Chapter 1

Introduction

1.1 The Semiconductor Industry

The semiconductor industry supplies components for the transportation, consumer electronics and communication industry. Motorola is one of the key players in the semiconductor industry, supplying semiconductor components for transportation systems (e.g. microcontrollers), consumer electronics systems (e.g. modems), communications systems (e.g. cellular phones) and also network and computing systems (e.g. microprocessors). In the first quarter of 1997, Motorola reported sales of about US$6.5 billion, out of which, about US$2 billion were contributed by the Semiconductor Products Sector (SPS) [1]. According to analysts, the worldwide semiconductor market will experience 27% growth, making it a US$19.6 billion market by the end of 1997 [2].

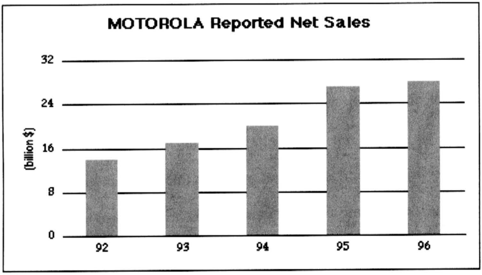

Figure1.1a : Motorola Net Sales trend by year

There are basically 2 manufacturing areas in the semiconductor products industry: wafer fabrication and semiconductor packaging. Wafer fabrication involves the production of silicon ingots, wafer slices, and the production of integrated circuits on the wafer slices through the oxidation process, masking, etching, implantation and doping, and finally metallization, to complete the wafer [3]. A single wafer would consist of multiple dice (die), therefore it would require further processing to separate the individual dice (die).

On its own, the die is exposed and vulnerable to outside influences. The surface of a die is sensitive to scratches and chemical reaction with hostile elements in the environment, which could damage the integrated circuits and render the chip useless and non-operative as a device. Furthermore, the die needs to be connected to an external circuit to be operative. It needs to be fed power and be able to produce outputs. Current surface mount technology does not have the capability of mounting a die in its bare form. Therefore, the die needs to be packaged in such a way so as to protect it from outside influences, be it chemical or physical, yet not isolate the chip/die from the outside electrical circuits in which the chip/die would operate.

Semiconductor packaging is the operation ensuring the device is physically and chemically isolated while still electrically connectable. Semiconductor packaging involves the separation of individual dice (die) from the wafer (die preparation), physically connecting the dice (die) to packages (die attach), electrically connecting it to the package (wire bonding) and encapsulating it off to protect the whole die-wires-package assembly. The packaged device would then be tested for functionality and sent to customers who would then mount the packaged device to their circuit boards.

There are many types of packaging used to isolate the semiconductor dice (die). The packages are classified based on the major material used to encapsulate the device, the shape of the package, the type of connectors used and the arrangement of the connectors. The Plastic Dual In-Line Package (PDIP), for example, is a package that is made of plastic, with connectors in the form of leads on two sides of the package, parallel to each other, arranged in a row (thus 'Dual In-line'). Whereas the Ceramic Ball Grid Array (CBGA) is a package that is made of multi-layered ceramic, with connectors in the form of solder ball on either the bottom or the top side of the package, arranged in an array.

At the speed at which information and semiconductor technology is advancing, it becomes more and more critical for a manufacturer to be more competitive in this ever-increasing global market. One of the ways to remain competitive is to keep cost at a low level. In a manufacturing company as big as Motorola, a portion of the cost in producing semiconductor components comes from having to throw away defective products. For example, in 1996, a manufacturing department in Motorola (M) in Sungei Way FTZ (henceforth to be referred to as KLM) generated a yield loss of 2.8%, meaning for every one million products produced, 28 thousand products were considered as defective. Out of the 28 thousand defective products, about 10,600 (almost 40%) were discovered at the die attach process. Reducing the number of defective products at the die attach process will substantially reduce the number of defects being thrown away, thus improving the manufacturing costs of the company.

1.2 The Hermetic Package Assembly Process

A hermetic package is defined as a package that hermetically seals the device from outside influences (air, moisture etc). The most common difference between hermetic packages and other sort of packages are three basic components that make the package: the base and leads, which sometimes come either pre-assembled or not, and the cover. The hermetic packages assembled in KLM are made of either single layered ceramic, in the form of Ceramic Quad Flat Pack (CQFP) and Ceramic Dual In-line Packages (CerDIP), or multi-layered ceramic, in the form of Pin Grid Array (PGA).

The CQFP is a ceramic package that is most normally square in body shape, with lead counts ranging from 28 to 240 leads. These packages are sealed using ceramic lids (or covers) with a preform of sealing glass [15]. KLM's Hermetic Department assembles CQFP packages with lead types ranging from 112 to 240 leads.

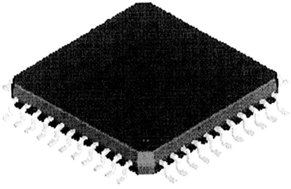

Figure 1.2a: Ceramic Quad Flat Packages (CQFP)

The CerDIP package is a military approved package with excellent reliability characteristics that is usually build with lead counts ranging from 14 to 40 [15]. Due to its lower lead counts, it is seldom used to build high performance devices like microprocessors.

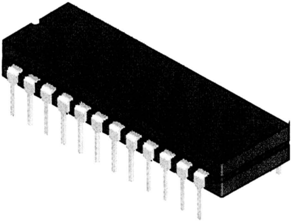

Figure 1.2b: Ceramic Dual In-line Package (CerDIP)

The ceramic PGA package is a square multilayer ceramic package that has an array of pins [15]. KLM Hermetic Department assembles PGA with pin counts ranging from 64 to 241. Instead of ceramic lids or covers, PGA uses a Kovar lid with solder seal ring metallization surrounding the cavity to produce a true hermetic encapsulation.

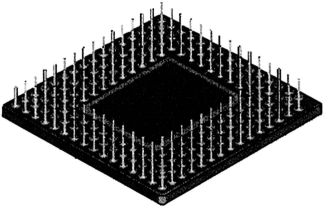

Figure 1.2c: Ceramic Pin Grid Array (PGA) package

The basic difference between a hermetic package and a plastic package is the encapsulation process. While the plastic package is encapsulated by molding thermoplastics around the leadframe and assembled devices, the hermetic package is encapsulated by sealing a cover on a frame-base assembly that contains the die and interconnecting wires. The presence of a cavity in a hermetic package gives rise to concern if foreign material were to be present in the cavity. Matters present in the cavity could react with and affect performances of devices. Therefore, hermetically packaged devices are often assembled in an environmentally controlled, Class-100 cleanroom and the presence of any type of foreign matter (FM) on the packages during the stages prior to the encapsulation process is considered a defect.

Furthermore, with the advance of semiconductor technology, integrated circuits are becoming smaller and smaller. The number of transistors that could be present on an integrated chip/die is increasing at an average rate of 1.4 times per year [4]. Pad to pad distances can now be shorter and the pad pitch is becoming smaller. This makes them prone to shorting even if the smallest of conductive particles were to fall on them. With the advance of the information technology, customer needs are also becoming more and more advanced, and integrated circuit designs are getting more and more complex, making die sizes bigger, increasing at an average rate of 1.13 times per year [4]. The higher surface area makes the integrated chip/die more susceptible to foreign particles falling on them during the assembly process.

Most shorting or leakage can be detected during functional test, but those that are not detected may cause reliability problems in the future. Previously attached material could get dislodged and become loose particles when the units are subjected to varying operating conditions, i.e. physically (vibrations) or thermally (temperature cycles).

In KLM, FM is considered to be a defect when: it bridges 2 connectors (either the leads on the lead frame or the pads on the die), or 2 wires.

A device in a hermetic package is assembled using the process steps described below:

Die preparation

The wafer is mounted onto metal rings, supported by a Mylar film. The wafer is sawn and cleaned using high-pressure water. This process is usually done using specially designed machines that require minimum handling by the machine operator. The wafer is then inspected under High power scope for wafer related defects.

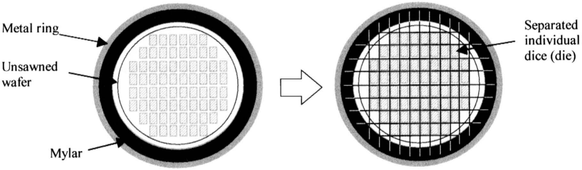

Figure 1.2d1: Wafer sawn into individual dice (die)

Inspection for defects during this stage is usually done under high power scope, to check for tiny cracks, chips or any gross defects in the integrated circuits of the die.

Lead embed

Aluminum Lead frames are glass embedded unto ceramic bases by heating the two components in a furnace.

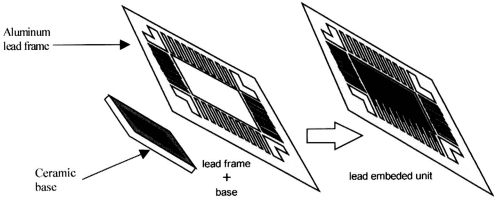

Figure 1.2d2: Ceramic base and aluminum leadframe make up the lead-embedded package.

Inspection during this stage is done under low power scope and inspectors look for incomplete glass coverage between the leads, deformation of leads or package and incorrect alignment of any part of the base and frame assembly.

Die attach

The die is attached to the lead embedded bases using an adhesive material. This is the process on focus in this study. Details of this process will be discussed in the next section.

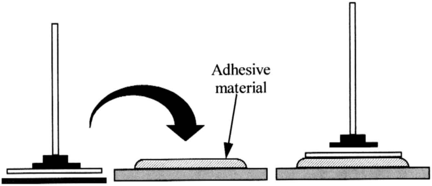

Figure 1.2d3: Individual die attached to package with adhesive

Inspection during die attach is done under low power scope and inspectors look out for incorrect position of the die in the package, crack and chips on both package and die, improper die attach and FM on both package and die.

Wire bond

The circuits on the die are connected to the leads via aluminum wires that are bonded on metallic pads on the die and to corresponding leads on the leadframes per a specific reference diagram. It is important that the conductive points on the die (referred to as 'pads') are connected to correct leads on the leadframe for the device to function correctly.

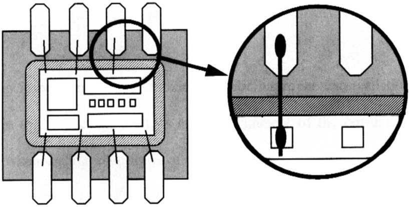

Figure 1.2d4: Wire connects the die to the package

Wire bond inspection include inspection of correct and stable connection of wires between package and die, in addition to die attach defects, including FM.

Sealing

The package is encapsulated by attaching a ceramic cover on top of the die-leadframe-assembly. The ceramic cover is hermetically sealed with the leadframe/base assembly via the melting of glass at its edges.

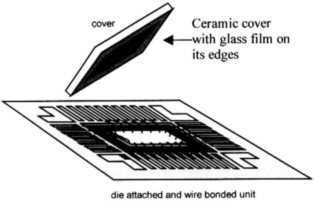

Figure 1.2d5: Die is hermetically encapsulated

Sealing inspection includes looking out for improper encapsulation in terms of glass coverage at the package's edges and misalignment of the cover and package. In certain cases when sealing integrity is of a concern, fine or gross leak testing is done to determine the presence of holes undetectable by the naked eye.

Marking

The encapsulated package is marked for identification and traceability purposes.

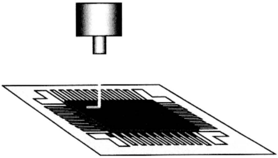

Figure 1.2d6: Packaged device is marked

Since the implementation of lasermarking, defects in this process are normally due to incorrect marking and seldom on the quality of marking itself.

Trim and form

The lead frame is then trimmed off and formed into a customer-desired lead shape.

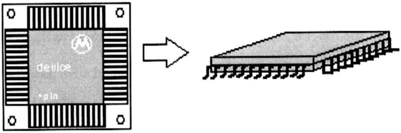

Figure 1.2d7: Package device trimmed and formed

Defects found during this process are usually deformation of the package or the leads, FM found on the packages, which are cosmetic defects, but may cause problems during interaction with other devices on the customers' circuit boards.

The package is finally sent for functional testing, whether on-site or off-site, before being sent to customers worldwide.

From lead embed and wafer preparation up to when the unit is sealed, the device is susceptible to contamination.

1.3 Die Attach Process

As described in the above section, the die attach process is the process of securely attaching the die to a substrate, which in this case, is made of ceramic. This process, as much other assembly process, has gone through much technological evolution. It evolved from a manual to an automatic process and from employing eutectic bonding to bonding using adhesives.

The die attach process currently practiced in KLM's Hermetic Assembly line is an automated process, which employs the use of adhesives. The machine used is an Alphasem die attach machine model SL9006 which has two basic main stations: the dispensing station and the bonding station. The dispensing station is where the adhesive material, usually a mixture of silver and glass in a paste form, is dispensed in a controlled amount onto the leadframe-base package. The bonding station is where the die is picked up from the wafer (sitting on a Mylar ring) and placed unto the dispensed paste on the package. Apart from this it also has three material handling station and feeder systems:

a) an input station and handling system for the prepared wafers (sawn into individual die but still sitting on the Mylar ring),
b) an input station and handling system for empty packages and
c) an output station and handling system for die attached packages.

The cut wafers that make into individual die sit in metal rings supported by Mylar (as described in previous section) and the packages sit in 'boats' (metal frames that holds the packages) for better and safer handling.

The Alphasem SL9006 is equipped with a computer that controls the automation of the die attach process. This includes:

a) the feeder systems,

b) the Image Processing Systems (IPS) at the die pick position (on the wafer) and the dispense position, and

c) the servo and pressure systems that controls the die attach process parameters such as the amount of paste dispensed and the force at which the die is pushed onto the dispensed paste.

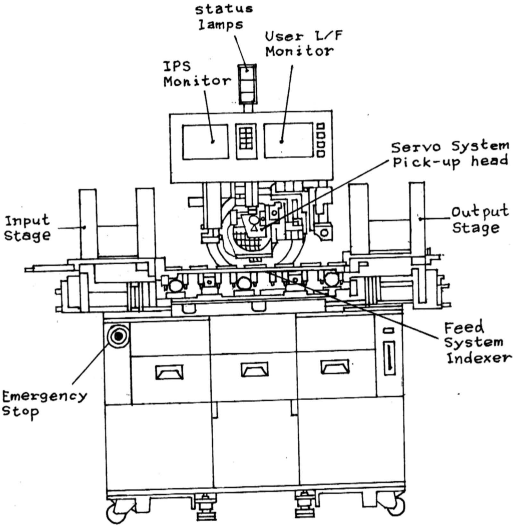

Figure 1.3a: Alphasem SL9006

Even though the Alphasem SL9006 is considered as an automatic machine, it still requires some operator assistance, especially in terms of parameter set-up, the loading and unloading of bulk material and for occasional monitoring.

The proper operating procedure at the die attach process is included in Appendix A.

After the die is attached on the package, the unit is heated through a furnace to cure the adhesive material. The furnace has 8 to 11 individually controlled heat zones that make up the furnace's temperature profile that is optimized to ensure adequate adhesion between the adhesive and the ceramic substrate, between the adhesive and the silicon die and also within the adhesive itself. This process is also called the Organic Burn-Off (OBO) process, because of its high operating temperature (up to 390°C). At this temperature, most organic material would either be burnt off or melted. Most of the material that is melted would often attach itself to the die or leads or the package.

1.4 Die Attach Materials

The materials used in the die attach or die bond process is basically divided into two categories. The direct materials are the materials that are used directly in producing the part. These are the materials that make up the final product. The indirect materials are the materials used in assisting the production of the final product.

1.4.1 Direct materials

The direct materials are what the customer, whether internal (the next process) or external (the final customer) are getting. Without these direct materials, the unit is considered as incomplete. The materials are basically the leadframe, the base, the die and the adhesive. All the materials have been proven and qualified to be functionally sound and would not produce adverse effects on the operation of the device.

The lead frames are made of aluminum and the bases are made of ceramic. The die is made of silicon substrate that has various layers of semiconductor materials and metal oxides on the substrate in a desired integrated circuit pattern, created by selective deposition, growth, etching and masking process [6]. Since lead frame, base and die are what makes the device complete, its components are of the least interest to us since it is supposed to be in the device by design. The adhesive, on the other hand, in its raw form, contains materials that should be sintered out during the OBO process and is not sent to the customer.

The adhesive that we use are silver paste, whose composition is vendor proprietary information, but whose basic components include silver flakes suspended in vanadium glass and organic solvents [7]. The solvents act as binders to assist in the dispensing and die bonding process, but do not participate in the actual die attach process. The actual die attach process occurs in the furnace, where the silver flakes and the vanadium glass fuses with the ceramic and the silicon substrate to produce interfaces. The solvents are sintered out into the atmosphere during the OBO process in the furnace. Improper sintering of the solvents has been known to cause stains on the lead frames [5] and these stains cause non-sticking wire connections if they happen to interfere with the wire bond impression.

1.4.2 Indirect materials

The indirect materials are used during the die attach process and in the processes leading to and surrounding it. These materials include what the operators running the operation wear, and also the other materials that may be present in the manufacturing environment. Most materials that fall onto the package in their original form are loose, meaning it's not attached to the die or package, it can be easily removed during inspection or when blown with air. We are more concerned with the material when it has melted and attached itself to the die or package.

The operators wear jumpsuits (or 'bunnysuits') and headgear made of "100% polyester continuous filament yarns with (interwoven) electrical conductive fibers" [8], facemasks made of "double ply, spun bonded non-woven/thermally sealed waffle pattern polypropylene" [9], and ultra-low residue, unchlorinated, latex fingercots [9] on their fingers. The static dissipative shoes (or 'booties') are made of antistatic PVC, conductive polyurethane and fabric similar to the bunny suit [8]. Underneath the bunnysuits, they wear hairnets made of "spunbonded non-woven, thermally sealed waffle pattern polypropylene (threaded by) synthetic material and (with an) elastic band from latex" " [9]. Underneath their bunnysuits, they wear their normal 'street clothes' of various types of materials. Though these 'street clothes' and hairnet do not actually come into contact with the device, any loose fibers from the clothing could be introduced to the device via the environment.

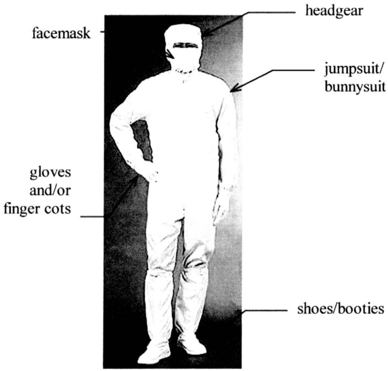

Figure 1.4.2a: A complete cleanroom attire

Other items that the operators wear or apply are Electrostatic Dissipative (ESD) Lotion on their hands. This lotion contains deionized water, stearic acid, isopropyl palmitate, propylene glycol, glyceryl stearate, aloe vera and vitamin E. Even though this lotion is electrostatic dissipative and is nonflammable, it does leave a residue when sufficient heat is applied to induce degradation.

To assist in cleaning up spills or excess paste on machines or utensils, the operators use nylon rags, cotton buds and solvents. To protect their hands against solvents or paste they use nylon white gloves. These gloves are also used during loading the units into the furnace.

To record data on the process, such as the output, yield and control parameters, they write on shop orders, charts and logbooks made of paper. It is found that paper burns and turns to ash when it goes through the furnace.

1.5 Die Attach Defects

1.5.1 Present Defect Levels

There are many types of defects that are contributed by the die bond process. They are basically divided into several categories:

> Process defects: Defects that may have been caused by a process or machine defect, such as incomplete wetting (insufficient adhesive coverage), misaligned die etc.
>
> Handling defects: Defects caused by mishandling of products, such as scratches on the die or package, bent leads, dropped units, count variance (lost units) etc.
>
> Environmental defects: Defects caused by the environment, namely FM.

At the time when this project started, the defect levels are as presented by the Figure 1.5.1a. If we average and breakdown the defects in our yield loss chart, we will find out that the highest contributor to yield loss at die bond is FM, as shown in Figure 1.5.1b. Due to the reliability concerns mentioned earlier in this chapter, KLM have been rejecting up to 5500 parts per a million parts produced (PPM) due to FM alone.

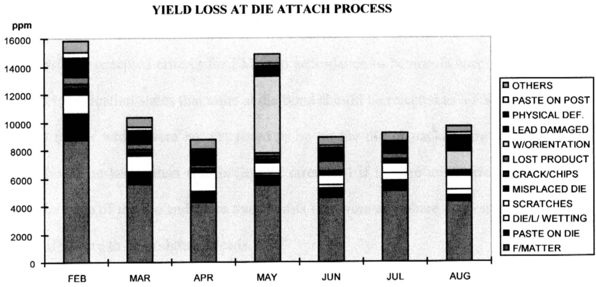

Figure 1.5.1a: The defect level at die attach process in 1997.

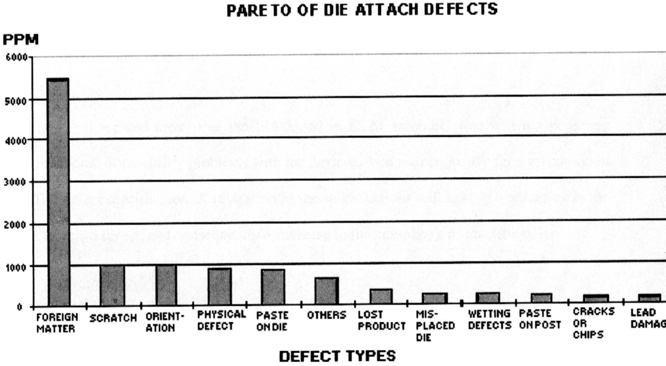

Figure 1.5.1b: Breakdown of defect categories at die attach process

1.5.2 Present Accepted Criteria

The present accepted criteria for FM is in accordance to Motorola specification 54564J. This specification states that units at die bond should be rejected as a FM defect if there exist matter which were not supposed to be on the die or package by design. These FM should be larger than 6 mils (in any direction) if it were anywhere on the package or the edge of the die and more than 3 mils if it were anywhere else on the die surface, and if it were to be bridging 2 leads.

This specification was conceptualized out of the assumption that if the FM were to be bridging to leads, it would produce shorts and affect the functionality of the device. If the FM were bigger than 6 mils, it may become detached and travel within the cavity of the package and land on any two interconnects to produce shorts, thus affecting the functionality of the device.

If we can prove that the FM found in KLM assembly line will not pose any functional or reliability problems with the devices, then we can justify for a relaxation in FM defect specification. A relaxation in the specifications will lead to a reduction in the FM reject levels, and consequently a decrease in the company's production cost.

1.6 About This Study

The goal for this study is to characterize FM defects, identify its sources, identify measures to reduce FM defects and to determine whether the FM that are found in KLM's Hermetic Department's assembly line poses any functional or reliability problems in our devices. Proof that FM does not affect the functionality of devices will lead to a relaxation in FM defects specification, a reduction in the FM reject level, and consequently a decrease in the company's production cost.

In Chapter 2, the experimental techniques used to categorize, map and simulate the FM in the die bond area are discussed. Also discussed in this chapter are analysis and testing methods that are used to determine the material and electrical properties of the FM, and whether the presence of these FM affects the functionality and reliability of the end product.

The study in Chapter 2 will be divided into 6 evaluations:

The first 5 studies concentrate mainly on characterizing the FM .

- The categorization FM rejects , which further breaks down the FM defect category into smaller categories based on the physical characteristics of the defects, such as shape, color and location.
- The mapping of where FM is present. This evaluation does not conclude where FM is discovered, for it is normally found at the visual inspection stages, but where it may be present and where it may have originated.
- The simulation of FM rejects where we attempt to recreate the FM rejects by subjecting units to the same processes that a normal unit goes through but under controlled conditions, and with controlled elements introduced to the units. By this we expect to identify the actual sources of specific FM defects.
- The analysis of materials contained in this FM and its sources. This section seeks to determine the composition of the FM defects and to associate it with its possible sources. This section will also give an insight of what the electrical properties of the units with the presence of FM defects might be. Depth analysis is also done in this

section to find out if the defects is merely on the surface or does it go deeper, thus posing a more serious problem.

- The analysis of the electrical properties of the units due to these defects will give us an idea of how it may affect the functionality of a certain device if FM were to be present during operation.

The last study covers the question of whether the presence of FM actually affects the functionality and lifetime of the device.

- Functional testing of defects will give us the real impact of releasing FM defects to the internal customer (the Test Line) and the external customer.

In Chapter 3 and 4, the results of the above mentioned evaluations are presented and discussed. Results presentation will be in the form of figures and tables, wherever appropriate. Discussion on the significance of each result will be presented at the end of each section.

Chapter 3 presents and discusses results of the FM characterization study. Also discussed in this chapter are other studies conducted or steps taken as a result of conclusions that could be made from the characterization of the FM.

Chapter 4 presents and discusses the results of the functional and reliability testing conducted on units that were rejected based on the present accepted criteria.

Chapter 5 concludes the report and present suggestions for further work.

In summary, the theme for this report is:

The current sub-processes in the die attach process yields 10,600 defective parts for every 1 million it produces. Through process improvements and further examination of the 10,600 defective parts, I intend to prove that only 5,300 are actual defects.