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REPORT

Application of photoimageable solder resists

Advantages and disadvantages of the various application methods available

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1. Which application processes shall be compared?

When applying **Lackwerke Peters'** photoimageable solder resists of the series' **Elpemer®** spray application which is widely used in the USA, is gaining importance in Europe alongside curtain coating and screen printing processes. Therefore, besides the two established application processes, this process will be described in the course of this text and advantages as well as disadvantages of each process will be discussed.

1.1 Curtain coating technology

In case of curtain coating the printed circuit board is accelerated to a speed of up to 90 m/min, transported through the lacquer curtain and subsequently decelerated to normal transport speed of a few metres/min. The lacquer curtain is defined with regard to thickness and flow speed. Since the lacquer curtain and printed circuit board transport speed are nearly equal, solder resist is applied to the printed circuit board in a uniform layer.

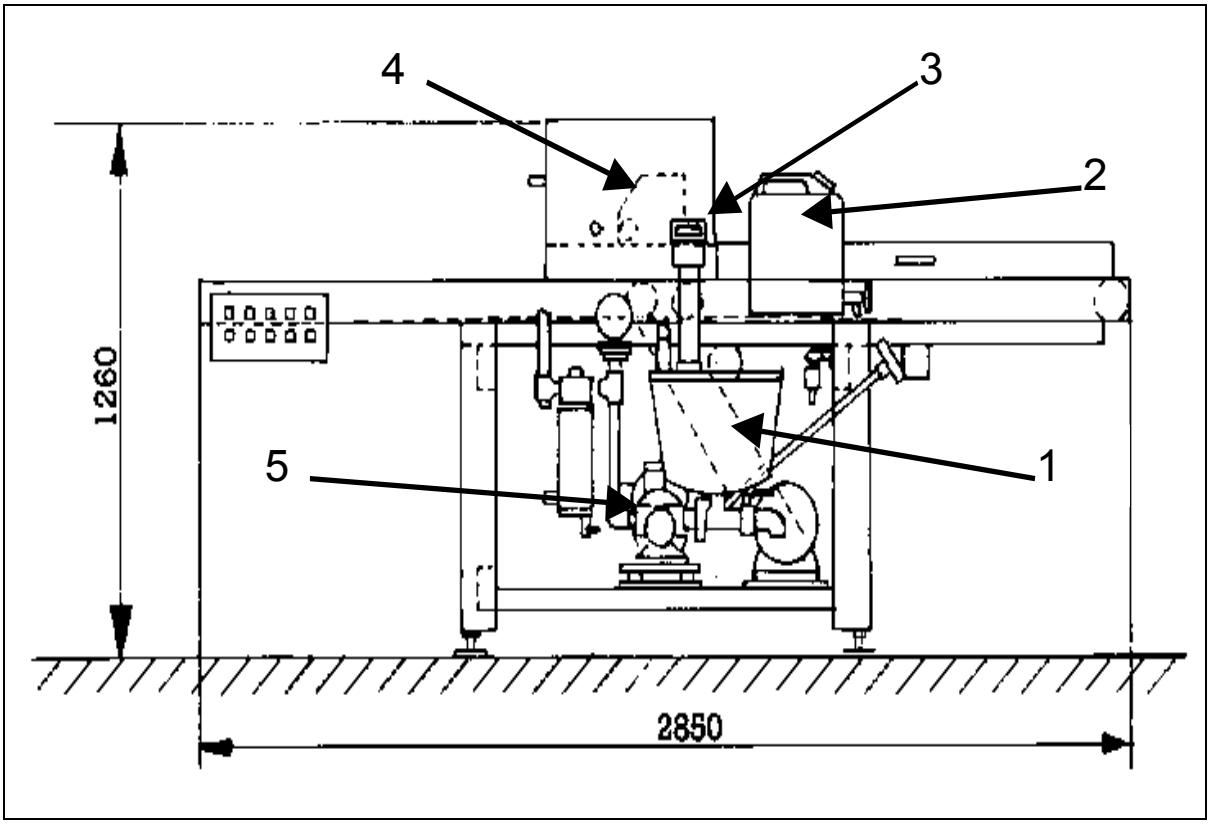


Figure 1: Side view of a curtain coating unit

The solder resist is permanently pumped from the storage tank [1] into the pouring head [4] and flows back to the storage tank via a collection duct. In order to obtain consistent process parameters, the viscosity of the solder resist is controlled permanently by means of a viscosity measuring unit [3] and is kept within preset viscosity tolerances by the addition of solvents from an automatic dispensing system [2].

Since the lacquer viscosity is dependent upon the temperature, attention must be paid to a constant tempering of the lacquer. As a rule, the lacquer in the storage tank is tempered by means of a cooling cycle as it is permanently heated up by the lacquer pump. The lacquer quantity to be applied, that depends upon the required layer thickness, is suitably adjusted by the number of revolutions of the pump [5]. The fine adjustment occurs by weighing the applied wet ink weight on a test board.

In case the second side of the printed circuit board is to be coated directly after pre-drying, it is mandatory to ensure that the printed circuit board is turned by 180 ° before coating the second side. Turning the board prevents one side of the inner walls of the holes and through-hole platings from being double-coated with solder resist when coating the second side. When double-coating the inner walls, the developing time must be extended in order to avoid lacquer residues from remaining in the holes, which may unnecessarily impair the achievable resolution of the solder mask.

A simple curtain coating line comprises a pouring head and a follow-up drying line for pre-drying the lacquer. For this purpose, pure IR as well as convection drying lines – but sometimes also combinations of both systems – are used. Since IR drying runs very fast and temperature progress is difficult to control, the use of convection dryers frequently is preferred. However, the compact construction of the unit at simultaneous high throughput speaks in favour of IR dryers. The drying process by convection drying is significantly milder and the danger of over-drying or solvent inclusions in the lacquer caused by the lacquer surface drying too fast is considerably lower. Curtain coating lines which are designed for a high throughput consist of two tandem pouring heads to coat both sides of the printed circuit board, whereby, for instance, a paternoster oven for convection drying of the solder resist coating is connected to each pouring head. Usually, the above described rotation of the printed circuit board by 180° is achieved by means of the first paternoster before the second side is coated.

The pouring heads are – depending on the equipment concept – equipped with a coating edge limitation, so that the respective outer plating edge sides can be kept free of lacquer. The complete handling system is adjusted to this technique after the first side of the printed circuit board has been coated/dried. In order to avoid marks on the first coated side of the printed circuit boards, after this process step they are held at the edges only. These special holding and clip systems even enable the coating and drying of very thin substrates down to 0.3 mm.

1.2 Screen printing application

Screen printing is a contact printing process, whereby by means of a squeegee screen printing lacquer is applied through the screen mesh to areas which are not covered by the screen coating.

Two different screen printing processes are applied in the fabrication of printed circuit boards. On the one hand single-sided, horizontal screen printing, by means of which not only conventional screen printing lacquers but also photoimageable ink systems can be processed. Furthermore, double-sided, vertical screen printing by means of which only photoimageable lacquer systems can be processed.

1.2.1 Screen printing, single-sided, horizontal

In case of the classical screen printing process, the material to be coated is fixed to a horizontal base (printing table) and coated by means of a printing screen placed thereon. For this printing process, machines ranging from simple manual printing tables to fully-automatic screen printing lines with loading and unloading equipment and optical registration of the printing material are used. Owing to the high registration accuracy, besides photoimageable lacquer systems, which do not require a high registration accuracy, conventional screen printing lacquers (thermal or UV curing) are processed.

When processing conventional lacquers, areas that must not be printed are covered with a stencil in the screen mesh. When printing photoimageable systems, usually only the edge areas are covered with the stencil material. However, in order to avoid lacquer accumulations in the drill holes, in special cases through-hole platings are also covered by means of a stencil. In this case a high stencil structure is unnecessary, since the stencil is used only for closing the screen mesh. Comprehensive advice on making stencils can be found in our Technical Information sheet **TI 15/11** "The screen printing stencil in the printed circuit board industry " which we will gladly provide upon request.

1.2.2 Screen printing, double-sided, horizontal

This type of classical screen printing for the application of photoimageable solder resists is mainly used in the Far-East.

As already described in section 1.2.1, in this particular case the solder resist is applied to the first side. For printing the second side, the first - still wet side – is balanced on pins. As far as possible, the pins are positioned in such a manner that the pre-printed side is only touched in uncritical areas, such as free base material areas within the circuits or between the boards on a complete panel. Due to the minimum contact surface of the pins, the lacquer coating remains virtually intact.

Application may be effected either by means of a single screen printing table, which is furnished with pins for both sides, or by means of two screen printing tables for each side respectively, whereby only the one for the second side is furnished with a bed-of-nails.

1.2.3 Screen printing, double-sided, vertical

In the screen printing process special vertical screen printing machines are used, which allow simultaneous coating of both sides of the printed circuit board.

Essentially, the vertical screen printing units function on the following fundamental principles,

- the panels are fixed in a vertical position
- the screens are fixed at an equal distance to the vertical panels
- both squeegees are always exactly in the same position on each side of the panel
- the squeegee angle is the same for both squeegees
- the squeegees have the same dynamic pressure on both sides of the panel

from which the following key advantages result:

- the whole equipment requires only a small space
- simultaneous coating of both printed circuit board sides; thus printing on two equally clean/oxide-free surfaces
- joint pre-drying of both printed circuit board sides
- printed circuit boards with big holes and openings can be coated without any danger of the lacquer bleeding through - in the same manner as in curtain coating technology.

General advantages of screen printing in comparison to curtain coating are as follows:

- when using stencils those areas to which no solder mask should be applied (i. e. copper border) can be left out
- owing to the higher solids content, a considerably lower wet film weight is required
- the rheological properties of a screen printing lacquer (structural viscosity) prevent it from running off the conductor edge, so that a better edge coverage is achieved with a lower coating thickness on the surface
- vertical positioning of the printed circuit board during pre-drying so that convection drying is completed after a very short time.

Despite the numerous advantages vertical screen printing has to offer, two decisive disadvantages of this coating method exist which considerably dampened the initial enthusiasm:

- larger quantities of lacquer get into small holes independent of the type of the ink system used. The holes are literally filled if the parallelity of the opposite printing squeegees deviates slightly. Therefore, it is often difficult to ensure complete free development of those holes, and/or the obtainable resolution suffers from the extremely long developing times that may result in order to ensure complete free development.
- the obtainable throughput depends strongly on the chosen print mode and the type of printed circuit board to be coated. As a rule, specified capacities of 100 – 120 pcbs per hour are far inobtainable. The obtainable throughput is lower in particular in the case of frequent format changes.

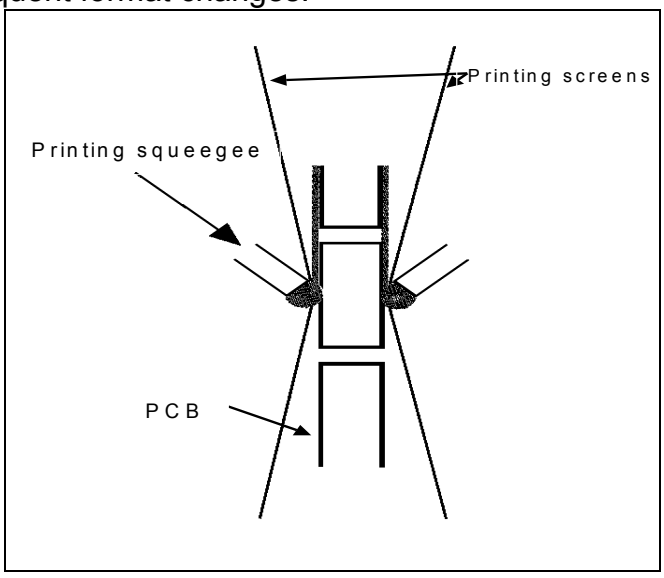


Figure 2: Scheme of double-sided, vertical screen printing

1.2.4 Units for double-sided, vertical screen printing

For double-sided, vertical screen printing semi-automatic and fully-automatic units are available. Semi-automatic units are composed of a manual loading and unloading area and a fully-automatic printing area whereas in case of fully-automatic units the printed circuit boards are additionally transported to the printing area via a stacker or a magazine. After the printing cycle, the coated printed circuit boards are transported automatically to a vertical conveyorized dryer.

Both, Cugher, Italy, who manufactured such machines until 1999 and Circuit Automation, USA, as a manufacturer of these systems (meanwhile also the owners of Cugher) have further optimised their equipment with regard to a higher degree of automatization and processing of thinner materials. Material thicknesses of at least 0.1 mm can be processed by means of hanging dryers which are increasing in popularity.

1.3 Spray application

When applying by spraying, the solder resist is finely atomised (usually "airless") or in addition electrically charged (electrostatic spraying) and transported to the earthed printed circuit board by means of the static charge and a low air pressure. In general practice, for the spray application of our **Elpemer®** solder resists in particular the Argus double-sided, horizontal spray coater has a proven track record, which is used by numerous companies in the USA and Canada in combination with our **Elpemer®** solder resists **of the series AS 2467**. Besides the low viscosity that is necessary for the spraying process the latter offer an optimum lacquer flow and a good coverage of conductor edges. Meanwhile, also European manufacturers offer spraying units, as for instance Systronic, Flein and All4-PCB, Therwill-CH.

1.3.1 Spray application

The Argus spray coater coats and pre-dries printed circuit boards horizontally; in this process the lower side is the first to be coated by the spraying head that oscillates across the direction of travel; the second, upper side is then coated according to the same principle. The spraying nozzles and the compressed air for atomisation are heated to about 50 – 100 °C [122 - 212 °F], so that the lacquer viscosity is reduced directly in the spraying nozzle for easier atomisation of the solder resist.

The heated spray nozzles enable the use of highly viscous lacquer systems which, on the one hand, permits the use of lacquers with a high solids content and, on the other hand, ensures a favourable, i.e. fast, pre-drying characteristic. Thus, the use of our **Elpemer®** lacquers has stood the test with numerous customers because the lacquers are virtually in curtain coating or spraying viscosity after mixing.

Mention should also be made that US-based Teledyne equally offers machines for double-sided spray application, which are suitable for processing **Elpemer®** solder resists.

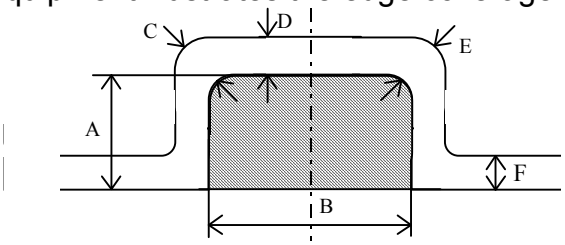
1.3.2 Advantages and disadvantages in the use of solder resists in the double-sided spraying process

One advantage of this application technology when using **Elpemer®** solder resists, the very short lacquer preparation time, has been mentioned previously.

A further important technological advantage which is already noticeable in vertical, double-sided screen printing is the fact that the coating and pre-drying of both pcb sides are effected in one operation sequence which enables a uniform degree of pre-drying for the entire printed circuit board.

If, in case of application by means of curtain coating or screen printing technology incomplete wetting of the gaps between fine conductor bundles, especially with high conductors, occasionally occur in the coating of printed circuit boards with a high conductor density and unfavourable layout (skipping), this problem can be excellently solved by means of the spray technology. Owing to the fine atomisation of the lacquer particles in the spray nozzle even printed circuit board areas that are difficult to access can be reliably wetted and covered with solder resist. The spraying technology also ensures that only small lacquer quantities are trapped even in very small via holes. Thus, the decisive disadvantage of vertical double-sided screen printing does not occur.

Moreover, detailed trials and microsection evaluations have shown that coatings achieved by spraying display an excellent ratio of lacquer on conductor to lacquer on base material. The following microsection evaluation of a printed circuit board processed on Argus equipment illustrates the edge coverage in this process:



	conductor height	conductor width	lacquer on conductor edge	lacquer on conductor surface	lacquer on conductor edge	lacquer on basematerial
	A [µm]	B [µm]	C [µm]	D [µm]	E [µm]	F [µm]
No. 1	60	275	18	10	10	26
No. 2	60	250	20	10	14	26
No. 3	60	250	18	12	20	30
No. 4	50	250	20	12	18	30
No. 5	60	250	14	12	16	28
No. 1	65	250	12	14	16	34
No. 2	60	225	18	14	16	32
No. 3	60	225	18	14	14	32
No. 4	70	250	22	10	12	30
No. 5	70	250	22	12	10	30

Of course, a serious disadvantage of spray technology is the overspray, which on the one hand leads to an increased lacquer consumption and on the other hand to a considerable contamination of the printed circuit board handling systems that make cleaning as mentioned above necessary. However, more recent developments with a defined recirculation of the overspray mean considerable savings can be expected.

2. Comparison of the various application technologies

For an objective comparison of the application technologies mentioned the following aspects should be compared:

- degree of automation
- availability
- processing method
- adaptation of the coating parameters to the pcb layout
- lacquer consumption.

2.1 Degree of automation

While application by the curtain coating process and the spraying process is, as a rule, accomplished by fully automatic coating/pre-drying units vertical screen printing units are usually offered as semi-automatic machines. It should be mentioned, however, that these vertical units are also available in fully automatic versions.

The spraying technology offers excellent productivity features if no format changes are required, and also vertical screen printing achieves relatively high throughput figures if no changes in format are required. Nevertheless, curtain coating technology is unbeatable if the formats to be coated change frequently as it is the only application technique that does not demand a change in parameters for this. In this respect, vertical double-sided screen printing is inferior to other methods.

2.2 Availability

A curtain coating line offers the highest availability as even in case of format changes no set-up time is necessary and it usually operates 24 hours per day. Here the other application techniques lose points as in case of a format change especially with vertical screen printing, a longer set-up time may be necessary. Moreover, extensive adjustments must be performed prior to start of operation or cleaning jobs done at the end of operation if the units are not used continuously.

2.3 Processing method

In this respect the "new" application techniques boast their advantages. Vertical screen printing as well as the spraying process warrant the coating and pre-drying of both pcb sides each in one working step so that 2 pcb sides of the same quality result while saving drying energy as only one oven cycle is necessary for pre-drying. Thus, furthermore, shorter exposure and developing times as well as a reduction of the undercut can be achieved which increases the stability of finest ink structures. In comparison with curtain coating the pcb sides can only be processed one at a time resulting in two pre-dried solder resist areas of differing strengths. In case of vertical double-sided screen printing attention must be paid to the problem of free development of smaller holes.

2.4 Adaptation of the coating parameters to the pcb layout

Similar to the aspect of availability, curtain coating can score an advantage here, as only the corresponding wet film weight has to be adjusted. In contrast to the screen printing processes quite extensive adjustments of parameters and maybe a screen

change have to be effected. Spraying processes take a middle position in this case. In case of frequently repeating formats there is a possibility to access the complete unit set-up by means of the computer control.

2.5 Lacquer consumption

Looking at the pure lacquer consumption per pcb area, the curtain coating technology will certainly come last because, owing to the comparatively low solids content of these lacquers, very large quantities have to be applied for the secure edge coverage of the conductors. In addition, merely the outer copper borders can be kept lacquer-free even if a coating edge limitation is installed.

Vertical, double-sided screen printing offers lacquer saving potentials because of the high solids content of the lacquers used and owing to the fact that the entire copper border can be kept lacquer-free. Lacquer losses are caused, however, by screen cleaning as a result of frequent changes of format.

Owing to the good rheological properties of the screen printing ink an improved ratio of the layer thicknesses is achieved. Therefore, for the same edge coverage as in curtain coating technology a lower layer thickness is applied to the base material which also reduces the lacquer consumption and avoids problems during the assembling process due to too high lacquer thicknesses.

Similar to screen printing, the spraying technology also boasts a lower lacquer consumption per area because, owing to the fine atomisation of the lacquer, no embedding of the conductive pattern takes place but an adequate conductor edge coverage is reached with a simultaneously low lacquer coating thickness on base material planes. The only negative feature is the overspray which can be minimised, however, by a clever adaptation of the parameters. The manufacturers of spraying units estimate the overspray at approx. 10 %, which can be called extremely low compared with the overspray values of older system technologies (e.g. electrostatic spraying). Certainly, attention must be paid to the fact that in case of unfavourable equipment adjustments the quantity of overspray might be much higher.

3. Elpemer® solder resists for each type of application

The **Elpemer®** solder resists, both the polyalcohol developable adjustments of the series **2469** and the aqueous-alkaline developable types of the series **2467**, are available in a variety of formulations for every application described in this paper. The curtain coating and screen printing adjustments prove to be fully compatible also for application on the latest equipment technology (paternoster circulating air dryer and/or vertical screen printing respectively).

The nearly vertical ink flanks enable the representation of finest details as for instance solder dams between SMD pads, a high productivity and economy is ensured by short processing times and optimum lacquer properties.

Finally the **Elpemer®** AS (Index AS = air spray) adjustments have proven their excellent suitability for use on spray units.

The photoimageable solder resists of the series **Elpemer® 2463 FLEX** are relatively new. They are aqueous-alkaline developable ink systems for application by screen printing that are especially developed for the manufacture of flexible circuits and enjoy strongly increasing popularity.

4. Summary

Generally, there is no outright "favourite" when selecting an application process. It is the spectrum of the printed circuit boards to be produced at a manufacturer that is decisive for the application process to be favoured. The chosen process should offer the most advantages under the existing circumstances. When selecting a suitable application process **PETERS Engineering für Elektroniklacke GmbH + Co KG** will be glad to assist you and draft complete unit concepts of renowned manufacturers if desired.

5. Literature

[1] Brochure of Argus International, USA

[2] Brochures of Cugher, Italy

[3] Brochures of Circuit Automation, USA

[4] Markus Wieler: The application of photoimageable solder resists in vertical, double-sided screen printing – Advantages of this process compared with the curtain coating technology –
paper presented at a panel discussion of the Association of former graduates of the technical college for metal design, metal and plating technology, Solingen on January 28, 1997 in Solingen, Germany.

[5] G. Herrmann: "Handbook of pcb technology", volume 3, 1993 (in German)
Publisher: G. Herrmann
in collaboration with 21 co-authors including Werner Peters
Published by Eugen G. Leuze, 88342 Saulgau Württ, Germany
ISBN No. 3-87480-091-1.

Appendix

Explanation of indices used in this report:

The indices of product names used in this report have the following meaning:

AS	air spray
FLEX	for flexible printed circuits
SM	silk-mat