Chapter 3

Foreign Matter (FM) Characterization Results and Discussion

3.1 FM Defect Categories

In order to study the different types of FM that is likely to deposit itself on the surface and affect the performance of the device, we collected FM reject units during a period of two weeks. From 190 units collected over that period we categorized the different types of FM found. They were categorized and named based on their shape, color, and location. FM is basically found either on the die or on the leads (or 'posts'). Studying the distribution, we found that 50% of FM are found on the die and 50% on the post.

FM shapes are either :

- long - has length and width and sometimes height
- globular - has almost the same width and length, sometimes in a circular form
- fibrous - has a high proportion of length to width, and very little height
- particles - relatively small length, width and height, sometimes appears in groups.
- Stains - liquidous, transparent color that has low proportion of length and width and almost no height, mostly in rounded shapes.

- Solids and stains - stains that are accompanied by the presence of solid substances, usually in flat, round shapes.

We can also tell the difference between a foreign mater that is burnt or melted by the shape. A burnt material is usually flaky, with irregular shapes, and sometimes even retains the shape of the original source. Melted material are usually more rounded in shape, with rounded edges and rounded profile, indication of a fluid material flow before hardening during cooling.

The names for FM categories were given based on our discretion. They have no scientific basis but for easier identification.

In Figure 3.1a are the different types of FM that were identified, their categories and their distribution.

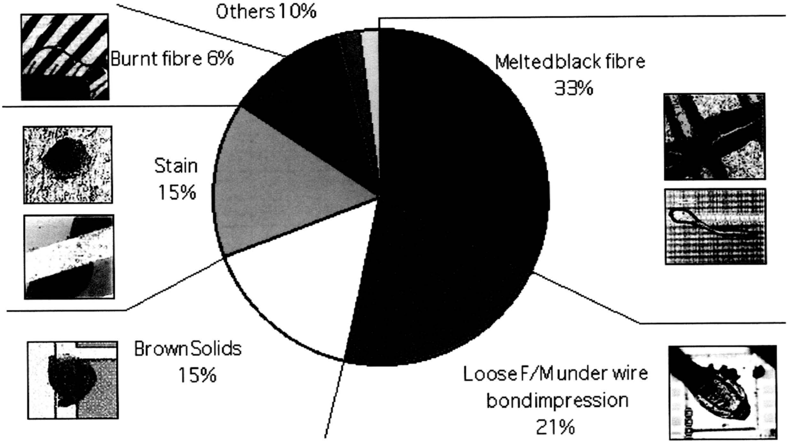

Figure 3.1a : FM defects breakdown and distribution

3.2 Areas of High FM

Table 3.2.a is the results of our sticky tape experiments. Due to space and movement constraints, we had to vary the size of sticky tapes placed at different locations. The total time exposed also varies, due to the fact that we could not place all sticky tapes at all the location simultaneously. 'Total time exposed1' is the amount of time from the start of the experiment to the time the sticky tape is inspected for the first time. 'Total time Exposed2' is the amount of time from the start to the end of the experiment. The FM collected during the first exposure was marked off and is not included in the count of collected FM after the second exposure. The FM collected was broken down into fibrous FM and particulate FM.

	Location	Size (sq. in.)	Total time Exposed1	Count		Total time Exposed2	Count	
				Fiber	Part.		Fiber	Part.
1	Autoloader AS05	1	2:54	1		20:19	10	
2	output AS05	4	2:52		1	20:22	5	
3	Inspection table AS05	9	2:33	2		20:54	1	
4	entrance Z21	9	2:32	3		20:54	5	
5	exit Z21	9	2:38	1		21:11	4	50
6	exhaust Z21	9	2:30			21:11	2	1
7	input AS06	9	2:23	1		20:32	1	1
8	output AS06	4	2:48	1	4	20:26	1	1
9	Inspection table AS06	9	2:35	1		20:44	3	2

10	auto loader Z17	1	2:53			20:31		
11	entrance Z17	9	2:46		2	20:34		
12	exit Z17	9	2:33	3		20:39		
13	Post OBO inspection	9	2:39	3		20:41		
14	Paste thickness measurement table	9	2:52		2	21:13	1	
15	Staging table	9	2:50	1	1	21:06	9	
16	Piece part room	9	tampered			17:20	6	
17	exhaust Z17	9	2:38			20:41		

Table 3.2a : results of the FM mapping study

From the results above, the FM collected per 9 sq. in. was calculated using the formula :

$$\text{FM count per 9 in}^2 = \frac{\text{total FM count}}{\text{sticky tape size in}^2} \times 9\ \text{in}^2$$

The time exposed were averaged to 2.5 hours and 20.5 hours :

	Count per 9 sq. in.	
Location/Time exposed	2.5 hours	20.5 hours
Autoloader AS05	9.00	99.00
Output AS05	2.25	13.50
Inspection table AS05	2.00	3.00
Entrance Z21	3.00	8.00
Exit Z21	1.00	55.00
Exhaust Z21	0.00	3.00
Input AS06	1.00	3.00
Output AS06	11.25	15.75
Inspection table AS06	1.00	6.00
Auto loader Z17	0.00	0.00
Entrance Z17	2.00	2.00
Exit Z17	3.00	3.00
Post OBO inspection	3.00	3.00
Paste th. Measrmnt table	2.00	3.00
Staging table	2.00	11.00
Piece part room	0.00	6.00
Exhaust Z17	0.00	0.00

Table 3.2b : FM count per 9 sq. in. by location and time exposed.

We constructed the Figure 3.2c from data in Table 3.2b :

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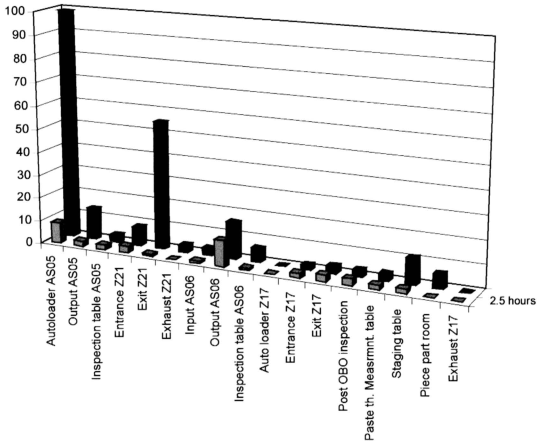


Figure 3.2c : Figure of Location vs FM found per inch square vs time

This figure not only shows that loose FM accumulates over time, but it also shows that there are some areas that experience more FM than others and as the exposure or staging time becomes longer, the more FM will accumulate. AS05 is the Alphasem die attach machine # 5, and Z21 is the OBO furnace. We can conclude that the die attach area is the location of very high FM occurrence. This is further illustrated in Figure 3.2d where it indicates that die attach area, staging area and the piece part room has a high amount of loose FM.

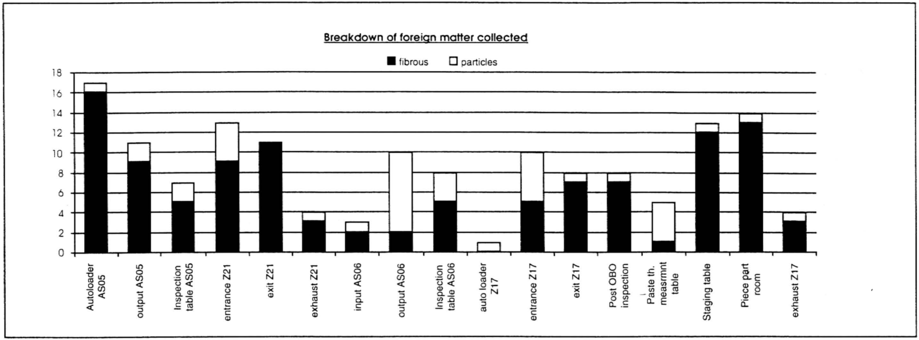


Figure 3.2d FM count (fibrous and particulate) vs Location

We then compared the collection of loose FM at the die bond area, mainly at the furnaces. As we can see from Figure 3.2e, the entrance and exit of Furnace Z21 exhibited high presence of loose FM, which accumulates at a steady rate over time. It is good to note that Furnace Z21 is located at an area with higher amount of human and production activity as compared to Furnace Z17. Since high amount of human and production activities result in the introduction of a high amount of FM, we can safely conclude that the FM originates from the materials worn by the operators and used in production activity.

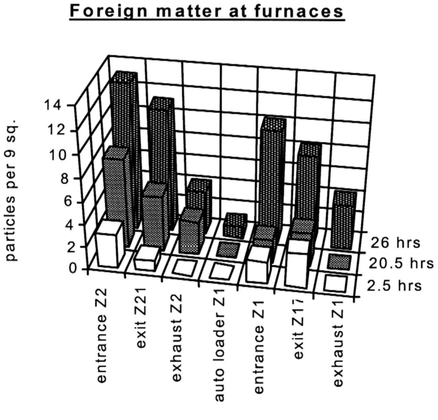


Figure 3.2e Comparison of FM found at OBO Furnaces

3.3 Simulation of FM Defects.

To find out the sources of our FM rejects, we took samples of fiber and particles from the materials worn and used by the operators and used in production activity around the die attach process area. These samples were put on blank packages, which were labeled accordingly and put through the OBO furnace. The pictures of the samples before OBO and after OBO were taken as record. The pictures of the samples after OBO were visually compared to pictures of actual FM rejects, where we looked for similarities in shape, color, and size.

Table 3.3a is the result of our comparison, where we managed to identify sources for four of the highest FM defects category.

Most of the sources mentioned in Table 3.31 are sources which we can see, and that we have an idea of how it could come in contact with the die and packages. For example, we know that ESD lotion is applied on the hands of the operators and it could be transferred onto the unit during handling. White furnace gloves are used by the operators during the loading of the furnace with production material and during the weekly acquisition of the furnace's temperature profile.

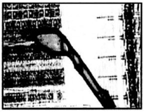
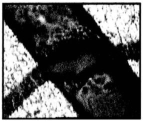
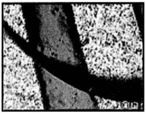
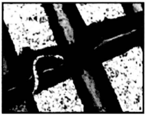
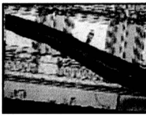
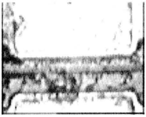
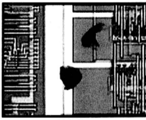
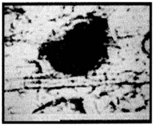
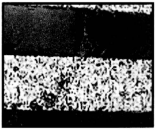
Item	**Simulation Before OBO**	**Simulation After OBO**	**Actual FM defects**
White furnace glove Fibre			 "tadpole"
Packing tray fibre			 "leech"
ESD lotion			 "brown solids"
Paste solvent	N/A		 "stain"
Face mask	N/A		"stain"

Table 3.3a : Table of visual matches between source and actual FM rejects

3.3.1 Tangible Sources

Tangible sources are sources that we know and can control. After knowing what the sources are, the next logical step would be to remove the source to reduce the FM incidences. In removing the sources, we took into consideration several aspects: the necessity of the item, the feasibility of replacing the item, and the viability of an alternative for the item.

Furnace temperature profile is acquired by running Thermocouple wires that are glass embedded unto empty packages, through the furnace. Thermocouple wires are insulated with fiberglass, which irritates the skin if put in direct contact. Therefore, operators who are acquiring the temperature profile wear white gloves for comfort and protection.

Packing tray fibers come from the packing tray of the pre-embedded packages. Pre-embedded packages come in packing trays that are loaded into the package auto loader unit. The units are picked up from the trays by an automated arm that transfers the unit onto boats. The units on boats are indexed to the dispensing and bonding stations for the proper die attach process before they are indexed into magazines at the output station.

The actual purpose of wearing ESD lotion is to protect the devices from electrostatic charges that could damage the circuits on the device. ESD lotion dissipates and reduces the accumulation of electrostatic charges that is created from normal bodily movement and brushing against fabric and dry air. ESD lotion, however, is a secondary protection, after the grounding strap, which is a strap worn around the wrist to establish skin contact, and is connected to grounding points via a wire. Therefore, ESD lotion could be removed altogether from the production area, without affecting the comfort or functionality of the device.

3.3.1.1 Alternative materials

For sources that were deemed to be necessary and cannot be removed, we searched for alternative materials for it. The alternatives for these materials were put through tests to assess their functionality and also whether they would produce the same FM as their predecessors. Since most of these materials are used by each and every operator, day in and day out, costs of these materials were also taken into consideration.

3.3.1.2 Restricted Materials

There were some materials that could not be replaced due to its functionality. The nylon white gloves for example, are by right, used by the sealing furnace operators as protection when handling hot boats at the sealing furnace output. They are also, however, used by die attach operators, OBO furnace loaders, and temperature profile operators to protect their hands from silver paste and the fiberglass of the thermocouple wires.

We evaluated several types of gloves to replace the FM-causing nylon white gloves. The result of the evaluation is as shown in Table 3.3.1.2a. Gloves that we evaluated were rated in terms of Flexibility, Functionality and Cost. Since the gloves will be used for handling small and delicate products, a high flexibility is very important. Functionality is gauged in terms of temperature resistance (for use at sealing furnaces), possibility of generating FM (by looking at strength of material and glove seams) and comfort. In terms of cost, lower cost is of course, more desirable.

Glove evaluated	Flexibility	Functionality	Cost
Glove1 Vinyl, powder free	Low	Low	Low
Glove2 Nylon Mesh	High	Moderate	Moderate
Glove 3 Latex, powder free	High	High	Low
Glove 4 Polyamide, high temp	Low	High	High
Glove 5 Nylon , (current)	High	Moderate	Moderate

Table 3.3.1.2a : Evaluation of several types of gloves in the market

Based on the evaluation on gloves, we found that for processes that do not require protection from high temperature, as in the die attach process, the latex, powder free and electrostatic dissipative gloves (Glove 3) would be the most appropriate. The latex gloves, however, could not be used to replace the nylon white gloves in the sealing operation due to its low melting temperature. It does not provide protection against the hot boats. Since all other gloves could not compete with the nylon white gloves in terms of flexibility, functionality and most importantly, cost, we decided to retain this item, but restrict its use for sealing operators only.

To ease the discomfort of temperature profile operators, a new type of thermocouple wires, one with sleeves made of metal instead of bare fiberglass, was introduced. Studies conducted to evaluate the metal-sleeved thermocouple wire showed that its performance is as effective, if not better than the normal fiberglass thermocouple wires [13]. Our second step was to instruct the operators at die attach and OBO loading operations to use ESD approved latex gloves instead of the nylon white gloves.

3.3.2 Environmental Sources

Some sources for the FM defects are difficult to pin point, their sources are not among the materials that come into direct contact with the dies and packages, or are not able to be identified at all. Based on the study conducted to identify areas of high loose FM collection, we could conclude that these FM come from the environment.

3.3.2.1 Re-layout and Air Scrubber

From Table 3.2b we found that the piece part room, where the packages are being kept, has a high level of loose FM. Though the lead embed operation is not required to be a cleanroom operation by specification, due to the high occurrences of FM that could be contributed by materials in the piece part room (packing trays for example), it is felt that the actual lead embed operation should be moved into the cleanroom environment, separate from the piece part room.

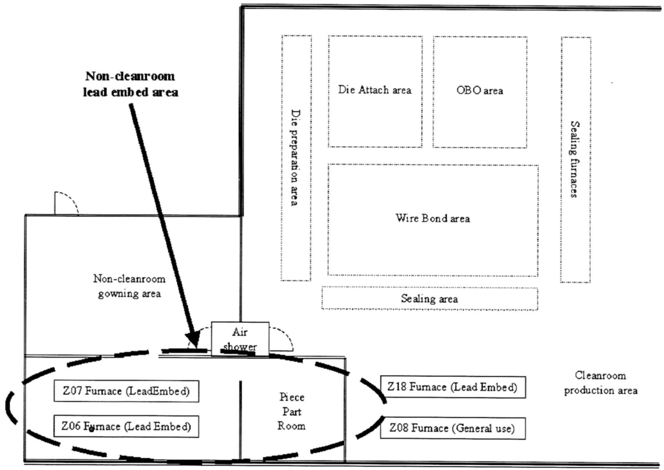


Figure 3.3.2.1a : Old layout of the Hermetic Front-End assembly area with the lead embed operation located in a non-clean room area.

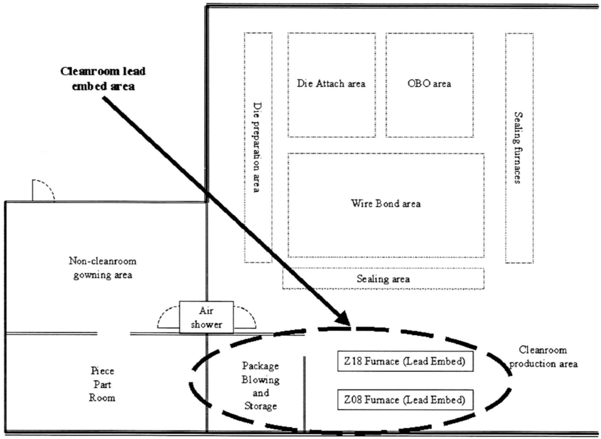


Figure 3.3.2.1b : New Layout of hermetic Front End Assembly area with the Lead Embed operation relocated into the cleanroom area for better environmental control

We also started using an air scrubber to clean up the air in the cleanroom area. The scrubber operates by sucking air from its intake, then running it through several stages of filters and then blowing cleaner air through its output. We first started using the air scrubber at the new lead embed area and found a decrease in particle count at this area. We then moved the air scrubber to the wire bond area and saw the effects were also significant.

3.3.2.2 Package Blower Study

To further ensure that the packages that are used in the die attach process and go through the OBO process is free of loose FM that causes attached FM defects, we studied the effects of implementing a package blower.

A package blower was designed to apply a moving stream of pressurized and ionized nitrogen gas across a boat of units. The number of times the ionized gas moves across the units, called 'strokes', and the pressure at which the nitrogen gas is applied can be set by the user.

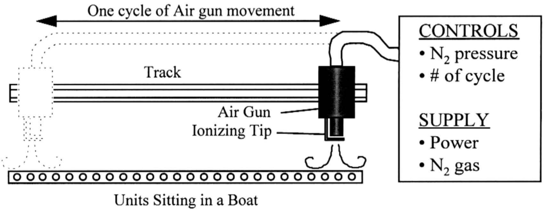


Figure 3.3.2.2a : Schematic diagram of the package blower

When dealing with a new equipment, the first thing that we need to do is to determine a setting that will give optimum output in terms of effectiveness of removing loose FM and productivity in the number of boats it can blow per hour. An experiment matrix was created to evaluate this. The matrix has 2 input factors, pressure and strokes, and 3 output factors, the number of loose FM removed, the amount of time it takes to blow a specific number of boats and whether the packages are blown away during blowing. Packages that are blown away during this operation may be damaged and could not be used to produce functional unit. The evaluation result is as shown in Table 3.3.2.2b.

Figure 3.3.2.2c graphically compares the performance of the different settings. Even though a higher pressure could remove more FM, it would also cause movement and possible damage to the package. Therefore we decided on the settings of 2 bars pressure and 2 cycle strokes.

PACKAGE BLOWER CHARACTERIZATION

INPUT		OUTPUT			NOTE
N2 Pressure (bar)	Cycle stroke (#)	FM removed (# units)	LD (#units)	Flying? (# units)	F/Matter Removed
1	1	13	0	0	big flakes, fibres
1	2	13	0	0	big flakes, fibres
1	3	19	0	0	big flakes, fibres
1.5	1	15	0	0	big flakes, fibres
1.5	2	16	0	0	big flakes, fibres
1.5	3	19	0	0	big flakes, fibres
2	1	17	0	0	big flakes, fibres
2	2	20	moved a bit	0	fibres, big flakes
2	3	21	moved a bit	0	fibres, big flakes
2.5	1	19	moved a bit	112 lds lifted	fibres, big flakes
2.5	2	21	moved a bit	112 lds lifted	fibres, big flakes
2.5	3	21	moved a bit	112 lds lifted	fibres, big flakes
3	1	23	moved a bit	112 lds lifted	fibres, big flakes
3	2	24	moved a bit	112 lds lifted	fibres, big flakes
3	3	23	moved a bit	112 lds lifted	fibres, big flakes

Table 3.3.2.2b : Package Blower Characterization Matrix

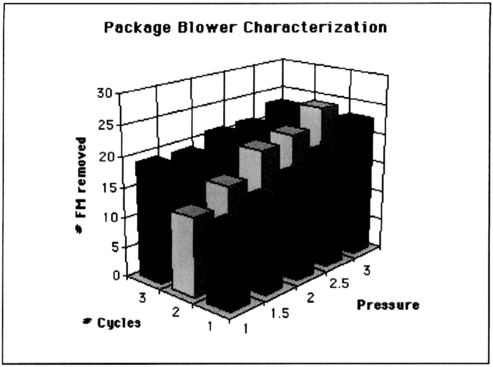


Figure 3.3.2.2c : Results of the Characterization matrix

After obtaining the optimum setting, we ran another evaluation to determine when the package should be blown in order to achieve the most effective results. Several production lots were chosen and they were divided into 3 groups:

1) A group that was blown before the die attach process only. (labeled "Bef. DB")

2) A group that was blown after the die attach process and before the wire bond process only. (labeled "Bef. WB")

3) A group that was blown before both operations, die attach and wire bond (labeled "Bef. DB/WB")

[illegible] FM reject levels for all three were collected and compared to the FM [illegible]

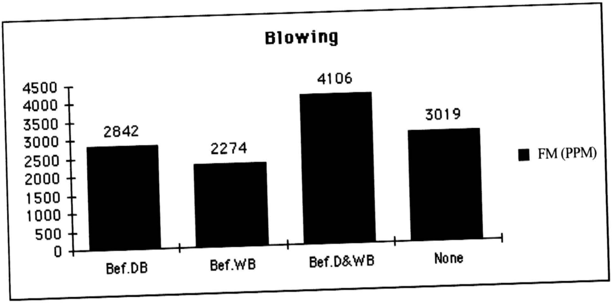


Figure 3.3.2.2d : Package blowing evaluation results

Figure 3.3.2.2d shows that blowing packages before Wire Bond would be the most effective method in removing FM. The increase in FM when units are blown before Wire Bond and Die Bond might indicate that too much handling would also produce adverse effects, perhaps by introducing more FM. Even though there is a decrease in the FM reject levels when packages are blown, the change, which is about 20%, is not as significant as we had hoped and is not feasible compared to the cost of operating the package blower. Furthermore, package blowing is a non-value added activity in the sense that it does not add functionality to the device as a whole. At the time this dissertation was written, the package blowing operation was put on hold due to restricted manpower.

3.3.2.3 Working With Suppliers

In working towards reducing the 'leech' type FM coming from packing tray fibers and the embedded burnt fiber type FM that most likely comes from the lead embed process, we also worked with our package suppliers to reduce our incoming FM. The vendor monitored and tracked the amount of loose FM found in their trays and on their units prior to packing the material and shipping it to us.

The action taken by the supplier was to implement a tray blower in their plant. The tray/package blower applies a stream of pressurized air onto the package and trays before they are packed and shipped to KLM. They continue to monitor and track the amount of loose FM found on their trays and package. From the percentage of the number of units with loose FM found in their area shown in Figure 3.3.2.3a below, the trend looks very encouraging.

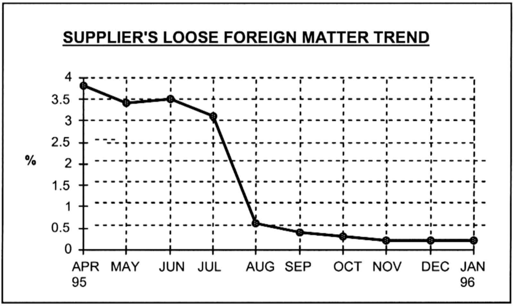


Figure 3.3.2.3a : Trend for Loose FM found at supplier's area

From all these cleanroom control actions we managed to see a significant reduction in FM reject levels, from about 5000 PPM to about 3700, as shown in Figure 3.3.2a.

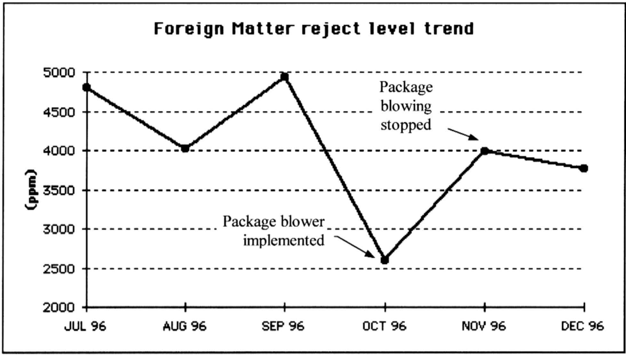
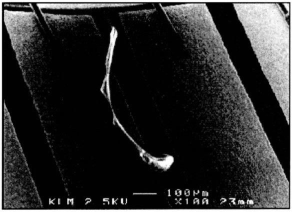


Figure 3.3.2a : FM reject level trend with implementation of cleanroom improvement activities.

3.4 Material analysis

3.4.1 Elemental analysis.

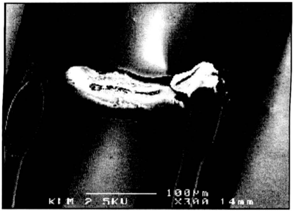
Material Analysis using SEM/EDX showed that these attached FM are made of carbon and are non-metallic.



Containing mainly carbon.

Gold comes from the PGA lead.

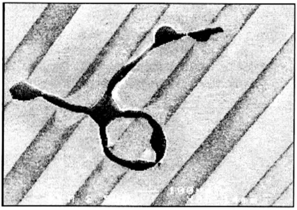
Figure 3.4.1.a1 SEM Picture of "tadpole" on PGA package at 100X magnification



Containing mainly carbon.

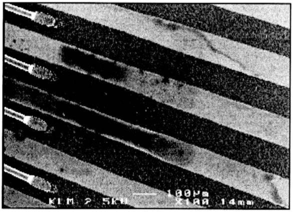
Aluminum comes from the CQFP lead.

Figure 3.4.1.b1 SEM Picture of "leech" on CQFP package at 300X magnification



Containing mainly carbon and oxygen.

Figure 3.4.1.c1 SEM Picture of "tadpole" on CQFP package at 85X magnification



Containing mainly carbon and oxygen.

Aluminum comes from the CQFP leads.

Figure 3.4.1.d1 SEM Picture of "stain" on CQFP package at 100X magnification

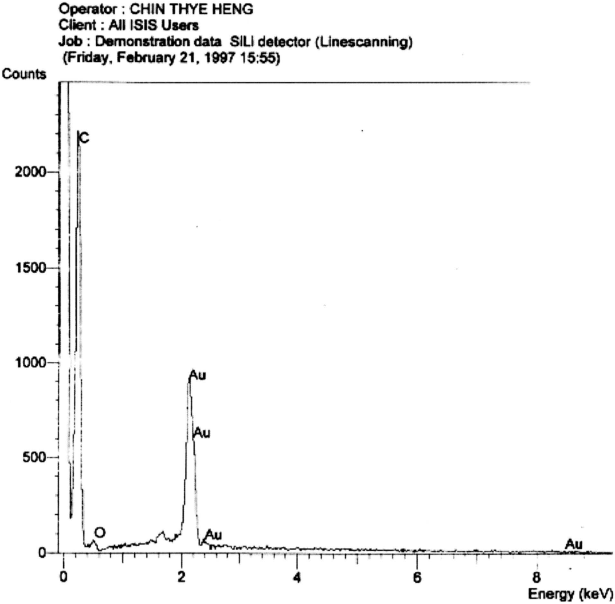


Figure 3.4.1.a2 EDX analysis on "tadpole" on PGA package

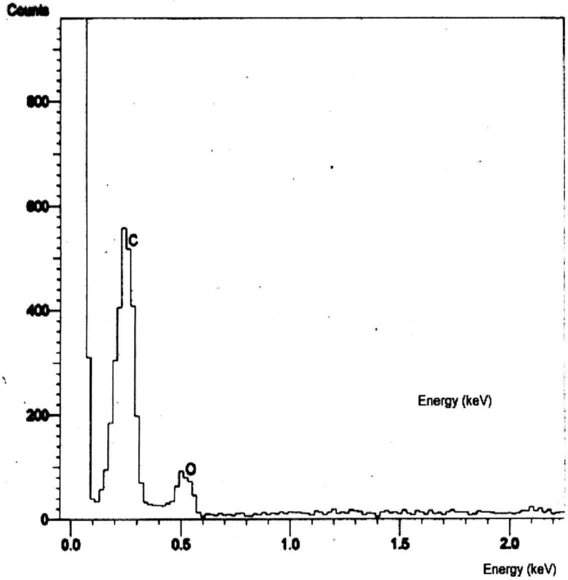


Figure 3.4.1.b2 EDX analysis of "leech" on CQFP package

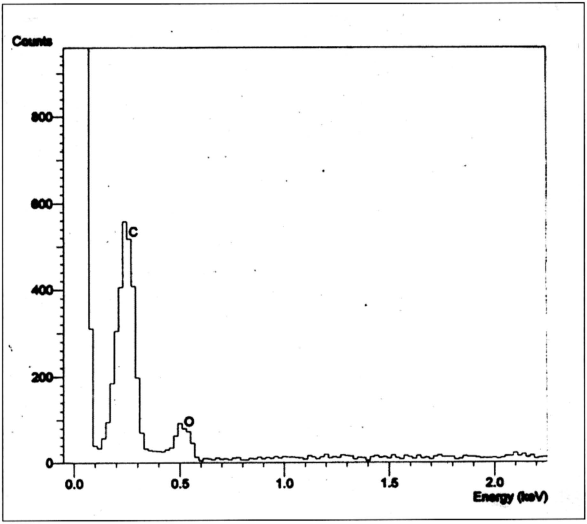


Figure 3.4.1.c2 EDX Analysis of "tadpole" on CQFP package

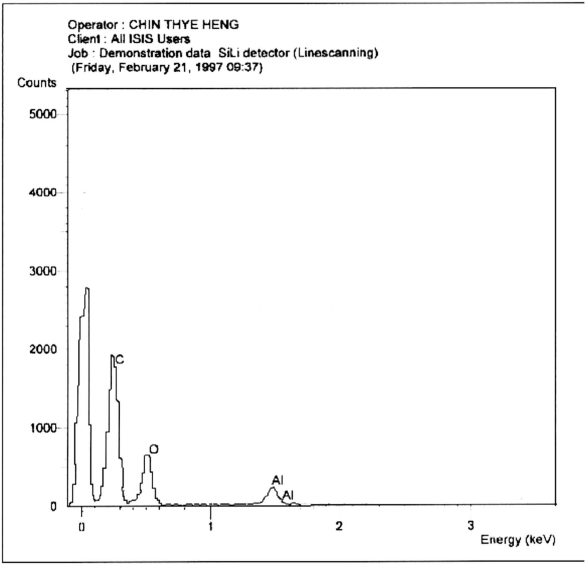


Figure 3.4.1.d2 EDX analysis of "stain" on CQFP package

3.4.2 Depth Analysis

Depth analysis of "Stain" type FM on CQFP lead is presented in Figure 3.4.2. The analysis showed that the FM does not penetrate deep into the leads. If the FM were to penetrate deep into the leads, then it could raise concerns of its presence disrupting flow of electrical inputs or outputs. Since it does not penetrate deep into the leads, we can safely conclude that the presence of FM would not affect the performance of a unit.

Due to lack of resources, depth analysis on more units could not be carried out. Section 3.4 has proven that all of the FM types were made up of organic elements carbon and oxygen, in a stable and non-corrosive form. Therefore, we could safely conclude that the other FM types do not penetrate deep into the leads or dies too, and would not affect the performance of a unit. This would be further proven in the Chapter 4 where we discuss the results of the functional testing of units with FM present.

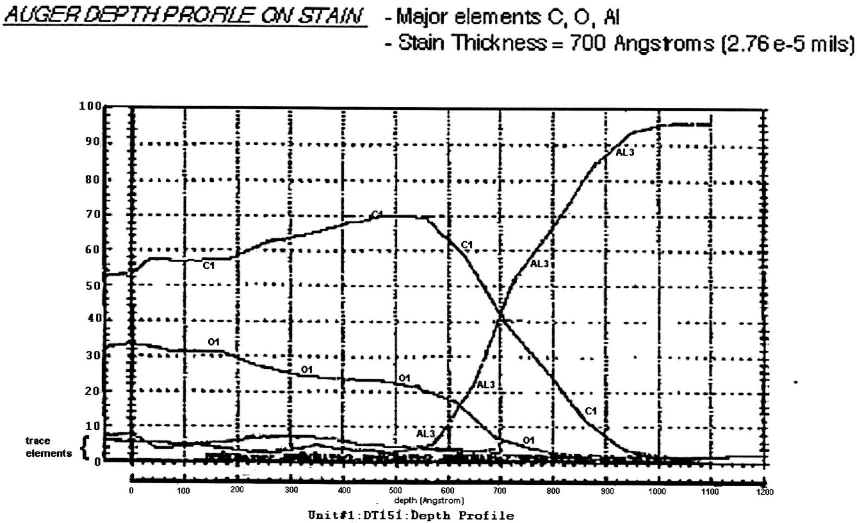


Figure 3.4.2 Auger depth profile of "Stain" type FM on CQFP leads.

3.5 Electrical analysis

3.5.1 Lead-to-lead electrical measurements

Electrical measurements of foreign matter rejects simulated from FM sources on empty 240 lead Ceramic Quad Flat Package (CQFP) and 160 lead Plastic Quad Flat Package (PQFP) were conducted using an LCR meter as described in Chapter 2. Measurements of blanks for both types of packages were also taken. Comparing the electrical readings of FM on CQFP and PQFP packages would allows us to determine if the presence of FM significantly affects the normal electrical functions of a device.

The CQFP Blank is an empty pre-embedded 240ld CQFP package. The PQFP Blank is a molded, 160ld PQFP package.

As we can see from the results presented in Table 3.5.1, the presence of FM on the packages produce a significant, though not large, difference in resistance readings, but not so much for capacitance and inductance.

How this difference would affect the performance of the devices could only be explored and proved during functional testing and whether FM presence causes detrimental heat sinks or hot spots during the performance could only be explored during reliability testing (discussed in Chapter 4). What we can conclude from the results is that the presence of FM does affect the electrical properties of the lead frame and this has to be taken into consideration when we revise the FM rejects definition. The presence of FM too close to or touching the bonding area might affect the performance of the device as a whole, but the presence of FM far away from the bonding area might not affect the performance of the device at all.

	Resistance		Capacitance		Inductance	
Sample	R_s	R_p	C_s	C_p	L_s	L_p
CQFP Blank	3.30 kΩ	1541 kΩ	2.3 pF	2.3 pF	-11.400 mH	-11.425 mH
Gloves	2.85 kΩ	1969 kΩ	2.2 pF	2.2 pF	-11.596 mH	-11.612 mH
p/p tray	2.76 kΩ	1884 kΩ	1.9 pF	1.8 pF	-11.920 mH	-11.968 mH
bunny suit	2.77 kΩ	1847 kΩ	2.3 pF	2.3 pF	-11.275 mH	-11.292 mH
finger cot	3.013 kΩ	1978 kΩ	2.1 pF	2.1 pF	-12.145 mH	-12.163 mH
PQFP Blank	18 mΩ	1968 mΩ	-849 nF	-842 nF	29.8 nH	30.1 nH
Gloves	17.9 mΩ	2085 mΩ	-835 nF	-828 nF	30.3 nH	30.6 nH
p/p tray	19.2 mΩ	1934 mΩ	-854 nF	-845 nF	29.7 nH	30.0 nH
bunny suit	18.3 mΩ	1907 mΩ	-856 nF	-848 nF	29.6 nH	29.9 nH
finger cot	18.1 mΩ	1996 mΩ	-843 nF	-835 nF	30.1 nH	30.3 nH

Table 3.5.1 Results of lead to lead electrical measurements.