UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

SMART CONTROL SAMPLING SYSTEM FOR METROLOGY TOOL IN SEMICONDUCTOR PRODUCTION LINE

Cheerrein Tan Cher Ring

Master of Manufacturing System Engineering

2021

SMART CONTROL SAMPLING SYSTEM FOR METROLOGY TOOL IN SEMICONDUCTOR PRODUCTION LINE

CHEERREIN TAN CHER RING

A thesis submitted
in fulfillment of the requirements for the degree of Master of Manufacturing System Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

YEAR 2021

DECLARATION

I declare that this thesis entitled "Smart Control Sampling System for Metrology Tool in Semiconductor Production Line" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : CHEERREIN TAN CHER RING

Date : 20TH AUGUST 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is suffiient in terms of scope and quality for the award of Master of Manufacturing Engineering .

Signature : ....

Supervisor Name : DR. NUR AIDAWATY BINTI RAFAN

Date : 22TH AUGUST 2021

ABSTRACT

This research is to implement a Smart Control Sampling (SCS) system for metrology tool in the Semiconductor industry factory for better traceability and dynamic control on quality sampling for wire bond proces. Wire Bond process is one of the most critical process in the overall assembly line whereby it is the bonding of gold wire to a bond pad by a mechanical joining process. Investigation was conducted on the inspection platform by the metrology Automated Optical Inspection tool, the current production practice is dependent on human and causing the sampling compliancy issue. There is also no system setup for the metrology tools in the process flow for the product to be sampled accordingly hence no traceability for the sampled lot data. The SCS system designed with automated sampling schedule triggering to eliminate human dependant sampling frequency that are high potentially causes human error and risk on process quality. The main objectives of this project includes the identification of data needed to collect and the current sampling plan, to develop a SCS to automate the sampling schedule triggering, achieve 100% inspection sampling compliancy in the production, and to investigate the impact to yield loss performance and overall metrology tool processing time. This sampling system is completed developing in two phases where the first phase is the fundamental design of the sampling framework that able to auto-trigger the sampling frequency based on the sampling-rule while second phase of this system is even smarter to add in the risk-based-sampling features that are more dynamic in a way. SCS system is very efficient to improve the yield performance of 0.13% with ANOVA test of 95% confident level yet continuous improvement is needed to add more function, features and connect to more application to better monitor, collect and analyze the sampling data.

ABSTRAK

Penyelidikan ini adalah untuk menerapkan sistem Smart Control Sampling (SCS) untuk alat metrologi di kilang industri Semikonduktor untuk pengesanan yang lebih baik dan kawalan dinamik pada persampelan kualiti untuk proses ikatan wayar. Proses Wire Bond adalah salah satu proses yang paling kritikal dalam garis pemasangan keseluruhan di mana ia adalah ikatan wayar emas ke pad ikatan dengan proses penyambungan mekanikal. Penyiasatan dilakukan di platform pemeriksaan oleh alat Pemeriksaan Optik Automatik metrologi, amalan pengeluaran semasa bergantung pada manusia dan menyebabkan masalah kesesuaian sampel. Juga tidak ada penyediaan sistem untuk alat metrologi dalam aliran proses agar produk dapat diambil sampelnya sehingga tidak dapat dikesan untuk data lot sampel. Sistem SCS yang dirancang dengan jadual pensampelan automatik memicu untuk menghilangkan frekuensi persampelan bergantung manusia yang tinggi berpotensi menyebabkan kesalahan manusia dan risiko terhadap kualiti proses. Objektif utama projek ini merangkumi pengenalpastian data yang diperlukan untuk dikumpulkan dan rancangan persampelan semasa, untuk mengembangkan SCS untuk mengotomatisasi pemicu jadual pensampelan, mencapai 100% kepatuhan pemeriksaan pemeriksaan dalam produksi, dan untuk menyiasat kesan terhadap prestasi kehilangan hasil dan keseluruhan masa pemprosesan alat metrologi. Sistem persampelan ini selesai dikembangkan dalam dua fasa di mana fasa pertama adalah reka bentuk asas kerangka persampelan yang dapat secara automatik mencetuskan frekuensi persampelan berdasarkan aturan persampelan sementara fasa kedua sistem ini bahkan lebih pintar untuk menambah risiko -konsep-berdasarkan sampel yang lebih dinamik dengan cara. Sistem SCS sangat cekap untuk meningkatkan prestasi hasil 0.13% dengan ujian ANOVA 95% tahap yakin namun penambahbaikan berterusan diperlukan untuk menambahkan lebih banyak fungsi, ciri dan menghubungkan ke lebih banyak aplikasi untuk memantau, mengumpulkan dan menganalisis data sampel dengan lebih baik.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my supervisor Dr. Nur Aidawaty for the continuous support of my master project, for her patient, motivation, and immense knowledge. Her guidance helped me and guided me in all the time of research and writing of this thesis. She shares her experiences with me and directs me to walk on the right path in order to complete my master project. My sincere thanks also go to my fellow course mates for the stimulating discussion, for the sleepless nights we were working together before deadlines. We discuss about the bottlenecks when we conduct this master project, the ideas generated by our brainstorming helps me a lot in conducting this research. Last but not the least, I would like to thank my family, my beloved parents and to my husband for supporting me spiritually throughout writing this thesis and my life in general.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.0 Background

The study is deploy in the semiconductor industry factory that produce memory chip by processing different product form like wafer form, strip form and singulated units as final product. In each of the process operation, in-line or post-process inspection and measurement is carried out by metrology instrument tool or automated optical inspection (AOI) system to ensure the process performance and product quality are within specification. Figure 1.1 shown an example of AOI tool from ADVANCED TECHNOLOGY INC. company to perform the post Wire Bond process strip form automated inspection in semiconductor factory.

Figure 1.1 Wire Bonding Inspection AOI tool from ADVANCED TECHNOLOGY INC. (ATI) KOREA COMPANY used for strip form inspection

The inspection or measurement performed by the metrology AOI tool is normally in sampling manner, meaning not 100% of all the products are inspected. This statistical sampling method is common as the lot size is large and 100% full inspection could be challenging for all the processes due to capacity and resources constraint. Sampling inspection is basically a technique to determine whether a lot or population should be rejected or accepted on the basis of the number of defective parts found in a random sample drawn from the lot and if the number of defective parts exceeds a predefined level, the lot is rejected. This sampling method is beneficial to the manufacturing as it involves less amount of inspection and less time to achieve a good quality control. However, in general the sampling defined and implemented in the production is only documented in the process specification and customer specification list of quality control plan (QCP) without any system to trigger it automatically in the manufacturing line. The line operators have to comply to this specification documented as part of their Standard Operating Proceudre (SOP), however the overall triggering of the sampling is manual and operators have to practice the sampling frequency for each shift for inspection without any system triggering. Hence, this research is target to implement a smart control sampling system for metrology tool in semiconductor production line, by designing a system with automated sampling schedule triggering to eliminate human dependant sampling frequency that are high potentially causes human error and risk on manufacturing process quality.

The main consideration is due to financial, method, material, time and resources available the semiconductor factory currently. The main need for this project is the IT resources that are able to help on developing the sampling software that can link with the production metrology tool and the server that is customized to trigger the sampling frequency required in the production based on the rule setup by users. For this project, the factory's IT team and the global IT team is able to support for the development and the metrology tools in production is also available to be access all the resources needed in factory, then able to understand the whole project idea to implement this sampling system for all production metrology tools as well. There is no additional cost needed to develop this project as the company in-house IT and Big Data Science team is able to support fully for the system software deployment and the tools in line are capable with the SECS/GEMS communication as well with no needs of tool upgrade nor modification. The whole project will be able to be managed in more effective way as the idea is already generated and can be planned out the project timeline and strategy with internal functional team for full expedite after details discussion.

This research project though seems challenging and required a lot of cooperation between functional group to achieve the wins of this whole projects, but also the achievement and advantages to the production would be fruitful and beneficial to the team. It will also be a gain to increase the knowledge of data-based analysis to connect the hardware tools with the internet server so that can learn more and achieve towards the spirit and goal of Industry 4.0 and reduce human interaction and dependency in the manufacturing industry.

1.1 Problem Statement

In the semiconductor production mostly inspection and measurement sampling frequency is very dependent on human which is the operators, this causes the sampling compliancy issue as human tends to make mistake and have limitation. Besides, in the factory there is also no system setup for the metrology inspection or measurement tools in the process flow for the product to be sampled accordingly. The production lots are appeared to be at process step in the system while waiting for the measurement or inspection to be completed, and this cause no visibility and traceability of the real-time status of the lot location and status. If the operator accidentally or intentionally did not follow the sampling inspection on the particular production lots for quality verification and there is no system hard-rule set to prevent that condition may cause many quality issue subsequently without preventive action. In addition, there is no automation sampling platform in the factory available to adjust the sampling due to certain deviation event such as capacity constraint of the metrology tools, or the needs to increase sampling due to quality issue since everything is manually track in the production.

There is several processes in the whole assembly line and the most critical and complex process is the Wire Bond process which is the process of bonding gold wire on top of the micro chip die with the PCB substrate board to establish connectivity and electrical interconnections for the purpose. Most highest rejection rate can be observed from this wire bond process as those wire is very fine and usually being bonded in bundle very close to each other, so any single wire breaking or sagging will cause a defects and reject the whole unit. Hence, the post-wire bond process inspection is being focus and a large sampling plan is performed, even some of the customers requested the factory to perform 100% inspection to avoid any kind of the reject being shipped to them. During the inspection, operator will record the number of defects part that are not meeting the quality specification criteria and if the number of defective part exceeded trigger limit, operator need to react based on the out-of-control-action-plan (OCAP). The OCAP will be normally to log down the machine and escalate help to machine technician to check on the machine issue and process team will need to investigate on those defective part to understand and find out the issue root cause as well. Thus in this project is focus in this wire bond process in order to solve the sampling compliancy issue currently and the effectiveness of overall yield performance in the production line. Although there is Quality Control Plan (QCP) being setup and managed by quality engineer for every processes and parameters, sometimes the problem also consists in deciding which lots should be measured and in which order these selected lots are measured, depending on control parameters and metrology capacity. Operators will decide randomly or based on their availability most of the time and these could cause bias in the sampling and did not serve the best purpose of quality control. There is also multiple manual touch point from operator to handle the lot for sampling inspection and no automation sampling platform current available to adjust the sampling in a flexible way due to certain event or quality issue. We need a system to auto calculate and trigger the sampling frequency and batch of lots to the operators based on the best logics setup after consider all the process variation and quality requirement, then we can eliminate all the human dependency and provide a automatic sampling solution to also minimize operators burdens.

1.2 Objectives

The objectives of this research are:

i. To identify data needed and sampling plan on current Wire Bond inspection process in order to verify efficiency of the sampling.

ii. To design a Smart Control Sampling (SCS) user interface to automate the sampling schedule triggering, eliminate human dependant and achieve 100% inspection sampling compliancy in the production.

iii. To analyze the impact of yield loss performance and metrology tool processing time in relation to the smart control sampling implementation.

1.3 Scope

The inspection process in this project that will be studied for the sampling plan and data collection is the Wire Bond process in a Semiconductor assembly factory. Wire Bond process is the critical process in the overall assembly manufacturing of micro chip memory product and the data involved is the inspection process cycle time, overall sampling size, percentage of the rejection rate and the process yield loss. The machining involved in this project is the KNS wire bonder machine, automated inspection machine, called ATI IVY and the SCS system will be developed by company IT team using Visual Studio software.

1.4 Report Organization and Layout

This research report comprises five chapters which include the introduction, literature reviews, methodology, result and discussion, and lastly is conclusion and recommendation. Chapter one presents the introduction and background of the research. In this chapter, there also includes the objectives and scopes of this research, defined problem statements and the report layout.

Chapter two presents the literature review of this research which describe the overview of literature reviews and some important related topic to help on understanding the concept, theory and knowledge application of this research project. In this chapter, there are some reviews from other research which related to the title and focus key points of this research.

Chapter three is the methodology of this research, which stated the methods to carry on the research based on the objectives and scopes. There are four main parts of methodology is written in order to achieve the objectives of this research and also include on the experimental design used to setup and validate the overall system.

Chapter four shows the results and discussion of the research. Based on chapter three, the results is obtained and listed in this chapter as well as the discussion of the results. Since the results are based on chapter three, there are four main parts of results and discussion in this research.

In last of the report, chapter five discusses the research conclusion about the auto-triggering sampling and dynamic and smart sampling system, and then the improvement of yield performance and the reduction in metrology tool processing time in the semiconductor assembly production line. This chapter also concluded some recommendation on the further research and study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Generally, the semiconductor industry is the aggregate of manufacturing companies engaged in the design and fabrication of semiconductors and semiconductor devices, such as integrated circuits. In semiconductor manufacturing, input materials include semiconductor materials, dopants, metals, and insulators while the corresponding outputs include integrated circuits (ICs), IC packages, printed circuit boards, and ultimately, various commercial electronic systems and products (May, 2006). Basically, the semiconductor industry is extremely competitive and requires ongoing technological advances to improve performance while reducing costs to remain competitive in the worldwide market.

Nowadays, the advanced inventions aim to make humans life easier and better and one of the widespread advances in daily life is electronics and automation which makes life easier than ever. This applies same for the manufacturing industry, with advances in information and telecommunication technologies and data-enabled decision making, smart manufacturing can be an essential component of sustainable development. In the era of the smart world, semiconductor industry is one of the few global industries that are in a growth mode to smartness, due to worldwide demand

(Khakifirooz, Fathi and Wu, 2019). Therefore, it would be an increased need for modeling, optimization, and simulation for the value delivery from manufacturing data. Hence, the development of semiconductor manufacturing industry is critical and important to the worldwide market demand and development interms toward the Industry 4.0 and reliazation of Internet of thing (IoT) in the daily living. The semiconductor industry not only bring conveniency and development to human living to live “smarter”, it also significantly contributes to the national economy and competitiveness, many countries and companies have investing aggressively in the semiconductor capital and R&D in order to strategically grow the semiconductor industry (Assessment, 2020).

Semiconductor manufacturing can be divided into four main steps and operation area which includes wafer fabrication which is the heart of semiconductor and the most capital-intensive operation, probe or sort, assembly and packaging, then the final post-assembly testing. In wafer fabrication, the integrated circuits (ICs) are fabricated layer by layer on silicon wafers then are sent to the sort or probe step where electrical probes are connected to each IC on the wafer to determine whether or not they are functional. The good ICs are identified and an electronic map of the wafer is made so that only the good ICs are put into a package at the next step, which is called assembly or packaging. Finally, the packaged ICs go through a series of test operations to ensure that only fully functional ICs are delivered to the customer (Gupta et al., 2007). Figure 2.1 shown a simplified process chart for the semiconductor manufacturing process which describe the four basic stpes of wafer fabrication, wafer probe, assembly and final test in semiconductor process and the wafer fabrication is the most technologically complicated and capital intensive. The first two phases are called front-end production, and the last two are called back-end production.

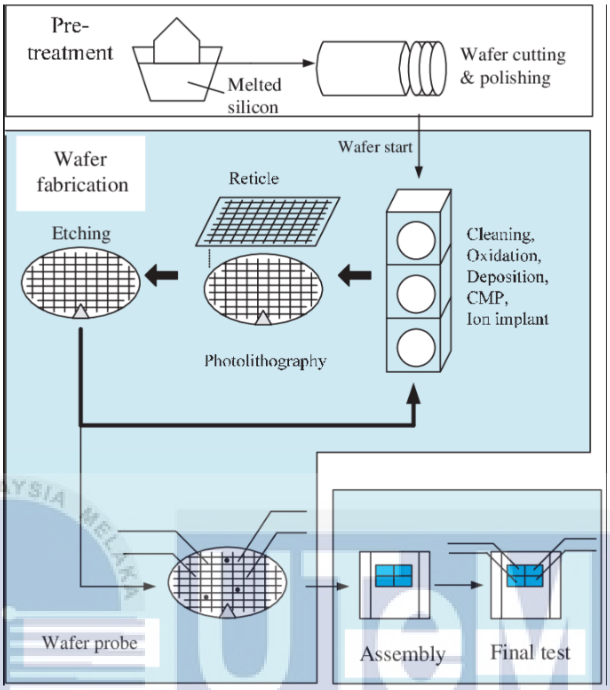

Figure 2.1 Simplified process chart for the semiconductor manufacturing process (Geng, Jiang and Allocation, 2007).

The fabrication of wafers, or also considered as the front-end process in semiconductor manufacturing, must undergo hundreds of processes using expensive equipment with relatively short lifetime due to rapid evolution of manufacturing technologies. The most challenging and common issue for this wafer fabrication is to make the best use of the expensive machinery within their short lifetime to minimize the production costs and this has become a crucial and challenging issue in most of the semiconductor front-end industry. This special issue is a collection of highly selective research addressing important issues including demand fulfillment planning, crosscompany short-term capacity backup, scheduling of unrelated parallel machines, and fault detection and classification in semiconductor manufacturing (Chen and Wang, 2013).

In general manufacturing quality control activities help to ensure a batch of products meet customer requirement and specifications, the same concept applies for semiconductor industry. The most common activity is the post-assembly final inspection, which quality checking some products against a checklist, and getting to a pass or fail result before product shipment. In recent year of most of the semiconductor manufacturing industry, quality is built into the processes and final inspection is not the only checkpoint anymore to ensure good quality of products as it is too late when the product already finished all the manufacturing processes. Engineers believe that most of the reject and defects in manufacturing process can be prevented through effective quality control in manufacturing and a good detection and measurement tools could help to understand the issue and root cause of each defects. The detection point at every single process is critical to check on the quality of each process with different parameters and more inspection or measurement tools is being designed to help on monitoring different parameters in different processes like wafer saw, wafer grinding, wire bond and encapsulation in the semiconductor industry production. Different kind of advanced automated tools is being fabricated to suit all these needs.

2.1 Sampling Concept in Quality Tool

Quality inspection is a crucial way to verify product conformance to requirements which under certain inspection procedures, it can help to identify whether the product quality conforms to specifications or not after a certain manufacturing process. The quality inspection for a product is basically nondestructive inspection on a Go-NoGo basis check, is intended primarily for use in process inspection of parts or final inspection of finished goods to have assurance that the percentage of defective units in accepted product will be held down to minimum.

In statistics in aspect of quality assurance, sampling is the selection of a subset which is a statistical sample of individuals from within a statistical population to estimate characteristics of the whole population (Singh and Masuku, 2014). The two main advantages of sampling are the faster data collection and lower cost. The quality inspection required to collect data from the production material using specific inspection tooling or automated optical inspection (AOI) tool after a process. In industries, one hundred percent (100%) inspection after a process is neither practical nor economical as it requires more labor and production time during manufacturing process, especially in products with complex dimensions that require longer inspection time (Zhang *et al.*, 2019). Hence, sampling inspection for quality assurance is commonly used in manufacturing process to selectively perform inspection on some batch of lots following certain fix and constant frequency.

Basically, common tools used to support quality control include the statistical process control (SPC) and Six Sigma principles is very helpful in monitoring and controls quality by tracking production metrics. It is the internal monitoring index and helps to identify, solve problems before products leave the factory to customer. It also ensure the final products able to meet customers' needs and have zero defects. Statistical method is critical when comes to production quality control like the acceptance sampling is also concerned with the design and implementation of sampling plans to inspect incoming or outgoing production lots (Luca, Vandercappellen and

Claes, 2020). Application of acceptance sampling in inspection of product which takes random sample from the production lot, and based on the inspection of some quality characteristic a decision is made to accept or reject the complete lot. Acceptance sampling plans can be classified according to the type of variables that are measured, like the quality parameters that are measured on a numerical scale are used in variables sampling plans, while parameters that classify product as defective or non-defective or "go-no-go" results lead to attributes sampling plans.

During the past two decades of the 20th century, the research interest in acceptance sampling decreased as it has been criticized since the application are described as one-shot deals to test whether a production lot is conform to specifications without giving any feedback into either the production process or engineering design that would be necessarily for quality improvement. However, acceptance sampling method is still playing an important role in modern industrial environments and there has been a resurgence of interest in this field in the 21st century (Luca, Vandercappellen and Claes, 2020). In fact, sampling methodology in the manufacturing inspection processes is useful to improve the risk-based sampling strategy and utilize the tools that having capacity constraint. On the basis of the implicit assumption that the quality characteristic is distributed according to normal with mean and standard deviation, the concept of variables sampling inspection has been studied by many researchers. Some studies on sampling plans when the assumption of normality of the quality characteristic fails or the functional form of the underlying distribution deviates from normal or the form of the distribution is not known are also found in the literature of acceptance sampling (Sathya Narayanan and Rajarathinam, 2013). In some papers analyze this method as single sampling plan by variables is formulated and evaluated