liquid photoimageable solder masks

The so-called LIPSM technology was developed in the 1980's to meet the new application demands placed upon solder masks by the rise in surface mount technology. This has necessitated a new approach not only in the technology of the solder mask but also in their application and processing.

With the UV curing and thermal curing products the processing was essentially two steps:

- **Application and Imaging by Screen Printing.**
- **Curing the printed film.**

With the LPISM technology the processing is more complicated:

- **Application of LIPSM to PCB.**
- **Evaporation of Solvent (Predry).**
- **Photo Exposure (imaging)**
- **Development of exposed board.**
- **Final cure**

So the application of the LPISM merely coats the circuit with a controlled thickness of photo-polymer. As the application step now is not and imaging step this has lead to different application technologies: Curtain Coating, Electro-Static Spray, Air Spray, being used to coat the panels. Details of the various application techniques will be discussed in Section 3.
The imaging process for the LPISM technology is carried out photographically, so the photo exposure and development steps are directly concerned with producing a specific image of the solder mask on the circuit board.

After application the liquid solder mask is dried under controlled temperatures and times to notionally remove the volatile organic solvent from the film. The dry photo-polymer (tack dry) is then image wise exposed using the appropriate solder mask artwork. The exposure step basically hardens of polymerises certain areas of the solder mask film to render them insoluble in the developer. The non-exposed areas of the solder mask (PTH pads, surface mount pads etc.) are not hardened by the long wave ultra violet light (300 – 360nm) and are dissolved in the developing solution. Exposure time is from 20 – 90 seconds depending upon the exposure unit used and the type of solder mask being processed.

The exposed solder mask is then passed through a conveyorised developer unit where a specific solution of "developer", (organic solvent or sodium carbonate solution) will selectively dissolve the unexposed areas (pads etc.) of the solder mask but the exposed of "hardened areas of the film remain unaffected by the developer. This photographic development will produce a very sharply resolved image of excellent accuracy and registration which is why this type of solder mask technology has increased in popularity and usage in the past 10 years. The positional accuracy of the solder mask image is now not dependent upon a printing process but upon a photographic process which gives an inherently more accurate better resolved image.
After development the solder mask is given a thermal bake to fully harden (polymerise) the film.

COMPARISON OF SOLDER MASK TECHNOLOGY

	UV Curing Solder Mask	Two Component Epoxy Thermal Cure	LPISM
1. Application	Screen Printing Fully automatic	Screen Printing Semi Automatic	Screen PrintingCurtain Coating spray
2. Laminate	FR2 CEM 1CEM 3	FR4 FR5	FR4 FR5
3. Market	Consumer Electronics Single Sided Copper	PTH Multi Layer	PTH Multi Layer Surface Mount
4. Production Rates	300 - 400 pph	60 pph	90 - 120 pph
5. Cost	Low	Low - Moderate	Moderate - High
6. Processing	Screen Print UV Cure	Screen Print Thermal Cure	Screen/Curtain Coat/Spray Predry Expose Develop Final Cure
7. Technical Performance	Moderate	High	High

Screen Printing Process

A stencil-like image is supported on a fabric mesh stretched across a rectangular frame. During printing the frame is supplied with ink which is flooded over the screen. A squeegee is then drawn across it, with the ink flowing through the open cells of the mesh. At the same time the substrate is held in contact with the screen and the ink is thereby transferred to it, from the open cells of the mesh. Irrespective of the type of machine used or if the process is manual the printing procedure is generally the same. A working supply of ink is placed at one end of the screen. The screen is then lowered into position and a rubber squeegee is drawn across the stencil to produce the print.

On most automatic flat bed machines the base to which the substrate is applied is a vacuum. This prevents the laminate sticking to the screen when tacky inks are used.

To a certain extent the thickness of the ink film printed can be controlled by the pressure, sharpness and angle of the squeegee blade. The 'snap off' is the off-contact distance between the mesh and the substrate (see diagram). The smaller print gap is recommended to keep screen stretching to a minimum. During printing the snap off may be too small, in which case the gap can be increased slowly until good quality print is achieved.

The squeegee pressure must be kept to a minimum at the start of printing and increased slightly to improve print image.

The squeegee should normally have flat edges; poor definition may arise from its having round edges. A round-edged squeegee will also deposit a higher film weight.

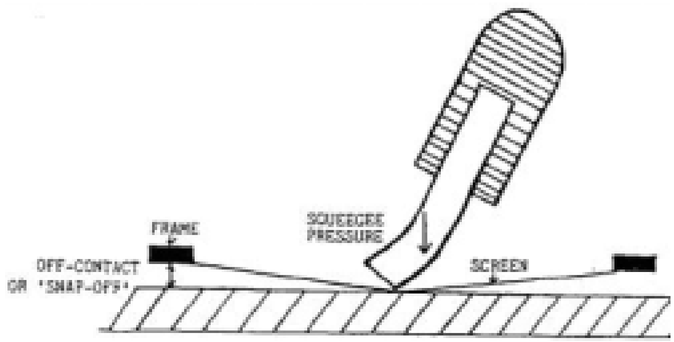
Screen printing was developed from the use of stencils for the repetitive decorating of drums. The basic principles of the screen process did not appear, however, until a stretched mesh was used. This served as a support for the stencil and as a carrier surface for the ink, which flows through the stencil with a squeegee.

The " silk screen process" did not emerge in commercial form until about 1921. The process was developed rapidly and is now highly automated and has become established in a wide variety of decorative and industrial fields, including the printed circuit industry.

Of all the available printing techniques, the screen process is well adapted to the requirements of printed circuit production as it can deposit resist on both unetched and etched boards over a wide range of film thickness, depending on application.

Printing equipment

Manual printing equipment retains economic advantages for certain classes of short-run work, and is therefore still used. However, there are semi- and fully automatic printers for printed circuit board production.
The diagram shows the main principles of both manual and automatic screen printing. The substrate can be held on a flat bed by a vacuum to stop any movement and the screen is separated from the substrate by a small "off contact gap." Each printing stroke is followed by a flood coating action which skims a thin film of ink over the mesh surface.

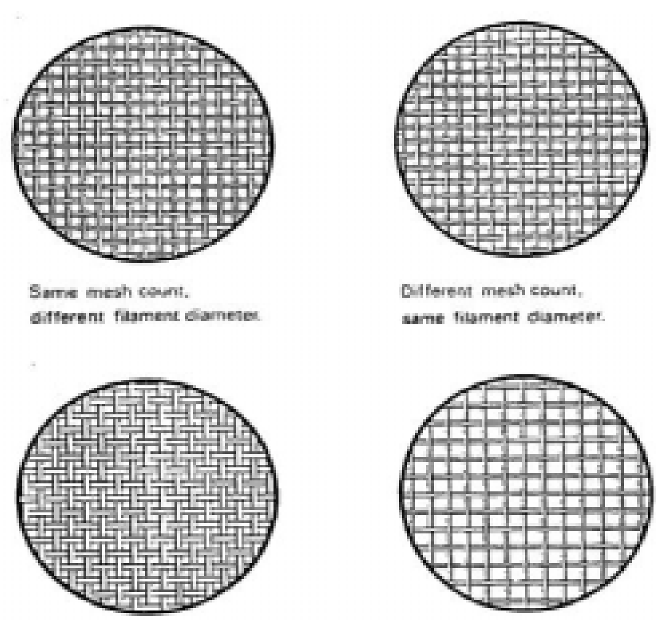


The squeegee The squeegee is made of either rubber or polyurethane. The latter material maintains its sharp edge profile on long runs, and is therefore often used in automatic printing presses.

Mesh

The choice of mesh influences the quality and economic viability of finished work. The mesh count (number of strands per centimetre), the thickness of mesh and the open area are the factors that affect the quantity of ink printed and the quality of the finished image. Generally the more threads per centimetre the lower the ink film weight and the better the definition of the finished print. The diagrams show how different mesh count and filament can alter the mesh opening, therefore affecting the amount of ink being deposited.

1.



Meshes are available in a variety of materials including silk, polyester, nylon and stainless steel.

Silk

Although the use of silk fabric gave rise to the term silk screen printing, today the natural fibre is seldom used. It is constructed of threads twisted together from several filaments, a structure that has a number of disadvantages:

1. Thread and mesh irregularities.
2. Swelling during printing.
3. Difficulties in cleaning and dimensional instability.
4. Silk meshes shrink when damp, so registration is difficult unless the humidity of the printing environment is controlled.
5. The screens are non-reclaimable; they cannot be stripped for re-use when the stencil becomes obsolete

Silk has an advantage in excellent elasticity and a rough surface, which provides excellent adhesion for stencils.

Polyester
Polyester is the most widely used screen material. It is less elastic, so it has better dimensional stability, but it has sufficient flexibility to enable it to be pressed into good contact with uneven surfaces. It is not affected by moisture, and is suitable for fine detail printing.

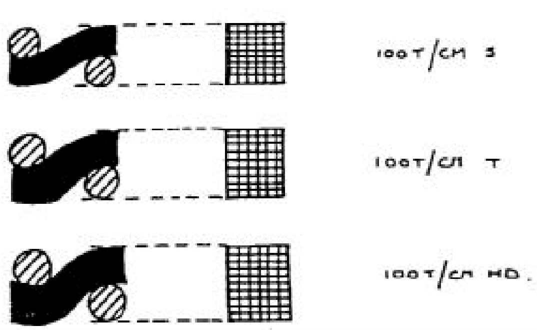
Nylon
Nylon was the first synthetic material to be used. Even though it has high elasticity, it tends to elongate images so registration becomes difficult. It is ideal for long production runs because of its tensile strength, but it is affected by moisture.

Stainless steel
Stainless steel meshes are not widely used today. They are very expensive and because they have low elasticity they are used when ultimate definition and registration are required.

Metallised polyester
This consists of monofilament polyester sheathed in metal. It is said to give a final fabric which has elasticity half that of polyester, therefore It gives very accurate registration.

Monofilament vs. Multifilament
Meshes made from single threads of material give a final product having a very regular open area, whereas multifilament fabrics have irregular structure. The latter has the following advantages:
1) Ink collects between the relatively loose fibrils, and is not easily removed on cleaning. This leads to eventual mesh clogging.
2) Poor sharpness of print detail, owing to the irregular structure of multifilament fabrics.

Mesh thickness Three common size diameters of monofilament thread are woven into screen fabrics; S (small), T (regular) or HD (heavy duty). Type T is most common and is suitable for the broadest range of applications. Type S is lighter in weight and has less strength, but is ideal for printing thin deposits of ink. HD has the greatest resistance to mechanical strength.
The inside mesh width changes owing to different thread thickness while the thread count remains the same. The diagram shows how the diameter of the thread affects the amount of ink deposited.



Mesh colour Synthetic nylon and polyester meshes are manufactured in standard white and also in red and amber colours. The latter two are available as they prevent the light under-cutting when using direct emulsion photo-stencils.

Mesh angle This refers to the direction taken by the warp and weft strands of the fabric when mounted in the screen frame, in relation to the direction taken by the squeegee moving along the print stroke. Three angles are in common use; 90, 45, and 22.5 degrees.

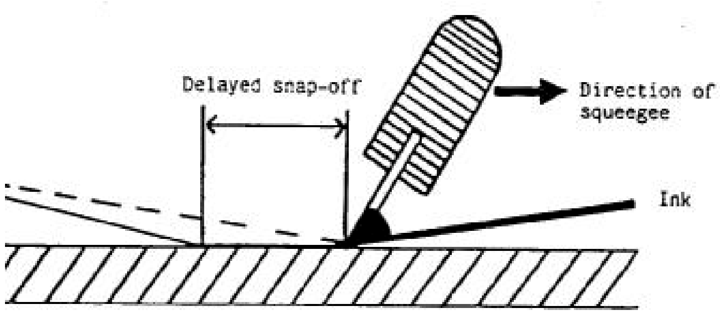
There are two main factors in the choice of angle:
1) First is the question of strain on the fabric, which is stretched over the frame tightly when it has to take the pressure of the squeegee which must bring the mask onto the fabric into contact with the substrate surface for printing to take place. Maximum flexibility is given when the mesh is at 45 degrees, and the distribution of the load on the fabric during each print stroke is at its most even with this setting. This angle therefore gives the fabric the best chance of recovering after every print stroke, and maintaining its tension at the correct level for satisfactory printing to take place. Good print quality will not be obtained unless the fabric lifts off the substrate immediately behind the print edge of the

squeegee. This 'peeling' action behind the squeegee is the essential feature of the screen process; the squeegee does not push the ink through the mask onto the substrate, as is often thought. The ink is drawn out of the mask by surface tension, and only when this happens will a satisfactory print image be obtained.

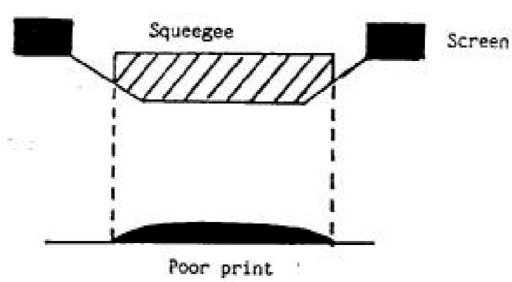
2) The second factor in the choice of angle is the possibility of 'interference patterns' (Moire patterns) arising from the directions taken by the filaments of the fabric and those taken by parts of the circuit being printed, e.g., conductor tracks. Under certain conditions of printing, incomplete deposit of resist can occur, giving serrated edges. This point has caused much discussion, especially as the 45 degree mesh angle is said to be the one which most frequently gives this effect, since here most of the circuit lines will lie in the direction of the squeegee track or at 90 degrees to it, and so will have to be formed by a mesh at 45 degrees, crossing all the lines at an angle. It is possible for mesh angle of 90 degrees to cause a fine conductor track to disappear completely, if its position in the mask should coincide with a filament. As a compromise, therefore, an angle of 22.5 degrees is sometimes adopted.

Screen stretching

Another factor important in influencing the final quality of the print is screen stretching. This is normally done with the aid of mechanical stretching apparatus. Insufficient screen tension can cause delayed screen 'snap off'. With insufficient screen tension a tacky ink will hold the screen fabric to the substrate causing smearing of the print and an uneven deposit of ink.



The screen frame must be of adequate construction to withstand the tension of the mesh without relaxing. The most suitable frames are made from corner-welded steel or aluminum. Between the frame and the edges of the print area there has to be sufficient mesh to guarantee a distortion free contact and release of the mesh. Normally the inner area of the frame must be on all sides at least six inches bigger than the printed area. In general the print area should not exceed 80% of the total mesh area when using nylon or polyester and 60% when using stainless steel. The diagram shows a frame that is too small for the squeegee, leading to insufficient clearance between the squeegee ends and the frame sides.

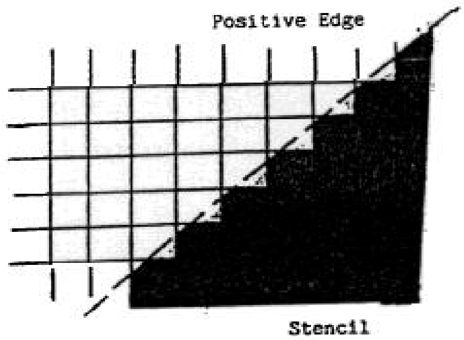


Stencils

Screen printing stencils are mainly photographic, allowing screen printers to reproduce finely detailed designs. Four types are available; indirect, direct, direct/indirect and capillary.

1) **Indirect stencils** The indirect emulsion is normally coated onto a polyester support film. The presensitised emulsion film is placed with the positive into a vacuum frame and exposed to a metal halide lamp. The exposure must be sufficient to harden the emulsion but not completely, leaving a 'soft top' for adhering to the mesh after wash off. The exposed areas can then be chemically hardened before the unexposed areas are washed out with warm water and mounted onto the mesh. After

drying the base support film is stripped off. This system gives very high definition, but the stencils are not robust.



Wash-Out

Unsupported stencil areas wash out giving 'stepped' edge.

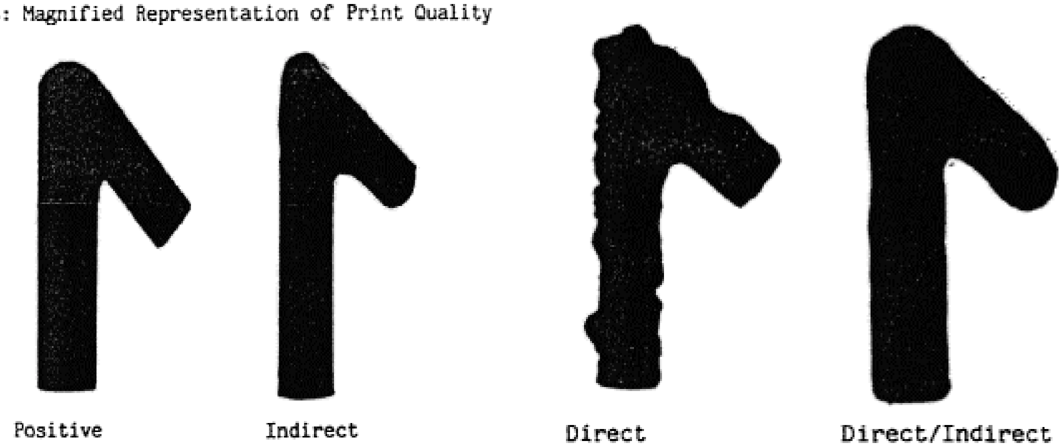
2) **Direct photo-stencils** A photosensitive liquid emulsion is coated onto both sides of the mesh.
Normally two or more coats are applied to embed the mesh in the emulsion. The coated screen is dried and exposed to light through a photographic positive of the required design. The unexposed portions of the screen are washed out with warm water to leave a solvent-resistant stencil. Direct photo-stencils are durable and long-running, but their print quality is inferior to that of the indirect stencil. The emulsion does not easily form a flat surface which can lead to ink spread, and it can shrink upon drying, causing saw-tooth edge problems associated with direct stencils. The result in both cases is known as 'saw tooth edging'.

Direct/indirect photo-stencils This method can be considered as a system combining some of the best features of the previous two systems. A film coated with emulsion is placed in contact with the stencil side of the mesh. A sensitised emulsion is then squeegeed through the mesh. Laminating the film to the screen and simultaneously sensitising it. After drying, the support film is removed and processed as a direct stencil.

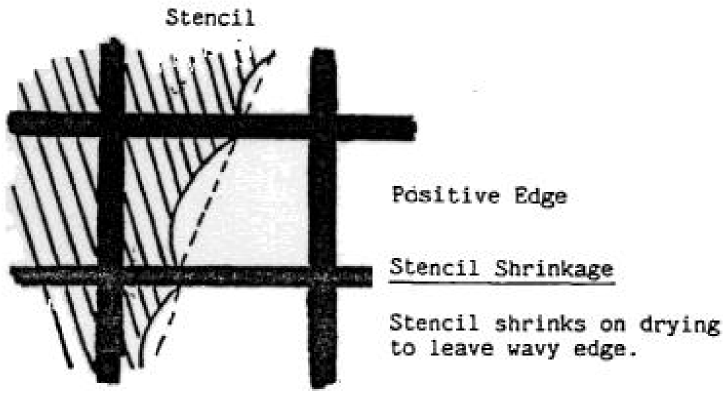
The definition of this method approaches that of the direct photo-stencil whilst retaining the robustness of the direct stencil.

4) **Capillary photo-stencils** These consist of laminating a pre-sensitised direct film onto a mesh which has previously been wetted with water. Capillary action ensures that the films adhere tightly to the mesh. Once lamination has taken place, the procedure is as for a direct photo-stencil. The definition of capillary photo-stencils is as good as direct/indirect photostencils, and they have a long life.

Stencils: Magnified Representation of Print Quality



Stencil Shrinkage. Positive Edge Stencil shrinks on drying to leave wavy edge.



Curtain Coating

The curtain coating principle is used in various industries. It can apply liquid material at very high speeds with low material loss. Curtain coating has become more widely used in the circuits industry as PCBs have become more complex, with higher track densities and narrower track widths.
A vertical falling curtain of coating material is produced by pumping the feedstock through a slit on the underside of a reservoir. The substrate to be coated is moved briskly through the resulting liquid curtain, collecting a thin and even deposit on the way. It is then passed on to separate machinery for baking.

Pump The pump is used for:
a) Pumping feedstock up to the coating head
b) Recirculating the feedstock
c) Emptying out the system, when necessary Fine sieves or screens must be built in to the pump to remove any foreign bodies or oxidised skin from the coating material; these would foul the gap in the reservoir, giving an uneven curtain or perhaps breaking it altogether. This would result in bald streaks on the substrate. The pumping action can cause the temperature of the liquid to increase, usually undesirable as it causes more solvent evaporation and stimulates premature crosslinking reactions. A cooling system is usually employed to reduce this.

Curtain coating head The curtain coater head is an elongated box-like reservoir set at right angles to the direction of travel of the substrate. The reservoir is covered, and has tapered sides that narrow to form a slot in the bottom through which the coating material is pumped to form the curtain. The opening is lined with two flanges called 'lips'; one is fixed and the other mounted on a sliding base, so that the lips can be adjusted to give different widths of discharge slot. This determines the coating flow. The amount of coating applied (weight per unit area) is a function of the volume being discharged and the speed of travel of the substrate. In some installations a plastic shield is used to protect the curtain from draft induced movement. This also reduces solvent evaporation. Curtain coaters are used to apply heavy laydowns' of coating material. Minimum dry thickness is 6-10 microns. All types and shapes of substrate can be coated owing to the non-contact nature of the system, but very thin coatings are not possible owing to the wettability and flow control properties of the curtain coater.

Collection pan Many substrates, like the sections of laminate used to make PCBs, are discontinuous. The curtain would pass between the gaps and the coating material is wasted. Consequently a collection pan is sited beneath the substrate path to collect the liquid for re-circulation. The pan is wider than the head to ensure that all unused material is intercepted.

Continuous conveyor For a fixed failing volume, increasing the speed of the conveyor will reduce the laydown. The volume of failing material has more effect, and is the coarse control. Substrate velocity under the head is the fine adjustment.

Curtain height The height of the curtain affects the uniformity of the finish. If the slot is a short distance above the substrate, the curtain behaves rather like a curtain made of some textile material. When a piece of substrate travelling along the conveyor meets the curtain it pushes it out of the vertical In the direction of travel. When its trailing end clears the curtain the resistance disappears and the curtain fails back beyond the vertical, resulting in liquid splashing on the conveyor. If the curtain is taller this effect is reduced and the curtain is virtually undisturbed from its vertical position.

Electrostatic Spray

Whilst Electrostatic Spray is a proven application technique used in the coating of metal parts it has not become popular as an application technique within the printed Circuit Industry. The principle of Electrostatic Spraying is based upon the physics principle of "Like charges repel. Unlike charges attract". Therefore the liquid resist is given a negative electrostatic charge and the circuit board is given a positive charge by earthing it:
The thinned liquid resist is pumped from a sump into the application chamber amber where the resist is given its electrostatic charge, it is sprayed by means of an air powered turbine bell which revolves at 25 - 35,000 rpm and the "charged resist" is spun from this fast rotating bell where it is atomised with air. The negative charge on each of the resist droplets helps to further reduce droplet size. Guard electrodes keep the charged droplets within a defined area. Panels are coated horizontally. Despite electrostatic attraction there is some 10 - 20% loss of resist due to overspray. Coating uniformity is good with good even coverage over all conductors. Production can be 60 - 70 panels per hour. Equipment is expensive.

Air spray

This is essentially a conventional spray technique where a thin liquid resist is intermixed with air at the nozzle of a spray gun and the resulting atomised droplets of resist and then carried by the force of the air pressure onto the circuit board. This application technique has been used in industry for 70 years plus but has only recently been introduced into the printed circuit market. Although the spraying principle is slightly different and the equipment less expensive there are many similarities between air spray and electrostatic spray. Production rates would be similar, loss in overspray is similar, coverage over panels is similar. Equipment is available to coat circuit boards horizontally or vertically.

Comparison of Application Techniques

Screen Printing	Curtain Coating	Spray
Low Capital Cost.	High Capital Investment	High - Very High capital investment
Manual/Semi Automatic	Fully Automated	Fully Automated
Low Productivity	High Productivity	Medium - High Production
Low Product Wastage	No Product Wastage	10 - 20% Product Wastage
Problems with Track Encapsulation	Good Track Encapsulation	Good Track Encapsulation
Fully automatic printing is available but at high capital cost	M/c availability high	
	Auto Viscosity Control	
	Auto Temp. Control (optional)	
	Film Wt. change fast	Film Wt. change fast
	Panel size independent	Panel size independent

SPECIFICATIONS AND APPROVALS

As the solder mask is permanent protective coating on the circuit board attention needs to be given to the performance of the mask under various processing and environmental conditions. The failure of a circuit board in use is potentially costly and possibly catastrophic, and if the cause was ascribed to a solder mask failure then a potential major problem was caused by the most inexpensive part of the board - THE SOLDER MASK.
So in today's modern circuit industry solder masks are subject to numerous approvals and have to meet to certain performance levels (specification).
In essence most solder mask specifications are concerned with the following criteria:

1. Visual Appearance
2. Film Thickness
3. Adhesion
4. Surface Hardness
5. Solder Resistance
6. Electrical Performance
7. Moisture & insulation Resistance
8. Resistance to Hydrolytic Attack
9. Electro Chemical Migration
10. Flammability

Most important O.E.M's (I.B.M., Motorola, Siemens, Northern Telecom etc.,) have their own solder mask specification generally based to the criteria given above and each individual company will have slightly different ways of testing and measuring solder mask performance.

In addition to these "internal" solder mask specifications there are external specifications or approvals which are necessary for every solder mask to meet:
IPC SM840 SOLDER MASK SPECIFICATION
UL 94 UNDERWRITERS LABORATORIES FLAMMABILIY STANDARD
The SM840 specification is virtually known and accepted world wide as a solder mask specification and is generally seen by solder mask suppliers and board manufacturers as the first specification to pass. From here a solder mask will need to pass the board manufacturers own internal test criteria or specification and of course the final end users specification (IBM, SIEMENS, FORD, MOTOROLA, HEWLETT PACKARD ETC).
As every electrical or electronic appliance is subject to a flammability rating then every solder mask also needs to be tested by the manufacturer for flammability. This is carried out independently by the Underwriters Laboratories in North America who will test every solder mask, laminate and circuit board to ensure they meet the required standard for flammability. The gaining of the necessary specifications and approvals is both costly in terms of time and money and effort but it does ensure that the standards of the industry are at least maintained and possibly improved as well.

For more information contact:

Coates Circuit Products
Norton Hill
Midsomer Norton
Bath BA3 4RT United Kingdom
(44) 01761-414471 Phone
(44) 01761-417446 Fax