The Contamination Audit — A Vital Tool For Yield Improvement

S. Hamilton

TEKNEK ELECTRONICS LTD,
Bridge of Weir, PA11 3SA Scotland
Tel: +44 (0) 1505 690707
Fax: +44 (0) 1505 614 708

Reprinted from **CIRCUIT WORLD**
Volume 22, Number 3, April 1996

Wela Publications Limited, Asahi House, Church Road, Port Erin, Isle of Man IM99 8HD. British Isles.
Tel: +44 (0) 1624 836044 Fax: +44 (0) 1624 835400 E-mail: wela@enterprise.net

The Contamination Audit — A Vital Tool For Yield Improvement

S. Hamilton

Teknek Electronics Ltd, Bridge of Weir, Renfrewshire, Scotland

ABSTRACT — With the increasing trends towards fineline circuitry, contamination has become a major cause of defects. This paper outlines the techniques used in conducting a Contamination Audit and in generating a Contamination Matrix, which is a map of the types of contamination and their relative levels within a facility. Using the Contamination Matrix contamination control measures can be targetted in the most effective manner to achieve yield improvements.

INTRODUCTION

Many printed circuit board manufacturers process in cleanroom environments to achieve acceptable yield rates, especially for fineline circuitry. Nevertheless, despite the considerable investment in cleanrooms, many companies still find significant amounts of contamination related defects. This points to the conclusion that currently accepted methods of assessing contamination fail to deal fully with the problem. It is from this starting point that the Contamination Audit techniques outlined were developed to provide a wider-ranging evaluation of sources of contamination.

Traditional classification of cleanrooms involves counting and sizing the number of particles in the air and relating this to the appropriate standards to reach a cleanroom classification. This classification is normally performed just after the room is commissioned, often without any processes operating. Ongoing sampling using an air monitor is used to verify that the conditions inside the room remain within the classification. This approach takes no account of particles which are too heavy to remain suspended in the air but which fall on to products during processing. These particles are a major cause of defects and lower yields. Cleanrooms use laminar airflow to keep particles in the air but this is effective only when there are no obstacles to airflow. In production environments there is machinery which blocks the laminar flow. The turbulent flow generated around the obstacle lowers the velocity of the air allowing particles to drop out of the airstream on to surrounding surfaces. The movement of people may disturb the particles from the surface and move them on to material awaiting processing.

These particles are the focus of the Contamination Audit as described in this paper.

Contamination Audits identify and quantify the main contaminants in area of the facility and, thus, enable the most appropriate, cost-effective measures for reducing contamination and increasing yield to be taken.

CONTAMINATION MATRIX

The Contamination Matrix is a map of the type and concentration of contamination within a specific area. A Contamination Audit produces two types of Contamination Matrix.

First, there is a Contamination Matrix for each department on which all the samples taken in that department are logged, together with their analysis results. By presenting the contamination analysis in this way it is immediately obvious where housekeeping protocols need to be increased or changed within the department. This also identifies what the major types of contamination are.

Secondly, there is also a summary Contamination Matrix for the facility as a whole, where the departments are listed, with their total contamination levels logged. This matrix illustrates the flow of contamination throughout the plant. A sample of this type of matrix is shown in Table 1.

From these matrices, which can be colour shaded to make them easier to read, the major areas where contamination poses a high risk to process yields can be identified and suitable actions taken to reduce the contamination levels.

After each remedial step has been taken, it is advisable to repeat the contamination audit in that area to establish the change in contamination

Table 1

Sample Matrix

	Operator				*Process*						*Resins*										*Miscellaneous*																			
	Clothes fibres	Threads	Hair	Clear fibres	Epoxy resin	Epoxy glass	Copper	Dry film	Solder mask	Red emulsion	Clear	White	Yellow	Red	Blue	Green	Black	Grey	Amber	Orange	Plastic film	Metal	Brass	Wallboard	Rust	Foam	Rubber	Non-woven fabric	Cellulose	Glass	Vegetable matter	Stones	White waxy sub.	Black debris	Brown debris	Foam mat	Coated fibres	Spheres	Skin	Insect
Artwork (Main)	3	3	2		1	1	2				1	3	1	3	3	3	1	1	3	1	1	3	1	1		1	2		3	1	1	2	3	3	1	2	1	1		
Artwork (Lamination)	4	1	2				2				1	2	2	3	2	1	2		1	2	1	2		2	1		2		3	2	1	1	2	2			1			
Artwork (Darkroom)	3	1	3	2			1			1	1	2	3	1		2	2	2	2	2		3	1		1		1		2		2		2	3	2	2		1		
Inner Layer Print	4	2	2	1		2	3	2	1		2	2	1	2	1	1	2	3	1	1	2	4	1	1	1		2	1	4	2	1	2	2	2	1	1	1	1	1	
Inner Layer AOL	4*	2	2	1	1	2	4	2	2			1	1	1	1	1	2	1	1	1		3		1			2	1	2	1	1	1	1	2		2		1	1	1
Lay-up	3	1	1	1	4	3	1					1		1	1		1	1	2	1	1	1	1		1			1	1			1	1	1	1				1	
Outer Layer Print Dry Film Lamination	4	1	2	2	1	1	3	3			1	2	1	2	1	1	1	1	1	2	1	3	1	1	1		2	1		1		1	1	3	2				1	
Outer Layer Print Manual Exposure	4*	1	2	1	2	2	4*	2			1	2	2	2	1		1	2	1	3	2	3	3				4		1	1		1	1	3					1	
Outer Layer Print Auto Exposure	4		2	1	1	1	3	3			2	2	1	2	2	1	2	1	1	1	1	3	1		1		2		2	1	1	1	1	3	1	1	1	1	1	
Solder Mask Electrostatic Spray	3	1	2	1		1	2		3		1	2	1	1	2	1	2	1	1	1		2			1		1		3	1	1	1	2	2	1	1		2	2	
Solder Mask Auto Exposure Lines	4	1	2	1	1		3		4		2		2	2	2	1	2	2	2	1		4	1		1	1	2		3	2	1	1	2	3	1	1	1	1	1	1
Solder Mask Curtain Coating	4	1	2	1		1	2	1	4		2	2	1	1	1	1	2	1	1	1	1	2		1	1		3		1	1		1	1	2	2	1	1	1	1	
Key	76 - 100	4	51 - 75	3	26 - 50	2	1 - 25	1																																

level. At the same time there should also be monitoring of improvement in the process yield. The revised matrix can then be overlaid on the original one to illustrate the changes.

CONTAMINATION AUDIT METHODOLOGY

The Contamination Audit assesses both the air quality and the type and concentration of surface contamination within the audit areas. The audit also aims to identify the sources of the contamination through detailed observation of the production processes

The first stage in the Contamination Audit is to establish the process flow through the facility as shown in Figure 1. In general, there are two types of process from a contamination viewpoint: those which generate contamination as an inherent part of the process, such as drilling or wet processing; and those which are sensitive to contamination, such as resist application and exposure.

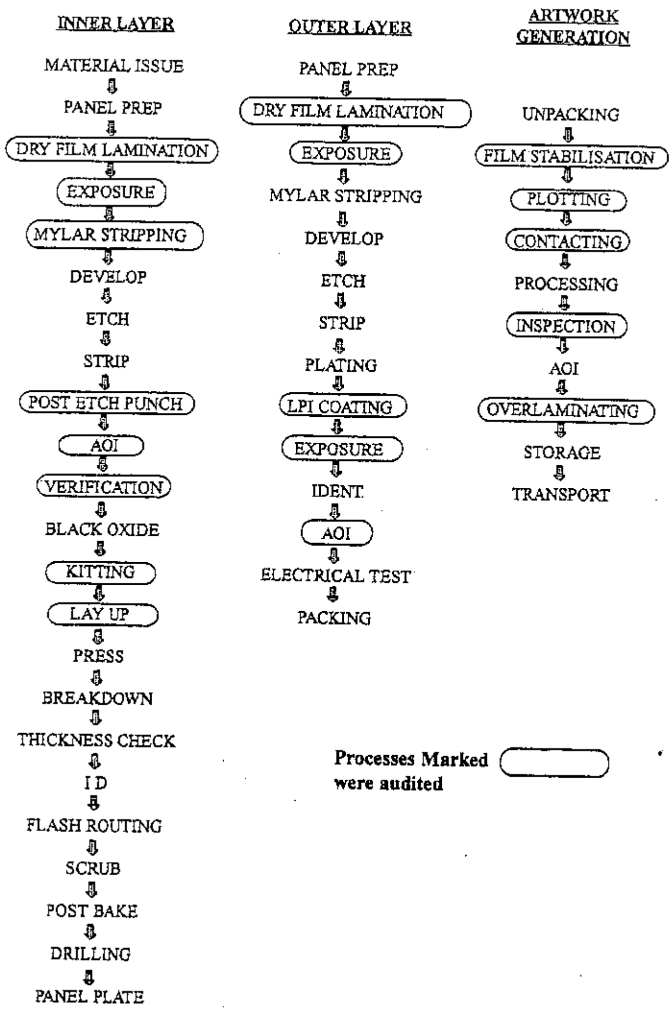

Fig. 1 *Process summary.*

The Contamination Audit should initially be concentrated on the contamination sensitive processes . These processes are outlined with boxes on the process flow chart.

The second stage of the Contamination Audit is the preparation of plans of every area to be audited. These plans should show the layout of all the equipment in the room and the positioning of all doors to the room. Any other points where material or product enters the room should also be identified. A corner of the plan should have space for notes regarding the type of clothing the operators in the room are wearing and any other relevant details. These plans will be used to note the position of all the samples taken so that the Contamination Audit can be repeated in exactly the same manner.

To assess air quality in the process environment, a tyndleometer is used. This provides a qualitative assessment of the number of particles in the air and can be used in environments which would quickly clog a standard air monitor. The tyndleometer works by capturing a set quantity of air and, using optics, illuminating the sample in a dark chamber. The number of illuminated particles can be compared with a standard chart to give a measure of air quality. The sampling process is very rapid enabling real time analysis of air quality at various locations within a room. The sampling positions are marked on the department plan.

Samples of surface contamination are then collected using a Teknek DCR roller which is designed specifically to pick up all loose particles down to 1 micron in size. The roller is run over a specific area of surface and this area is noted.

The contamination is removed from the roller using a sheet of special adhesive with a grid pattern on it. This concentrates and permanently holds the contamination for later analysis. The sample is then covered with a release sheet containing details of the exact location of the sample. Any relevant notes about the sample area should also be included, for example, peeling paint on equipment.

AREAS TO BE SAMPLED

Floors

The floor provides one of the prime sites for contamination analysis, as examples of most types of contamination eventually make their way to the floor. Floor samples should be taken at the inlet to the room and in a passageway remote from the door. Comparison of the two samples will allow an assessment of the quantity and type of contamination being carried into the room.

Floor samples should also be taken under conveyors and other handling equipment as any contamination knocked off the boards will fall there. Special attention should be paid to the area where the material enters the department, as floor samples there will indicate the contamination coming in on the product.

Walls

Samples taken on the walls of cleanrooms often show that the painted surface is flaking and shedding contamination. Noticeboards and whiteboards are also significant sources of contamination.

Ceilings

Any contamination from ceilings, being the highest point in the room, has the potential to fall directly on to the product being processed. Ceiling tiles are often made from pressed board which degrades with time. Also, the inlet and exhaust filters for the air supply are often situated in the ceiling and both can suffer from a build up of contamination which will suddenly fall into the area below.

Equipment

Samples from the top of equipment indicate the type of particles being carried in the airstream. Generally these will be lighter particles such as clothing fibres and dust. However, the appearance of larger, heavier particles may indicate excessive turbulent air movement blowing contamination around the area, thereby increasing the risk of larger particles landing on the boards during processing.

Few people ever assess the contamination inside their equipment, but it is an important area to audit, especially on optical equipment such as photoplotters, AOI machines and exposure units. Samples from inside equipment also have a secondary use in that the presence of high concentrations of metal particles can indicate wear of bearing surfaces and allow preventive maintenance to be carried out.

Product

Samples should be taken from the faces and edges of several boards immediately before any sensitive process, such as dry film lamination, exposure or AOI, to establish the actual level and type of contamination on the product. The presence of copper or epoxy particles or other process-generated contamination indicates a need for process evaluation, but other types of contamination must come from the environment to which the board is exposed.

Transport Systems

Totes and carriers, trolleys and carts are often used to transport product from department to department or operation to operation and are the major mechanism for transfer of contamination. Samples should be taken from their surfaces and, also, their wheels. The paintwork on transport systems is a substantial generator of resin particles as it sustains a lot of impact and abrasion.

Operators

People are a significant source of contamination even in a cleanroom. Samples should be taken from the back and legs of operators. Many companies only use cleanroom coats. Yet, by leaving the operators' normal clothing exposed at leg level, the risk of contamination is much increased. Most companies do not use any overalls in the AOI department and the samples taken from the operators will correlate with contamination found elsewhere in the process, sometimes in other departments.

SAMPLE ANALYSIS

The primary method of analysis is to use a microscope with a variable magnification up to 60X to examine each square in the sample grid. Each type of contamination within the square is identified from reference photographs and the number of particles of that type is counted. The totals for the completed sample are summed and the results entered in the Department Contamination Matrix.

If there are unusual or unidentified particles in the sample, it is beneficial to have colour photographs taken so that further investigation can be carried out. This contamination should also be entered into the Contamination Matrix.

CONTAMINATION MATRIX ANALYSIS

The Contamination Matrix shown in Table 1 is a typical example from a high volume multilayer board manufacturing facility. Some examples of the information gleaned from it are given below.

1 Operator related contamination, especially clothes fibres, is not only the most widespread kind, but also has the highest levels of incidence. It is prevalent even where there is little operator involvement, e.g. solder mask electrostatic spray. This would suggest that the fibres are being carried throughout the facility. At inner layer AOI, where no special clothing is worn, fibres were in every sample, including those from inside the equipment and from the product. This will contribute to false calls.

2 Copper particles were found in every sample in hard board print, which may indicate the need for better control in the copper baths, or for the introduction of edge bevelling.

3 Copper particles were also found in the Artwork Department. Since copper parts never enter this area, the contamination must be carried into it, probably by people.

4 There is a wide distribution of coloured resins throughout the plant. These are mainly paint flakes from equipment and carts.

5 The substantial amount of metal particles in the solder mask exposure lines are due to bearing failure in the conveyors.

6 Large amounts of cellulose in the inner layer print were due to cardboard boxes of dry film being taken into the room where the packaging was then removed.

7 There is a substantial amount of vegetable matter in the cleanrooms which can only be carried in by the operators or by carts.

This is merely a small selection of the information which was found during this audit.

PRACTICAL MEASURES FOR CONTAMINATION CONTROL

The range of measures which would follow analysis depends on the results found. While it would not be expedient to attempt to list all of the potential measures, a number of common points is given below as a useful guide to likely first steps.

1 Operators should be fully gowned where possible. If this is not acceptable, trousers made from lint free material should be worn with cleanroom coats. This applies in all departments.

2 All product should be cleaned immediately before sensitive operations.

3 All cardboard should be excluded from the cleanroom, including film boxes.

4 All painted surfaces should be regularly inspected and repainted as soon as the paint starts to deteriorate.

5 Responsibility for cleaning transport systems should be established together with cleaning protocols.

6 Tacky mats should be used to control the ingress of contamination to all departments.

CONCLUSIONS

Significant yield improvements can be achieved through a systematic approach to contamination control. The Contamination Audit with its associated Contamination Matrices provides a flexible framework with which to assess the contamination levels throughout the facility and identify the most beneficial contamination control methods.