testing and each test will generate data of multiple physical parameters through time. By combining these data with inline metrology results, we could predict what a certain kind of technology change can bring to the reliability performance. Also, by measuring the critical dimension of a test key, we may estimate the reliability performance of the test key and pick the most suspicious wafers for further investigation.

This paper will present the design of such a system for a reliability-testing laboratory. We will call it (Reliability Management and Index System: RMIS). The users involved are requester, project owners, test owners and lab technical assistants (TAs). The size of the measured data generated each day is around 1GB. This reliability-testing laboratory is responsible for evaluating the reliability performance from the production line. Its core area involves product-level reliability, process-level reliability, and wafer-level reliability (WLR). A typical reliability test flow is shown in Fig 1. Currently, engineers use paper forms to communicate with TAs and excel macros to analyze data. The lab lacks a unified framework to maintain and organize test requests records, test results, and lab equipment status. Therefore, the system is meant to achieve the below goals: 1. Information management of test request and test status. 2. Information management of laboratory equipment. 3. Information management of reliability test data.

The rest of the paper is organized as follows. We will first introduce the system requirement analysis, and then we will discuss the system design based on different modules and the database design. Finally we will discuss some data-mining related applications of this system.

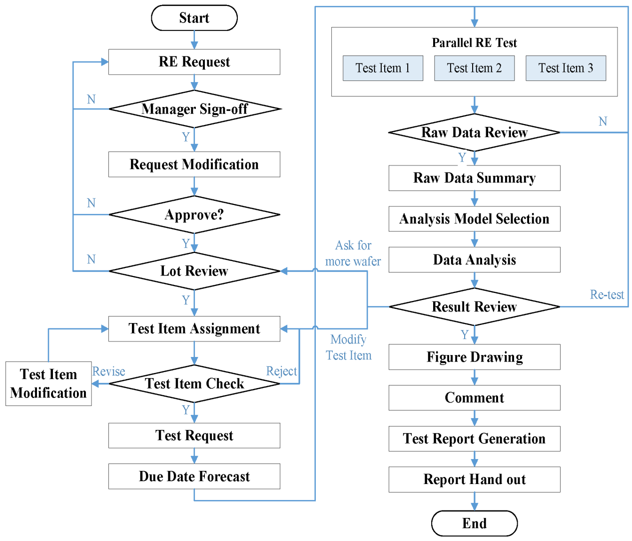

Fig. 2. A Simplified Work Flow of a Reliability Test

II. System Requirement Analysis

A. Function Analysis

After discussion with engineers and TAs from different working areas, the detailed functions requirements are summarized below:

1. Management of reliability test key: the system should provide a database of reliability test key where engineers can directly search the testing template.

2. Test owner portal: test owners should have work portals where they can see all test requests from project owners; they can also submit test requests to Lab TAs from here and monitor the test status and equipment availability.

4. Lab-TA portal: Lab TAs should have work portals where they can see all test requests assigned to their sections (PDR/PLR/WLR). They can select test equipment/boards to perform the test. They can start, pause and stop a reliability test and record all these information into the system.

5. Test status monitor and tracing: All the test status information and hardware status should be fed back to the system for monitoring and localization of test chips/boards.

6. Equipment utilization arrangement: the system should have the ability to recommend equipment selections based on current equipment utilization status and case urgency to TAs.

7. Data acquisition: The system should grab data automatically from designated directories, based on some fixed format of data files.

8. Data analysis: The system should provide both basic analysis and advanced data analysis functions to engineers. The basic analysis includes the ordinary analysis for reliability test. For the advanced data-analysis functions, we want to integrate portals to other advanced statistical software, such as JMP, SASS or R.

9. Barcode scanning: To trace each individual chip and the corresponding test board used for the test, we want to print laser barcode to the boards and the sockets, considering the high temperature. The system should be able to provide software support for this functionality. Each lab test section will also be equipped with a digital pad for remote input and scanning.

III. System Design

The system is based on Browser/Server framework. The advantage of using B/S design is that there are no strict requirements on the operating system and the hardware for remote workstations. Only Internet connections are needed. This is specifically suited to current lab situations, where the workstations from different lab work areas have different working systems and hardware configurations. With the B/S framework, users will operate on the web browser. All of data will be stored on a server, while algorithm will also be executed on server. Server-side program is developed on three-layer architecture, as shown in Fig. 2.

Inspired by "Industry 4.0" and "IoT", we make use of the internet and smart devices to make the system more intelligent. We propose that the lab should have Wi-Fi access and each section should be configured with at least one tablet PC and bar code scanning system. TAs can then remotely input all test information and scan test board information into the system. Engineers can then trace the status and the hardware used for each test. In the future, the system should be able to directly access all hardware controllers of the equipment and mapping them to a "virtual space". Engineers and TAs can remotely control the equipment operation and monitor the test status.

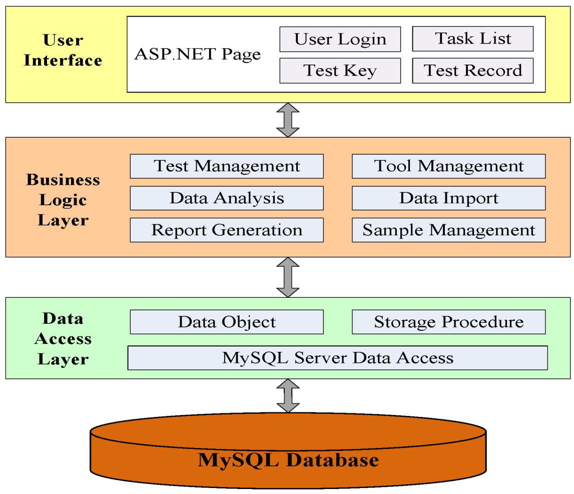

Fig. 2. Framework of RMIS

A. Functions by Different Modules

There are totally 9 modules in RMIS systems, which are discussed below. Each module contains specific functions and flows, aiming at information management of RE Lab:

1. RTK: It mainly performs as a knowledge base. It manages test specification (test key), such as test condition, line contact and operating tips.

2. RTR: It controls the whole RE test flow, including new test case applications, modifying existing test case applications, approving and rejecting a test case, test item management, and test status monitoring.

3. SBA Request System: It provides special work flow control of side braze assembly (SBA). Users may manage and handle SBA cases in this module.

4. Lab Management: It covers lab daily operation and give an overall vision of the RE lab. This module also manages basic settings of RE lab.

5. Database: It performs as the foundation of the whole system. This module stores system data, process data, test raw data, analysis data and etc.

6. Analysis & Report: It analyzes and generates test report based on test raw data. This module also allows users to choose customize analysis model to extend analysis ability.

7. Bar Code: It enables auto-scan function to conveniently input information of test samples, tools and consumptive materials.

8. Reliability Index: It calculates the monitoring index of mass production wafers and draw control charts.

9. General module: It contains several functions like system configuration, user and authority management, database operation, trace tags and etc.

Each module will be designed using Unified Model Language (UML) solutions.

B. Database Design

RMIS is using MySQL database, consisting of 11 charts based on previous requirement analysis. The entity relationship diagram (ERD) of RMIS is shown in Fig. 4.

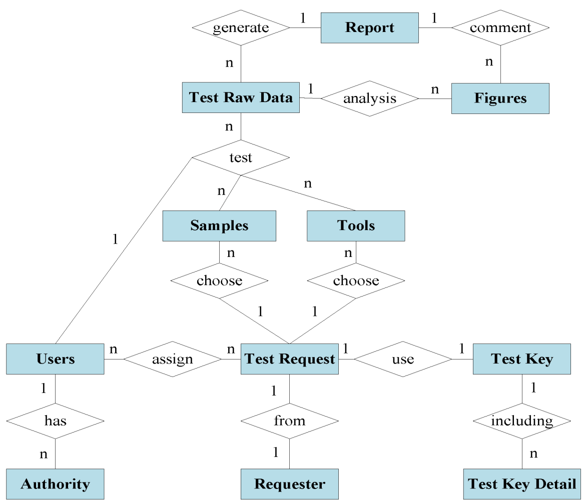

Fig. 3. Entity Relationship Diagram of RMIS

C. Dispatching algorithms

RMIS provides a rule-based dispatching algorithm, which helps TAs and engineers to arrange tasks properly and efficiently. Rules are discovered from a study of test data. We first gather data from test tools and flows, including test request, process data, control data and test raw data. Bar codes are glued or printed on request forms, test samples, burn-in boards, probe cards, etc.

After analyzing all of these data records, combining with the design of lab management module, we propose the several rules, such as the interval time rule (a test sample cannot wait over 96 hours before going to a next test), to decide the priority of each case. By applying these rules, RMIS can decide each case's priority and recommend appropriate tool to TAs.

IV. Data-mining Applications

The RMIS will collect historical reliability-testing data. With such collections of "big data", we are facing new opportunities but also new challenges for RMIS applications.

A. Early Prediction of Reliability Performance

Traditionally, after a wafer finishes its processing in the production line, it may take up to 60 days to fully estimate its reliability performance. As semiconductor technology changes every day, customers need faster reliability evaluation in order to adjust production process. On the other hand, for semiconductor devices, reliability modeling at the system or component level is complicated by the involvement of multiple failure mechanisms that have the same stress factors: voltage and temperature. The Arrhenius relationship with one value of activation energy for all temperatures has shown to be invalid at the component level if these failure mechanisms do not have the same activation energy. The same result can be observed when modeling voltage dependence. All these impose a challenge for modern reliability evaluation methodology on how to more quickly predict wafers' reliability performance with minor error, limited resources and cycling time. Now, equipped with historical reliability data from RMIS system, corresponding metrology data from production line as well as real-time data from Advanced Process Control System (APC) [6, 7], we may be able to build models to early predict a wafer's reliability performance. Based on the prediction results we can then speculate which processing steps are suspicious for a reliability issue or we can speculate which wafers have defects and therefore worth further reliability testing.

In reality, the above-mentioned methodology faces some challenge: the dimensions of inline metrology parameters (the independent factors) are usually more than the reliability test results (the data points). A common approach is to use dimension reduction methods, such as Partial Least Square (PLS) to find the most relevant factors or their combinations. PLS combines the advantage of Principle Component Analysis (PCA), Linear Regression, and Canonical Correlation Analysis (CCA) [8, 9]. Different with PCA which only considers the matrix of independent variable, the PLS also considers the "response" matrix, therefore having better predictive ability. The method can generate Variable Importance for the Projection (VIP) for each factor and we can then use these indices to classify the most relevant factors for building models.

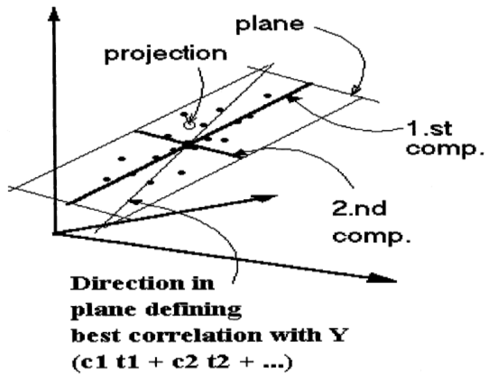

Fig. 4. Partial Least Square Method for Dimension Reduction [8]

B. Bayesian Reliability

Traditional statistical parameter estimation (frequentist) only uses sample and population information. Bayesian statistics differ in the sense that it also makes use of the estimated parameter's prior information. Equation (1) shows its mathematical expression: y is the observation and θ is the parameter to be estimated. The prior information p(θ) is sometimes based on expert experience, but sometimes purely based on mathematical convenience-the conjugate prior/posterior distribution.

$$p(\theta|y) = p(\theta|y)\frac{p(\theta)}{p(y)} \tag{1}$$

Bayesian reliability is one application branch [10, 11]. As illustrated in Fig. 7, we take use of previous information to construct a prior distribution model for these parameters at first. This model expresses our starting assessment about how likely various value of the unknown parameters are. We then make use of the current data via Bayes formula to revise this starting assessment, deriving what is called the posterior distribution model for the population model parameters. Parameter estimates are calculated directly from the posterior distribution, while the prior distribution would be taken into account when there is no current data. Thereby, reliability predictions can be obtained from these distributions. A good application example is the prediction of a device's reliability in the early product lifetime cycle stages. Under extreme circumstance with limited resources, we have to make a relatively accurate conclusion to predict a device's reliability in the early product lifetime cycle stages. In this situation, frequentists statistical approaches are less useful compared to Bayesian statistics and provide instable predictions since their methods just rely on sample information to infer overall information without accounting prior knowledge.

However, the benefit of Bayesian statistics relies much on the accuracy of prior distribution. Now with the "big-data" from RMIS, we are able to obtain more accurate Bayesian prior information, which is crucial for the successful implantation of Bayesian reliability approach.

V. SUMMARY

In this paper, we propose a system design for a reliability-test laboratory in a modern semiconductor manufacturing environment. The system design is inspired by "Industry 4.0" and "IOT" concept, with the goal to achieve fully information management for all lab-related affairs, as well as a platform for management of big reliability-test data. With data-mining techniques, the collected reliability data can be further incorporated with inline metrology data and failure analysis results to help improve production efficiency.

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