WE CONNECT CHIPS AND SYSTEMS

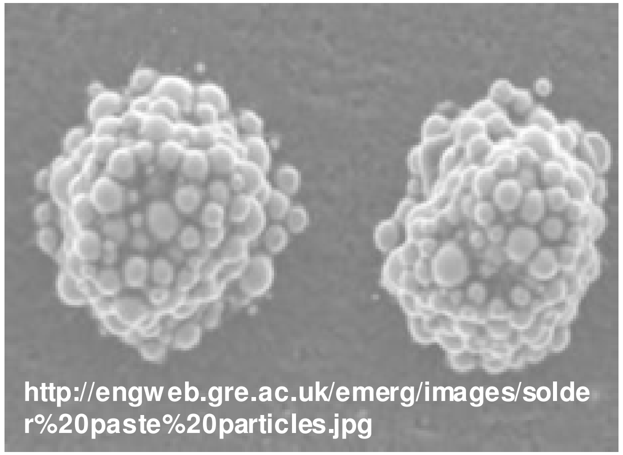
Stencil Design Guidelines for Electronics Assembly Technologies

Student professional contest The 22nd Edition, Brasov, 24th-27th April 2013

BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
DEPARTMENT OF ELECTRONICS TECHNOLOGY

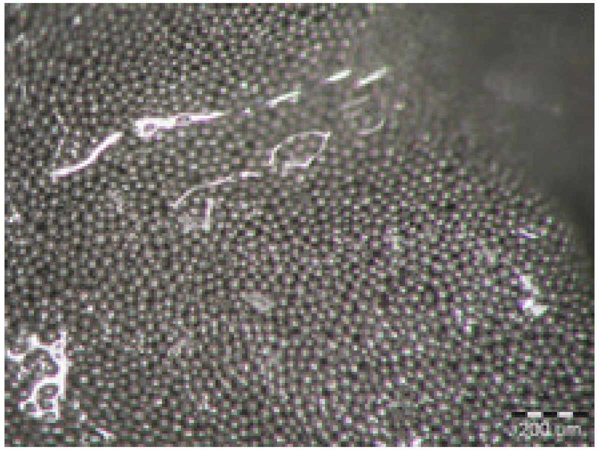
REFLOW SOLDERING - MATERIAL

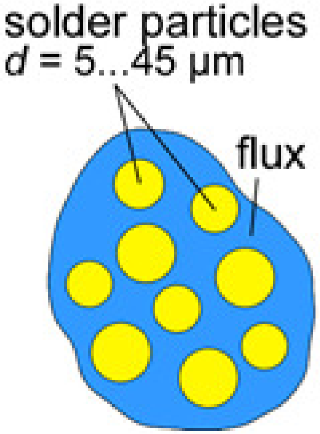
Solder paste is a combination of pre-alloyed spherical metal powder and flux medium.



http://engweb.gre.ac.uk/emerg/images/solder%20paste%20particles.jpg

Solder paste





Solder paste

© Senju

Packing of solder pastes: jar and syringe

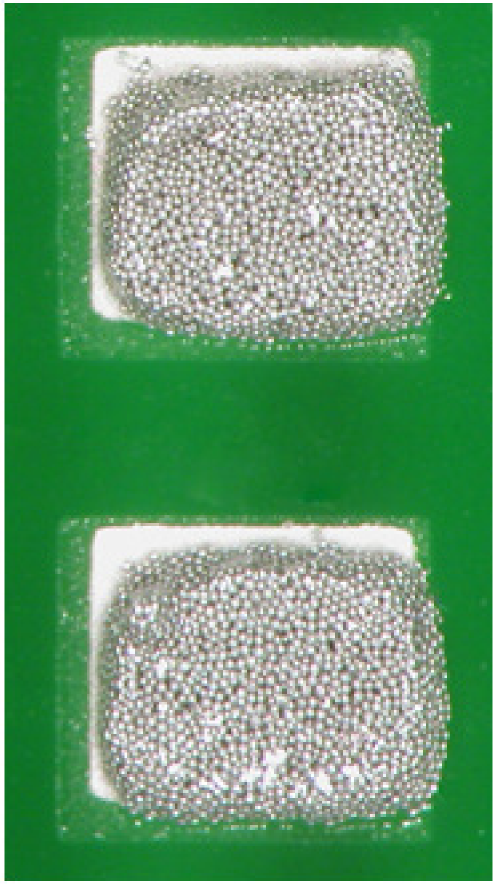
REFLOW SOLDERING TECHNOLOGY

The reflow soldering technology basically consists of three steps:

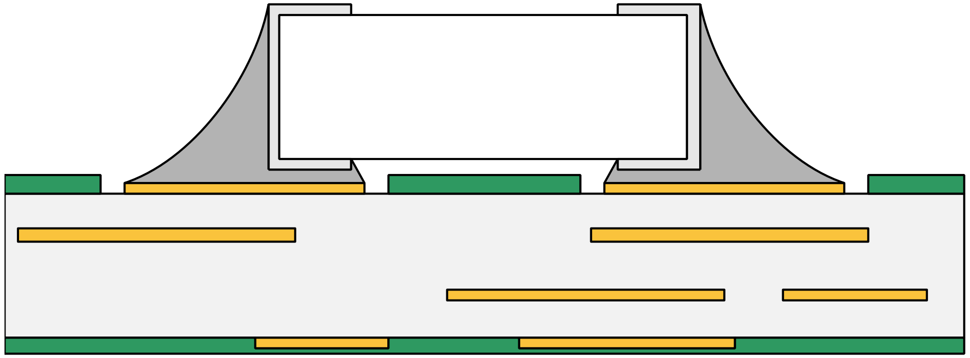
1. deposition of the solder paste
by dispensing (topic 1.2)
or by stencil printing

2. placement of the components
pick&place, collect&place,

3. remelting the solder alloy in the solder paste – usually in an oven.



Surface mounted resistor



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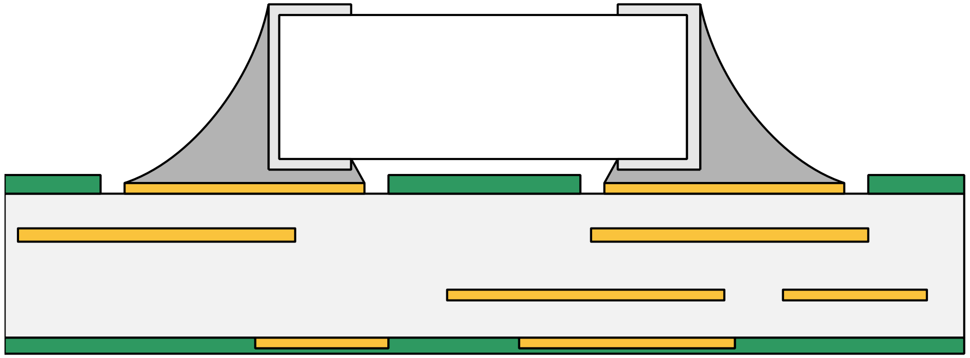

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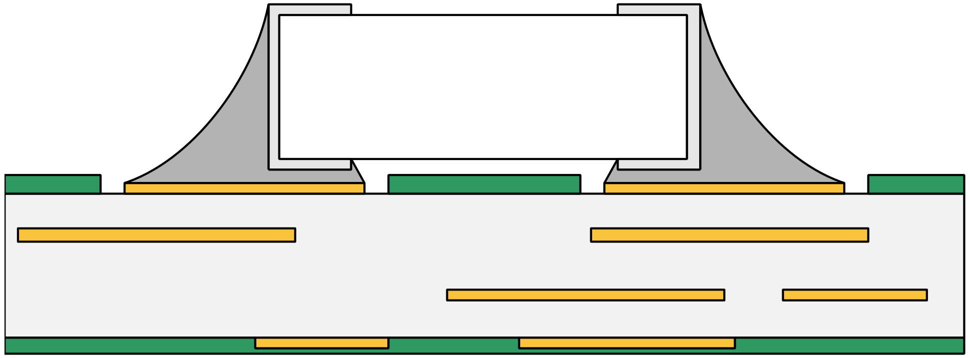
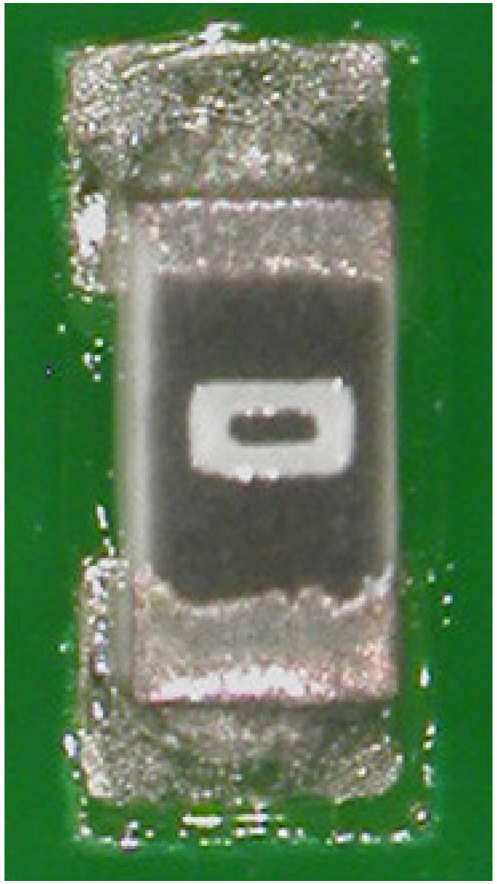
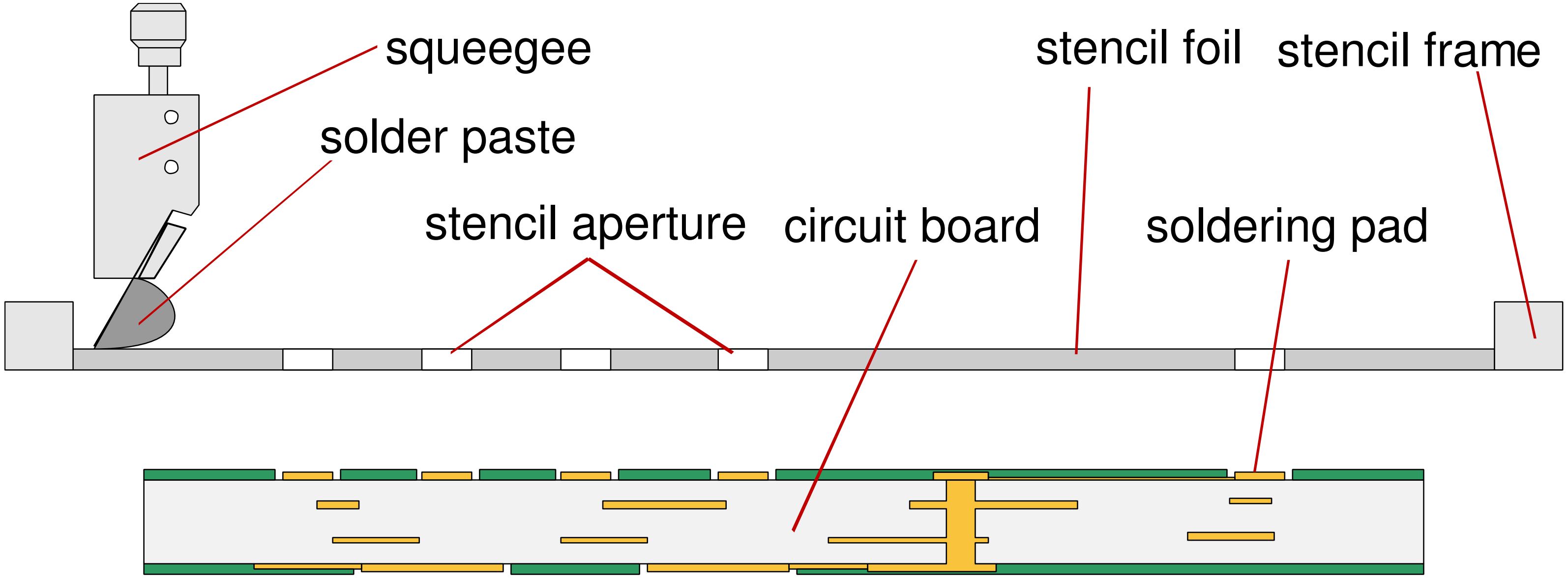




THE STENCIL PRINTING

The stencil applied for depositing the solder paste is a thin, 75–200 µm thick metal foil, on which apertures are formed according to the solder pads on the printed circuit board. Stencil printing provides a fast, mass solder paste deposition process; relatively expensive, appropriate and recommended for mass production.



PROCESS OF STENCIL PRINTING

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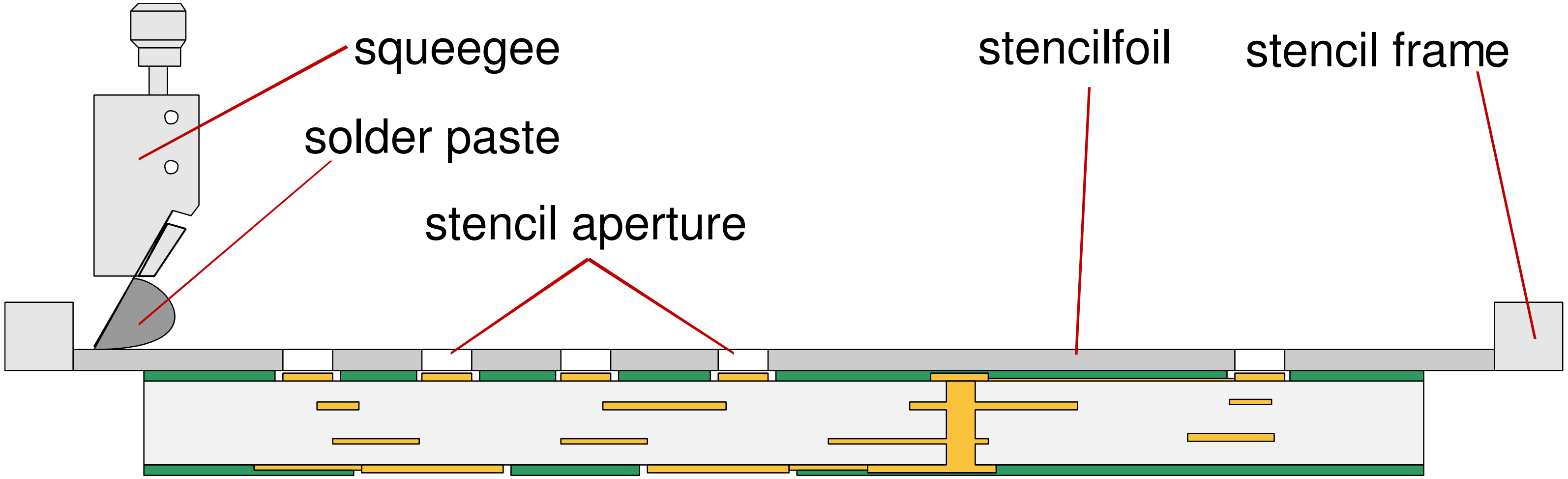
1. Aligning board to the stencil



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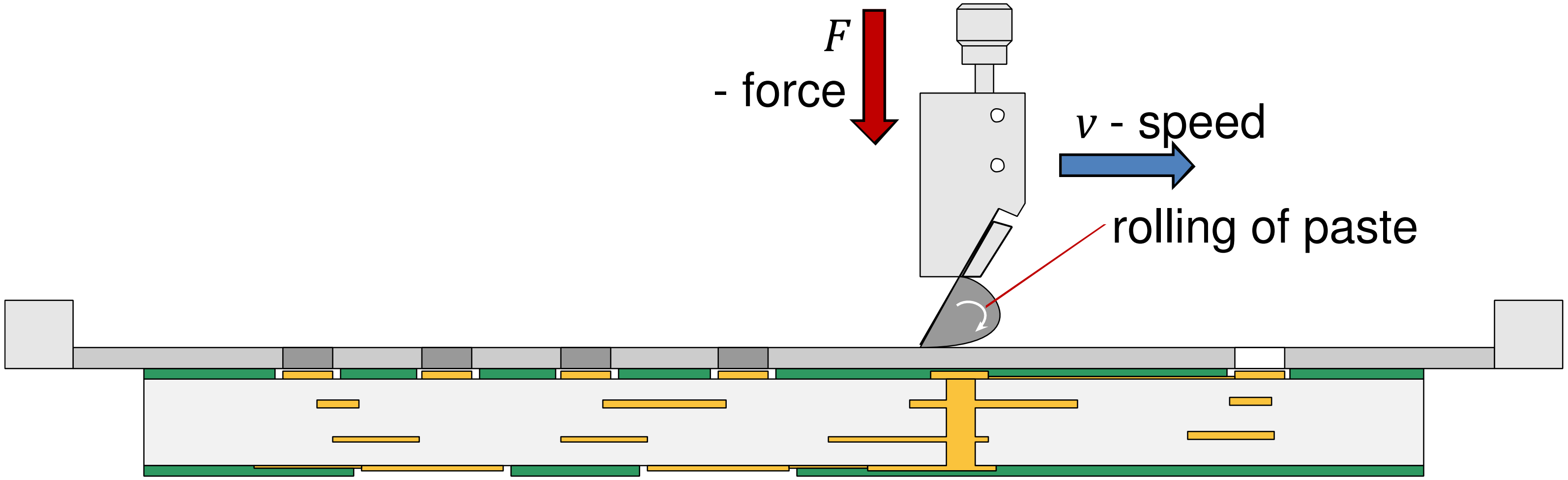
2. Moving squeegee on the stencil – filling apertures



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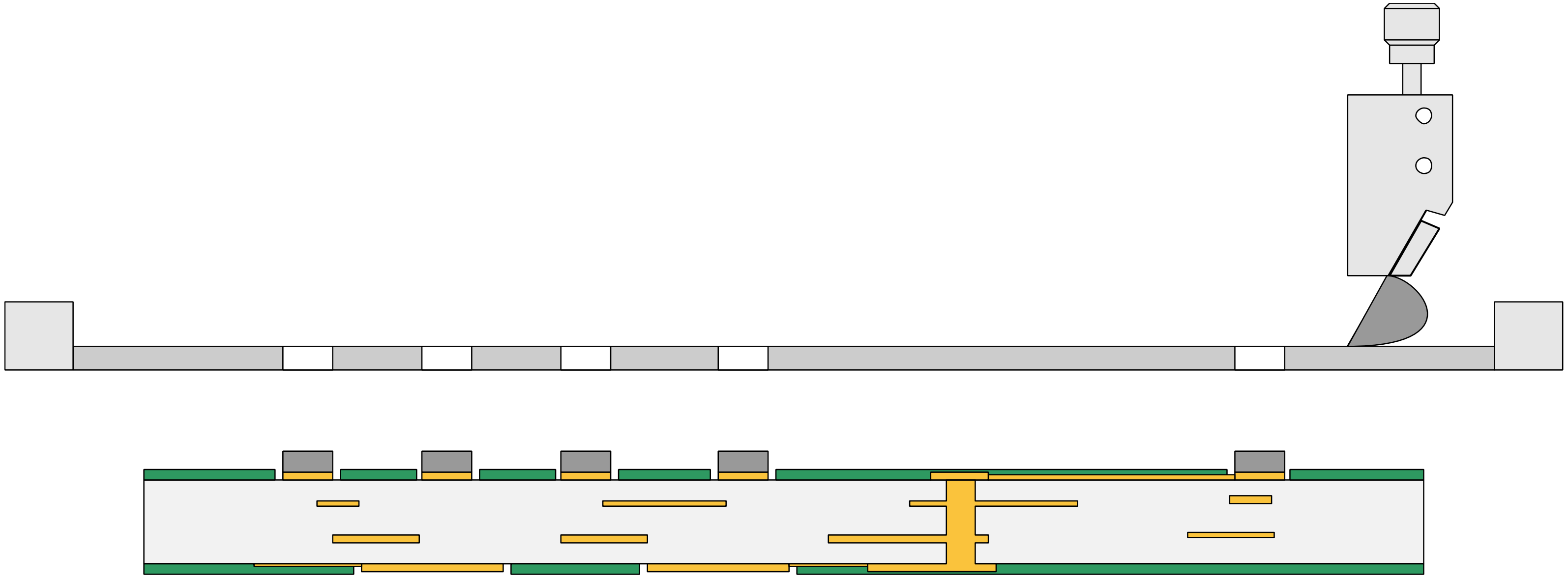
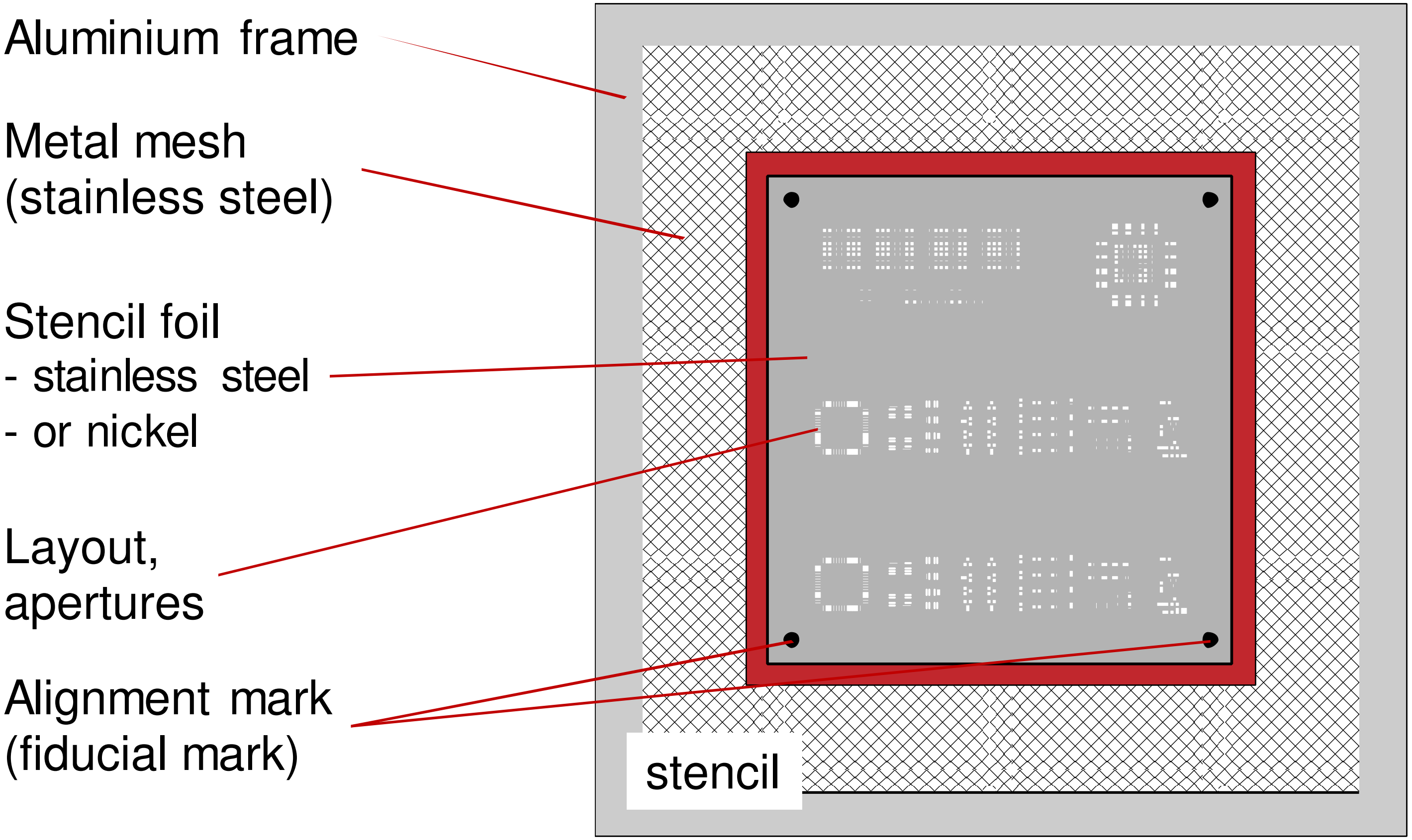
3. Separating stencil from the board



BUILD-UP OF STENCILS (TERMS)

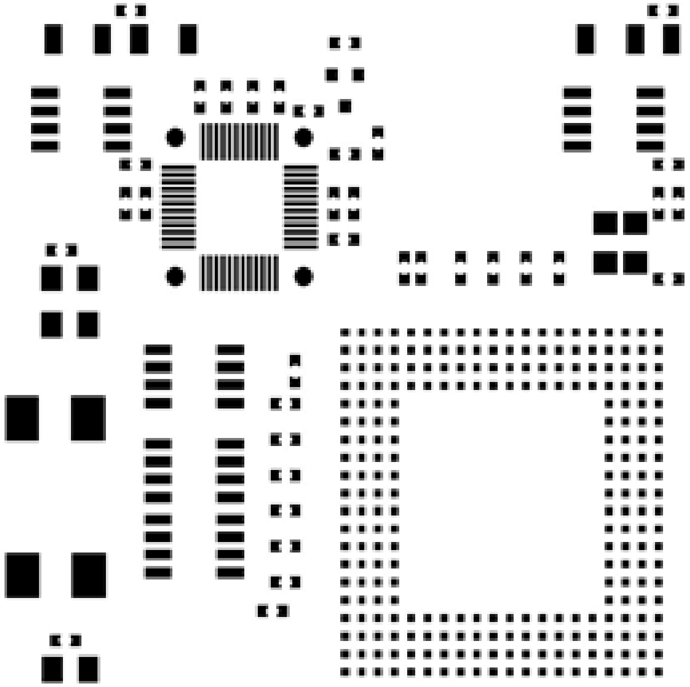
The stencil foil is tensioned and fixed to the frame by a metal mesh. The tension of stencil foil is around ~ 50 N/cm.



STENCIL MANUFACTURING TECHNOLOGIES

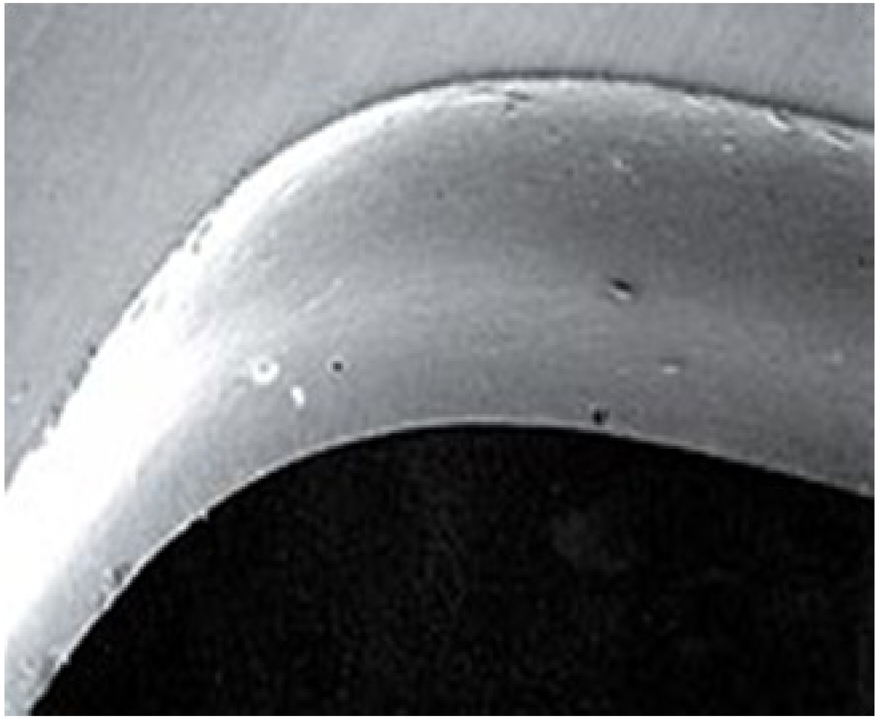
The main stencil manufacturing technologies are: chemical etching, laser cutting, electroforming.

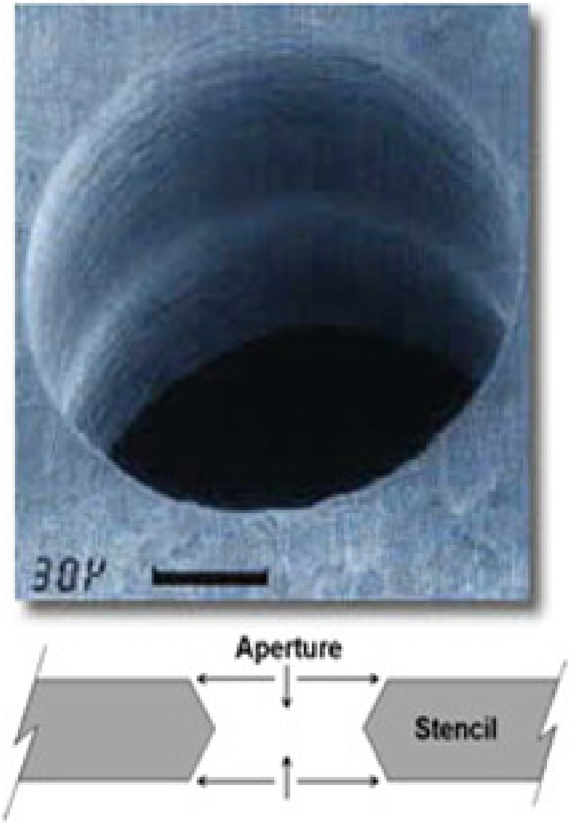
Stencils are mainly characterized by the quality of the aperture wall (the roughness of the wall.



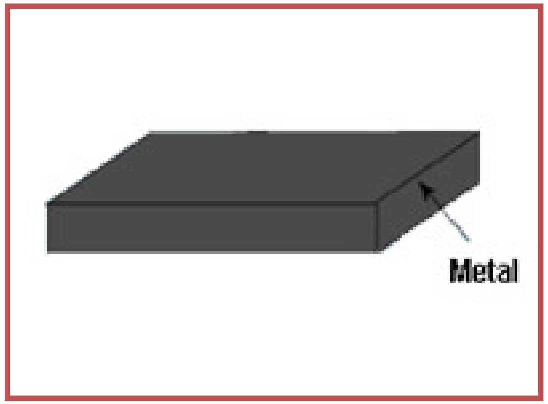
CHEMICAL ETCHED STENCILS

- Subtractive technology, low price ~ 40 EUR; the price is determined by the size of the stencil foil
- Hour-glass shape aperture, material: brass or bronze
- Appropriate for pitch size: >0.63 mm





STEPS OF CHEMICAL ETCHING



Chemically cleaned surface

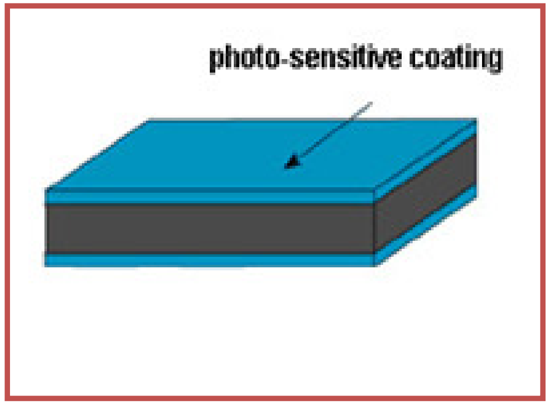
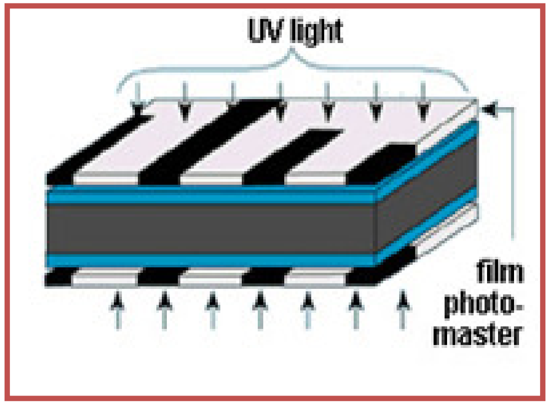
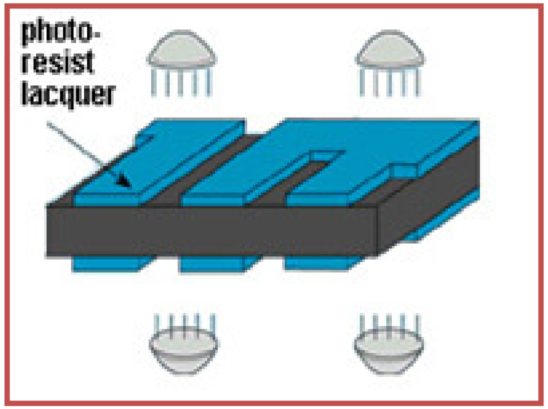


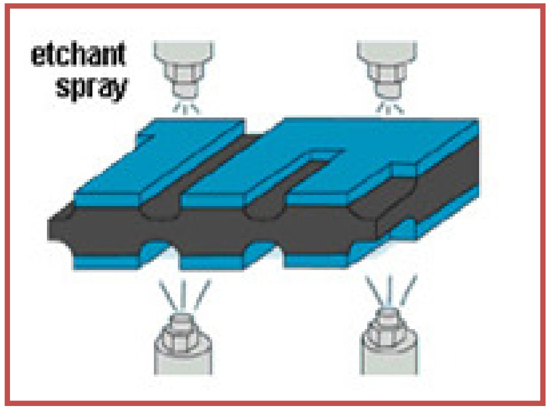
Photo sensitive coating applied to top and bottom



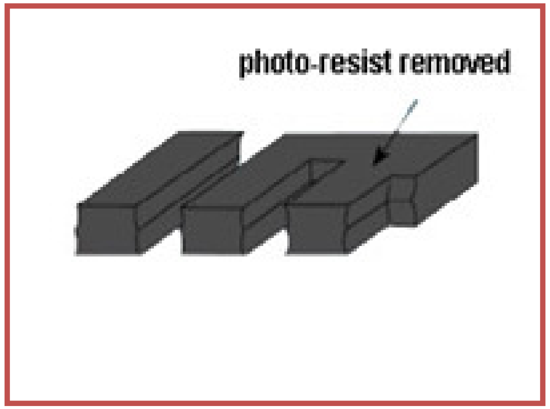
Developing solved photo-resist



Rinsing off photo-resist



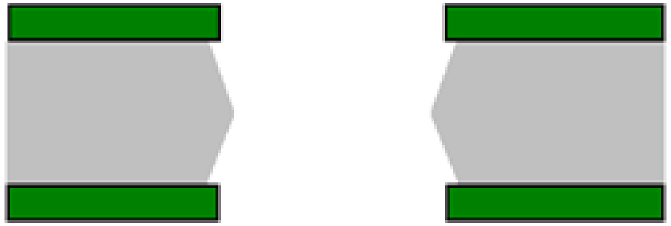
Etching of metal



Complete etched product

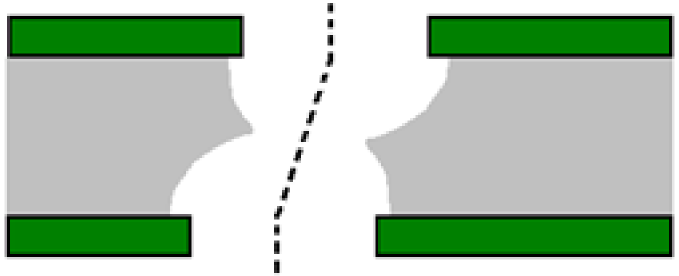
CROSS-SECTION OF CHEMICAL ETCHED STENCIL APERTURES

Single-side etching – high degree of undercutting



Double-side etching – „hour glass” cross-section

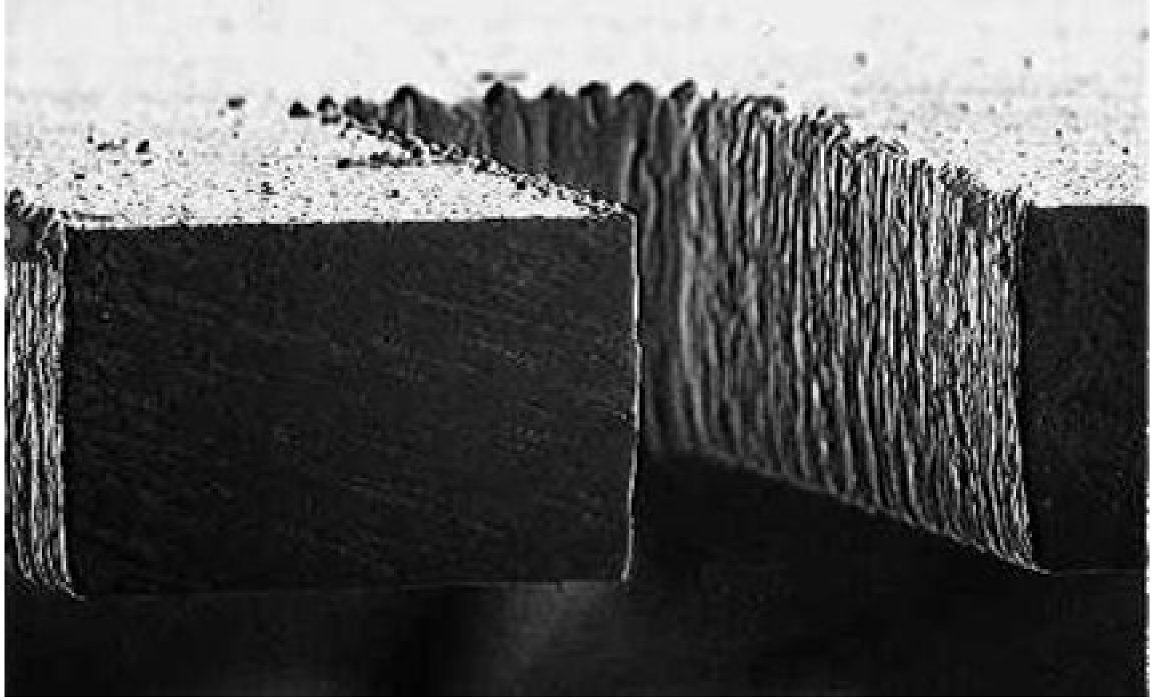
Single-side etching – formation of „knife-edge”

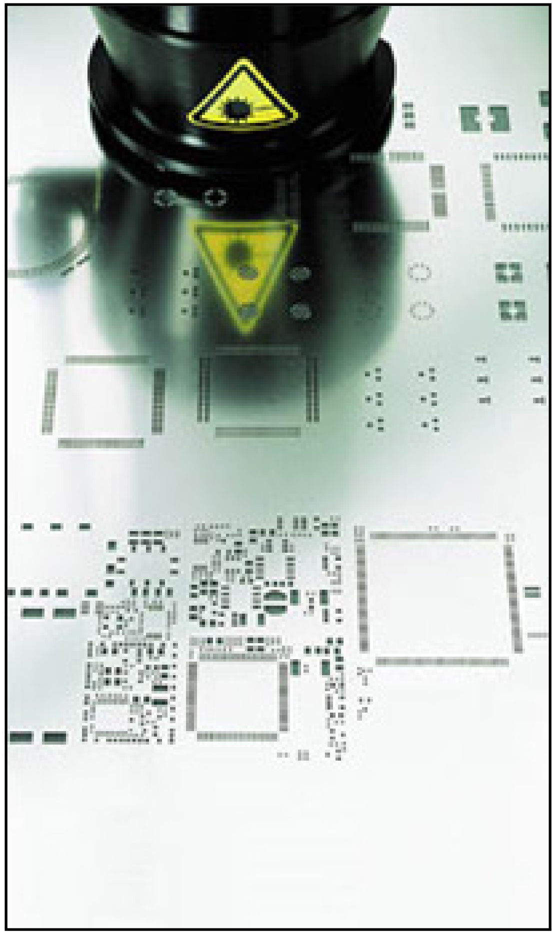


Misalignment of phototools between the two sides

LASERCUT STENCILS

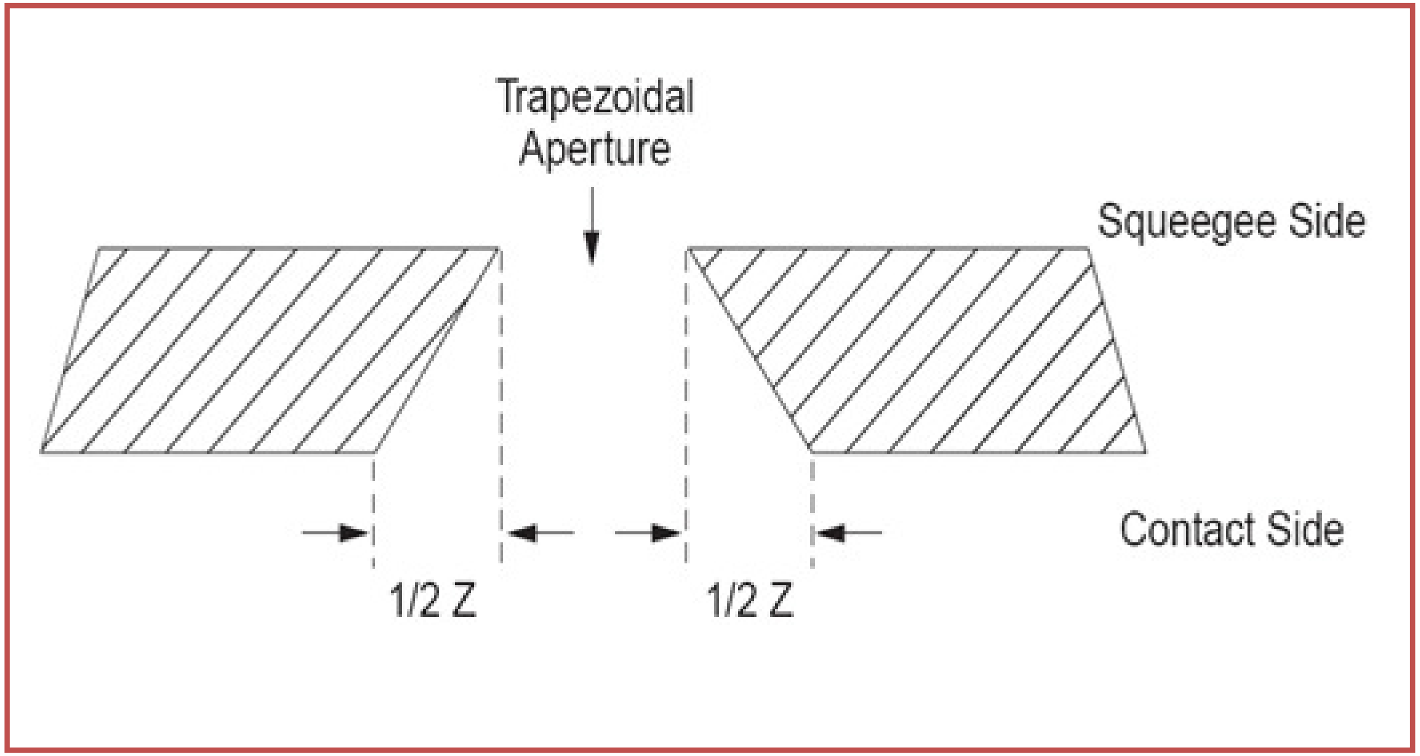
- Subtractive technology, the price is determined by the amount of apertures: ~300 EUR
- Trapezoidal aperture
- Material: nickel or stainless steel
- Appropriate for pitch size: >0.4 mm.





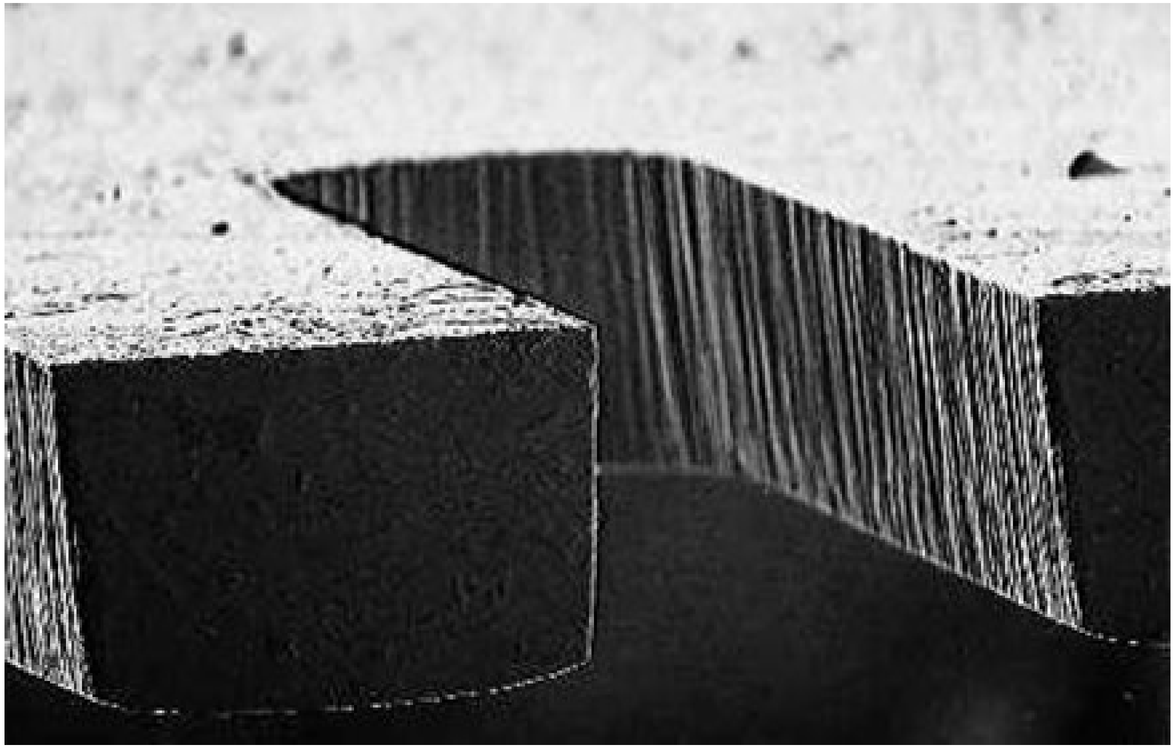
LASERCUT STENCILS

A trapezoidal aperture enhances the solder paste release. The aperture openings actually are cut from the contact side of the stencil. The stencil then is flipped and mounted with the squeegee side up.

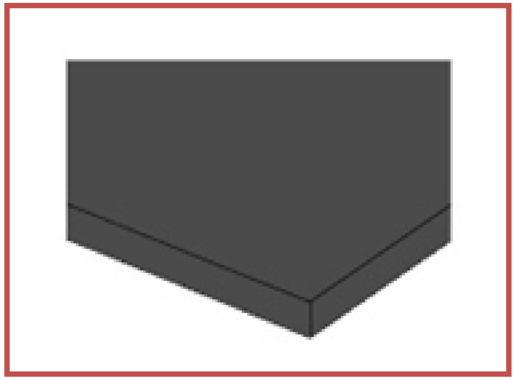


ELECTROFORMED STENCILS

- Additive technology, the price is determined by the thickness of the stencil foil: ~1200 EUR
- Trapezoidal aperture
- Material: nickel
- Appropriate for pitch size up to: 0.2 mm



ELECTROFORMED STENCILS



Metal substrate, cleaned and degreased

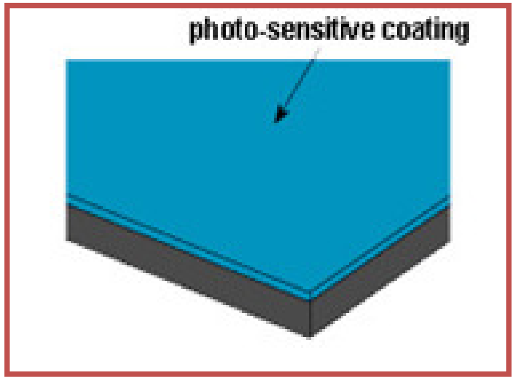
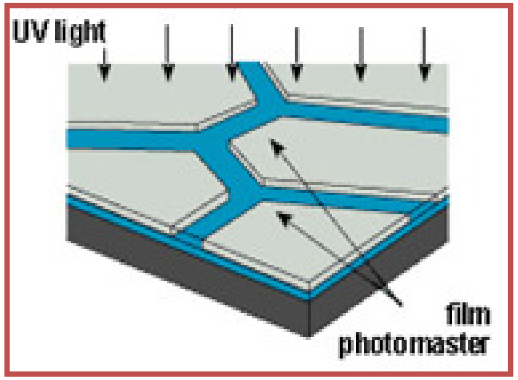
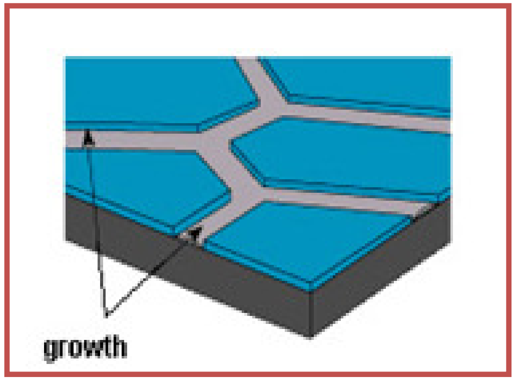


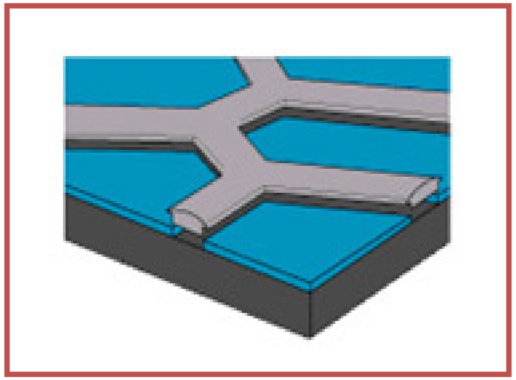
Photo-sensitive coating applied



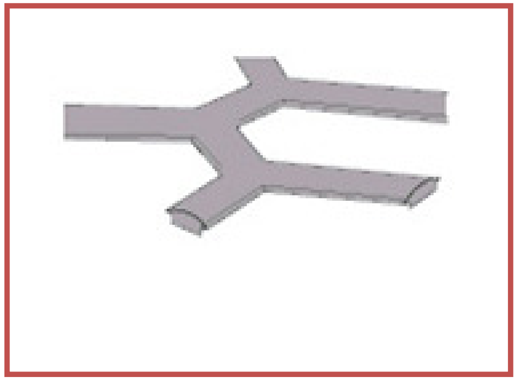
Developing and rinsing off solved photo-resist



Electro deposition of metal



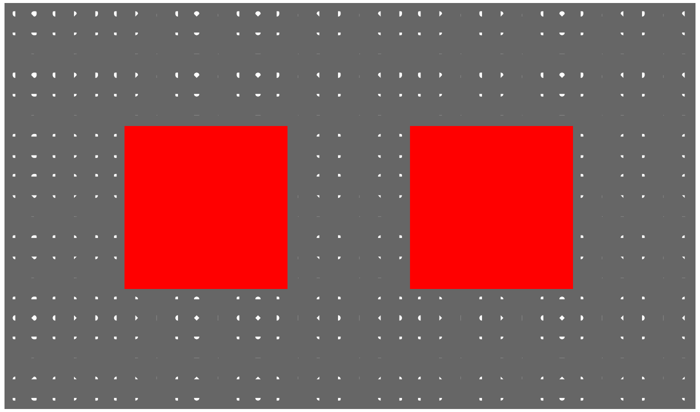
Separation of stencil



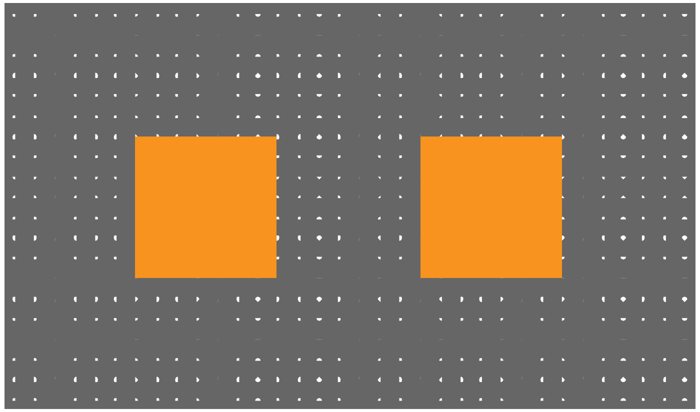
Complete stencil

STENCIL DESIGN

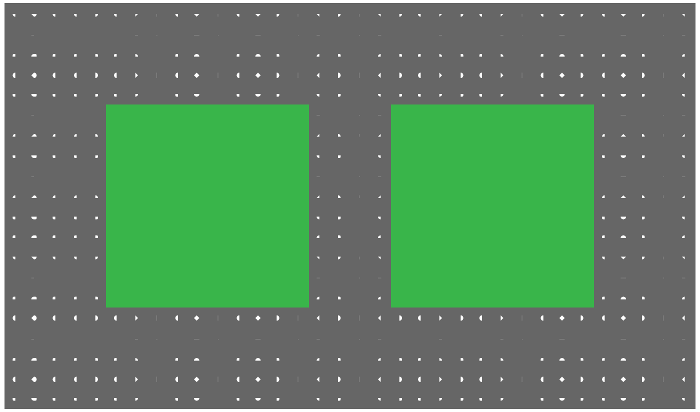
Top (Cu) layer – positive



Solder paste layer – negative



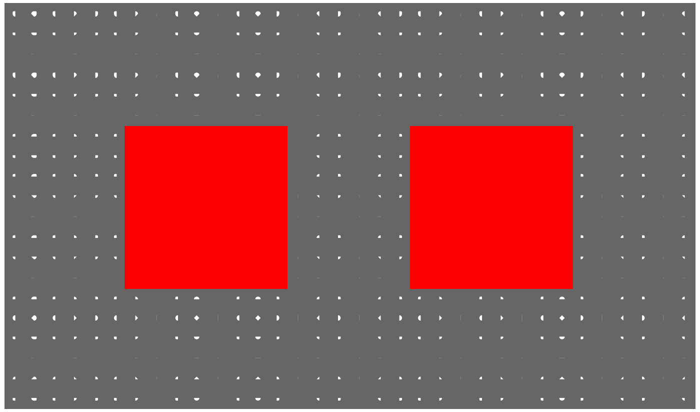
Solder mask layer – negative



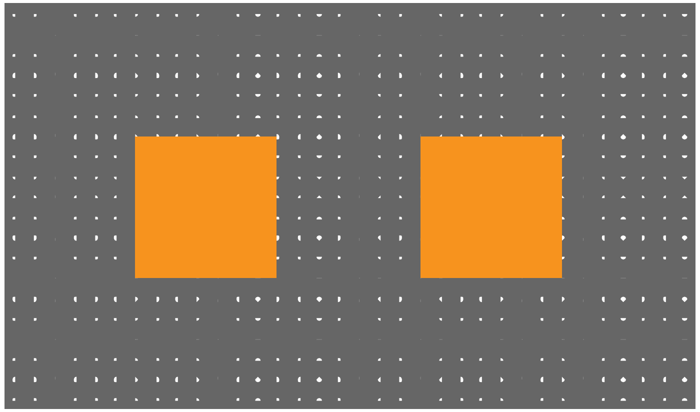
FR4 board with copper pads

STENCIL DESIGN

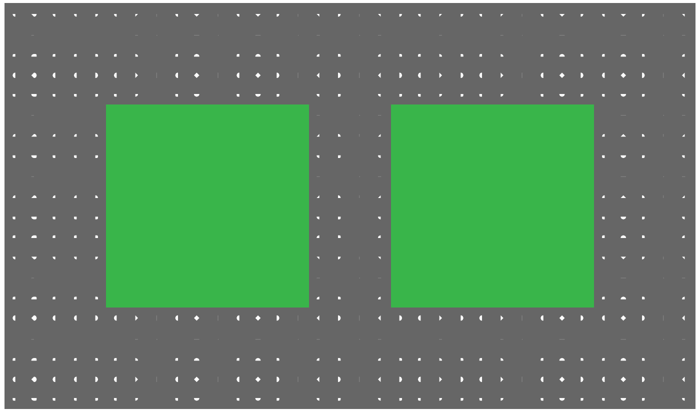
Top (Cu) layer – positive



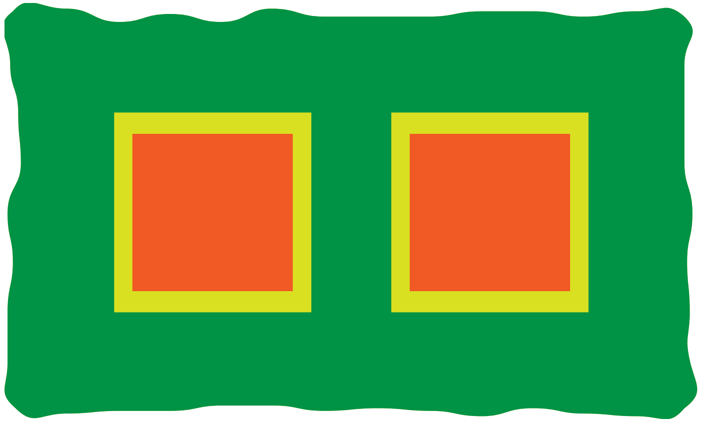
Solder paste layer – negative



Solder mask layer – negative

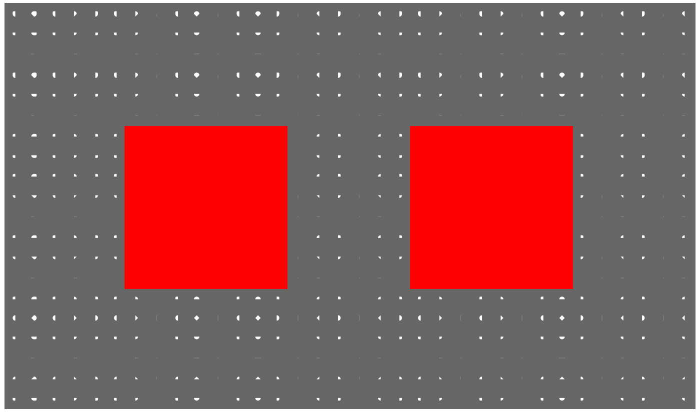


Copper pads and solder mask

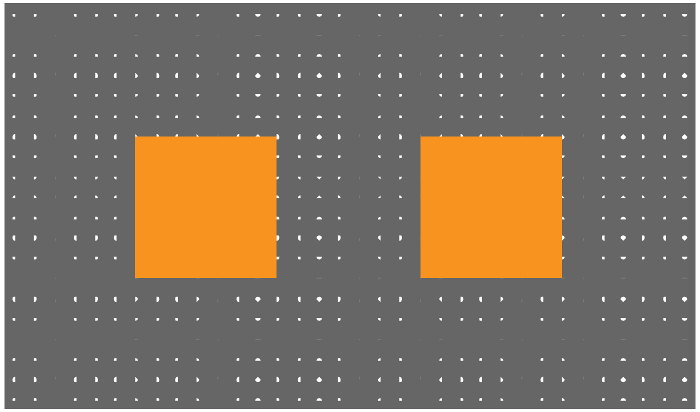


STENCIL DESIGN

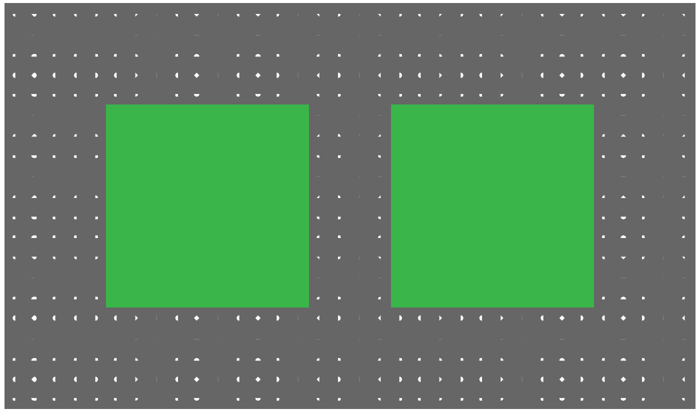
Top (Cu) layer – positive



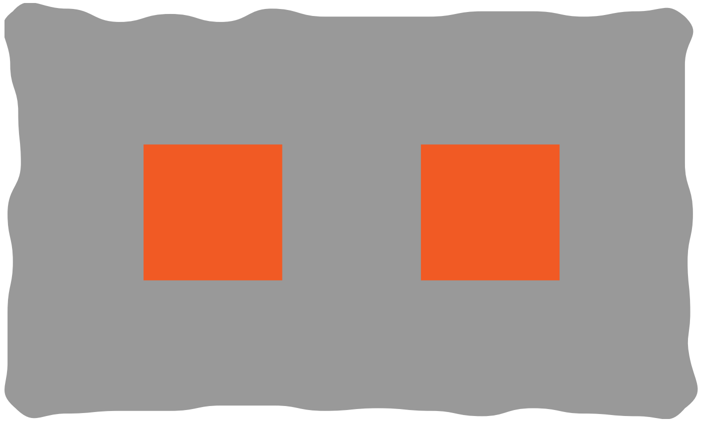
Solder paste layer – negative



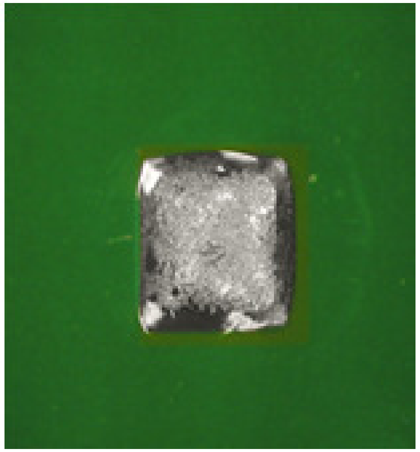
Solder mask layer – negative

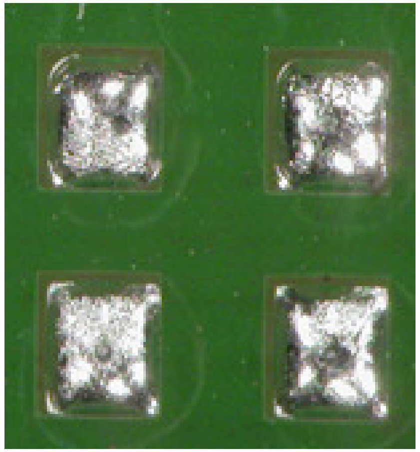


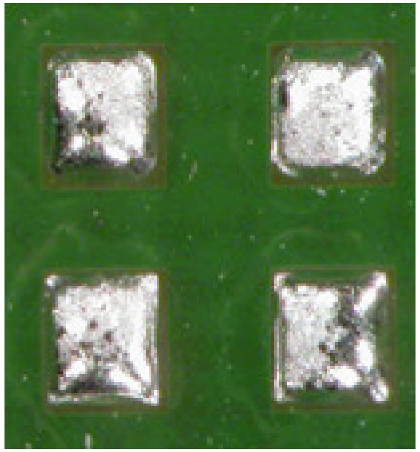
Copper pads with aligned stencil



BASIC STENCIL DESIGN GUIDELINES FOR SMD COMPONENTS


Ni/Au – 10% reduction

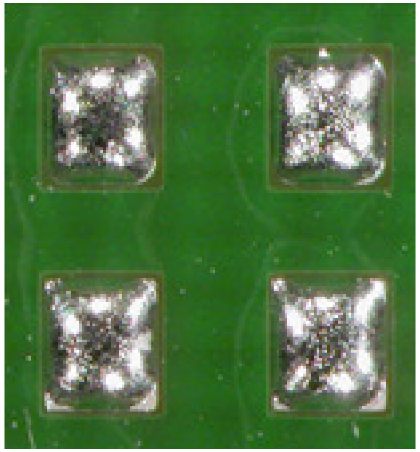

ImAg – 10% reduction

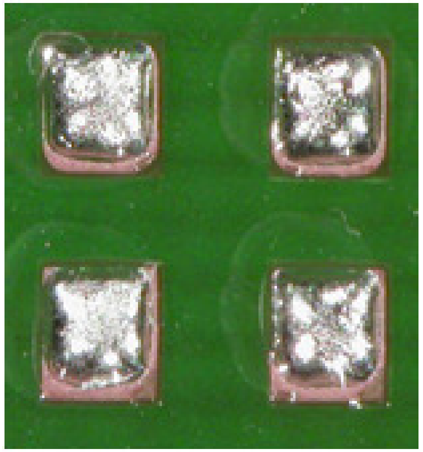

LF HASL – 10% reduction

The possibility of aperture reduction depends on the solder alloy

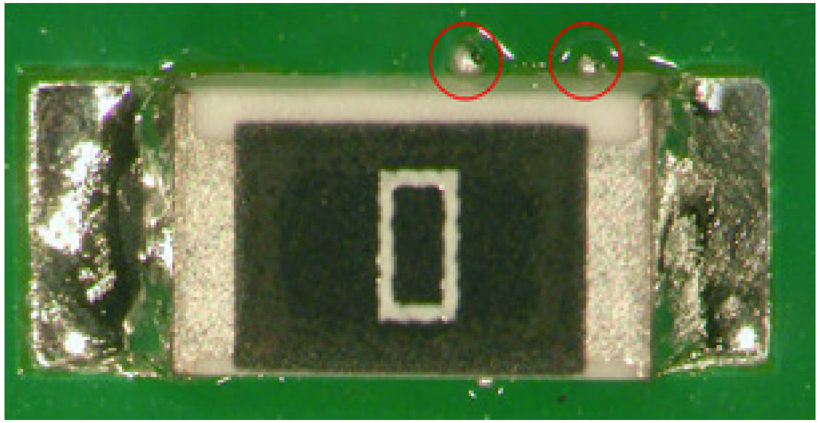
Leaded alloy: reduction is always possible

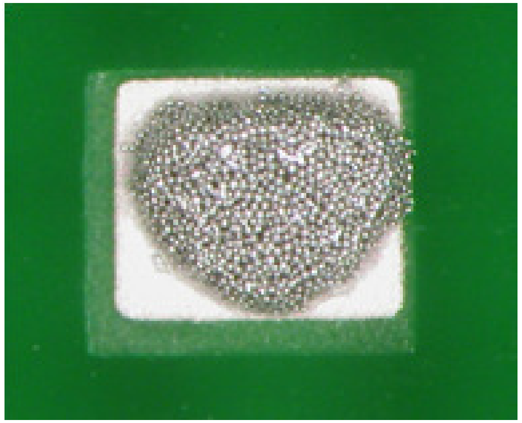
Lead-free alloy: reduction is possible only in case of PCB finishes with good wettability

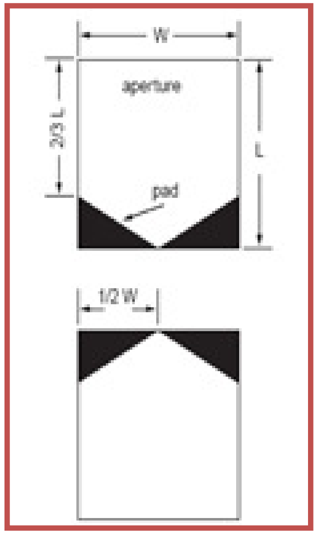

ImSn – no reduction


OSP – no reduction

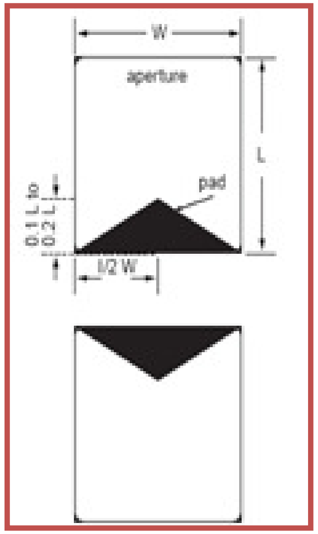
STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



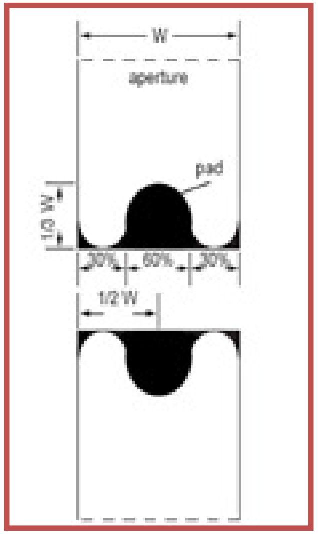




Home-plate

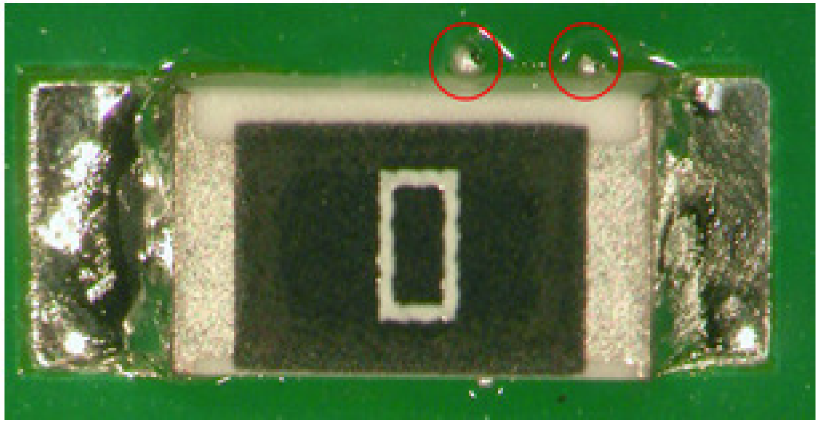


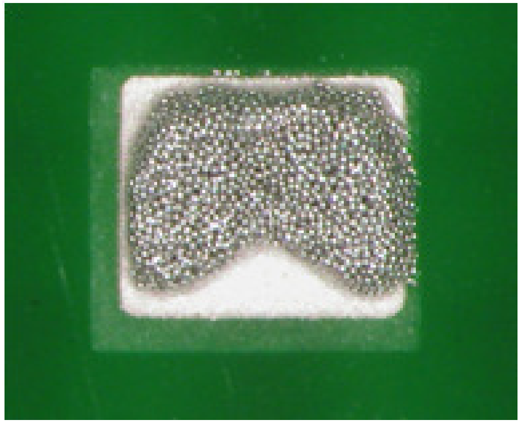
Inverse home-plate

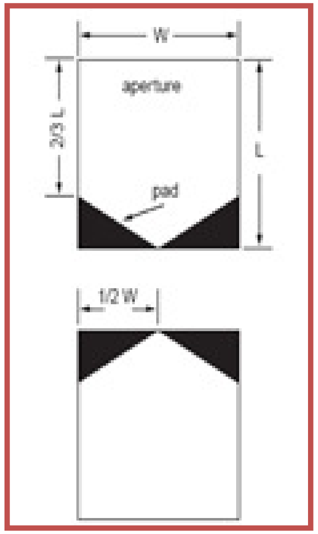


Rounded inverse home-plate

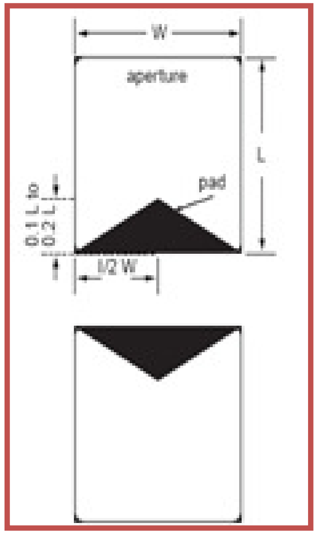
STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



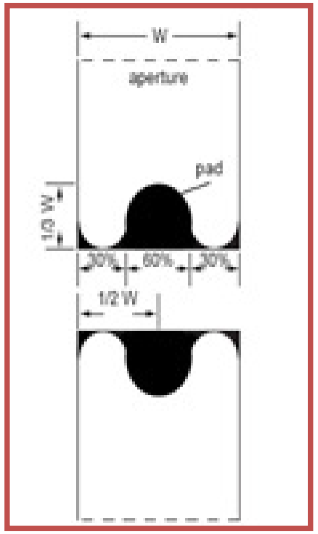




Home-plate

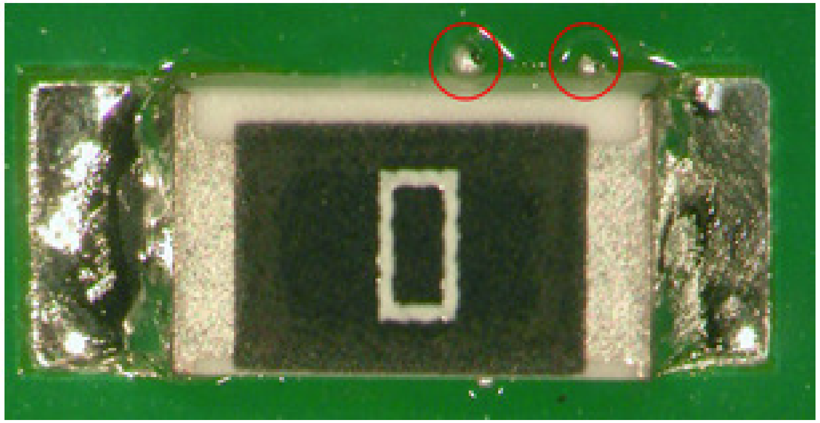


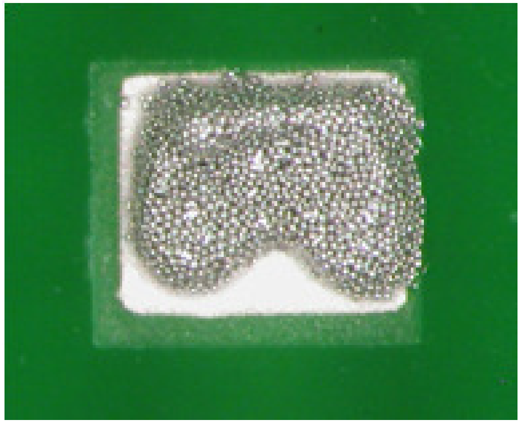
Inverse home-plate

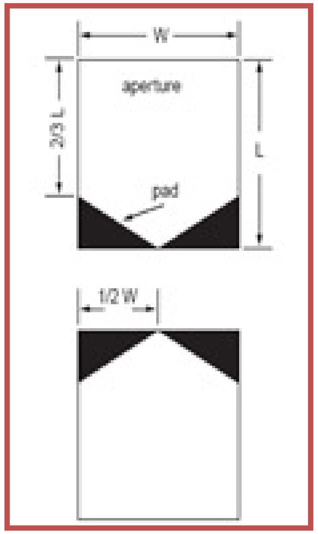


Rounded inverse home-plate

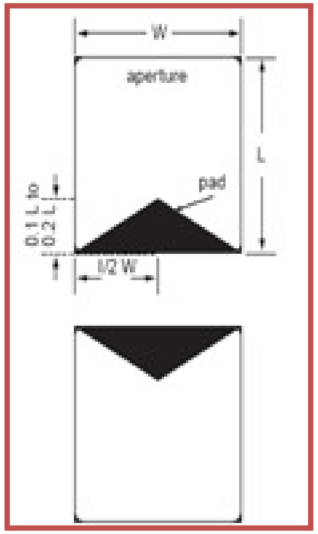
STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



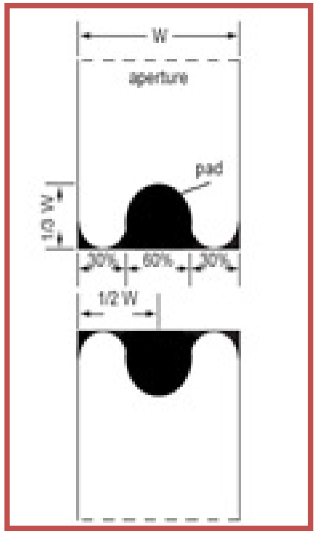




Home-plate



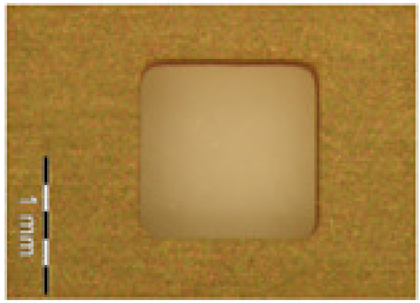
Inverse home-plate



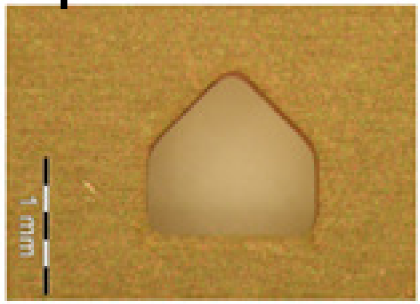
Rounded inverse home-plate

EXPERIMENTAL ON SOLDER BALLING

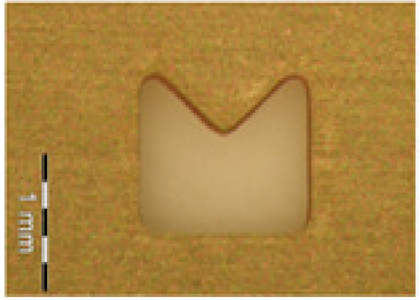
Square



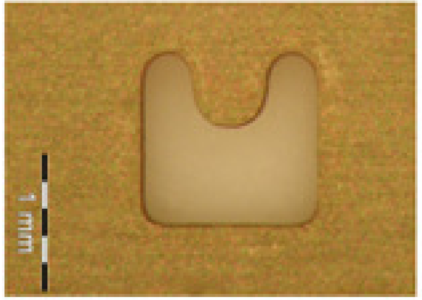
„Home-plate”



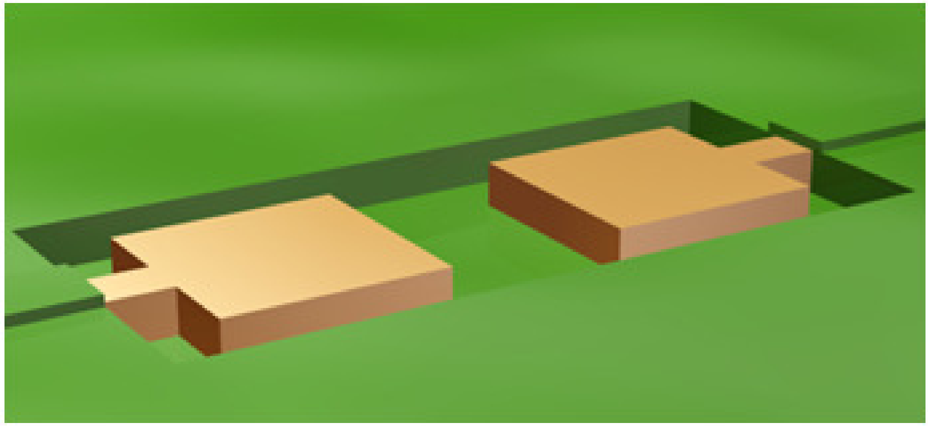
Inverse „home-plate”



Rounded inverse „home-plate”

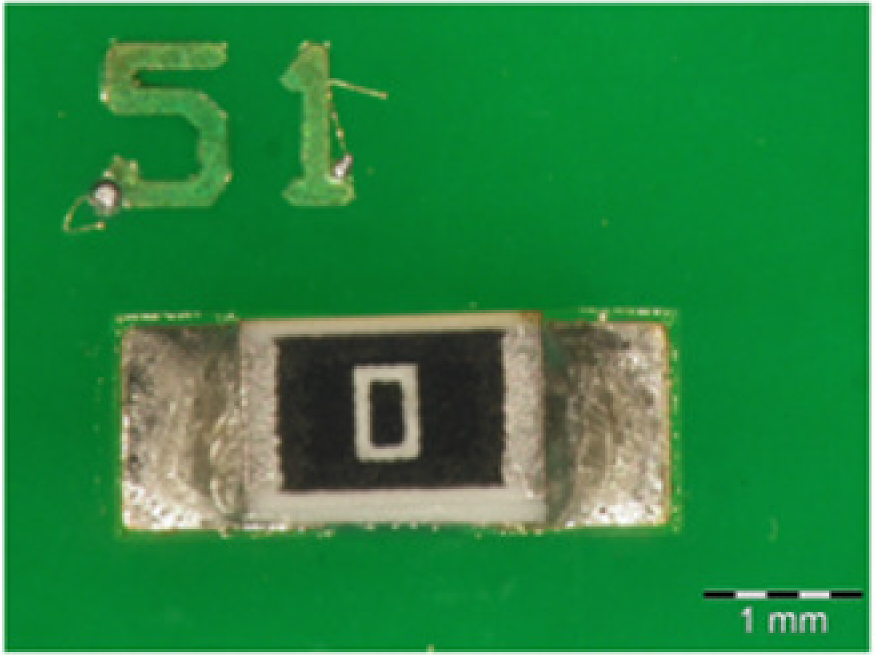


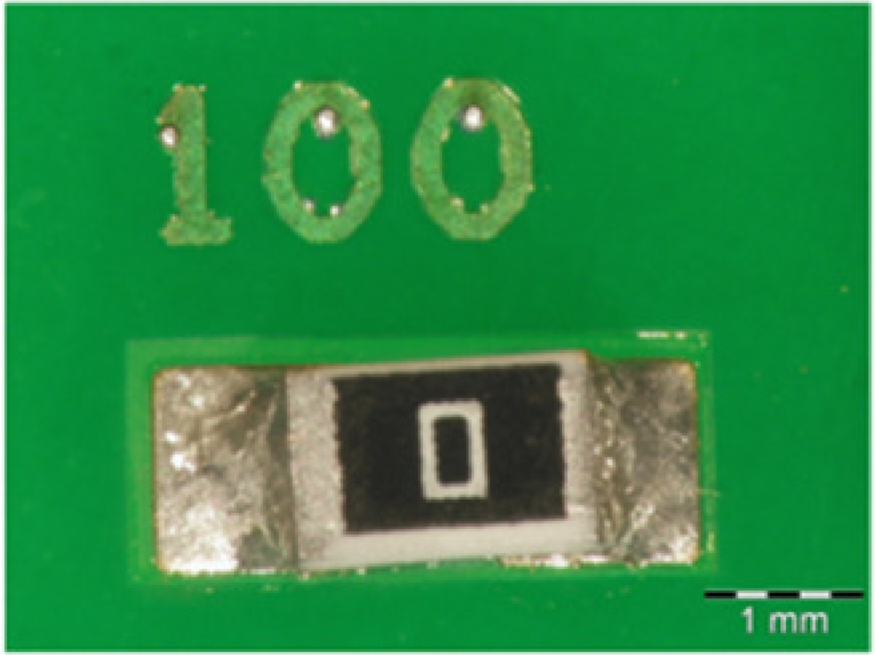
Stencil manufacturer’s recommendation – no solder mask bridge between the solder pads



- Lower solder balling
- No decrease in joint strength

RESULTS OF THE EXPERIMENT





	Square	„Home-plate”	Inverse „home-plate”	Rounded inverse „home-plate”	No bridge on solder mask
Solder balls	**60**	**31**	**20**	**30**	**50**

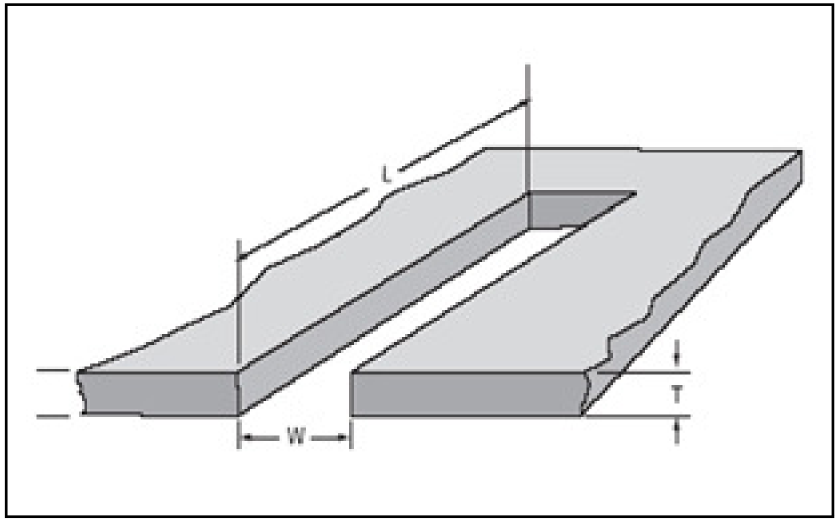
STENCIL DESIGN FOR FINE-PITCH COMPONENTS

- Transfer efficiency: ratio between the volume of the deposited paste and the volume of the aperture. It is determined by three main factors from the viewpoint of the stencil itself:
- **Manufacturing technology of the stencil**
- **Aspect ratio** (AS): length of aperture's shorter side divided by the thickness of the foil. Should be greater than 1.5
- **Area ratio** (AR): the ratio between the area and the wall surface of the aperture. Should be greater than 0.66

$$TE = \frac{Applied\_paste\_volume}{Aperture\_volume}$$

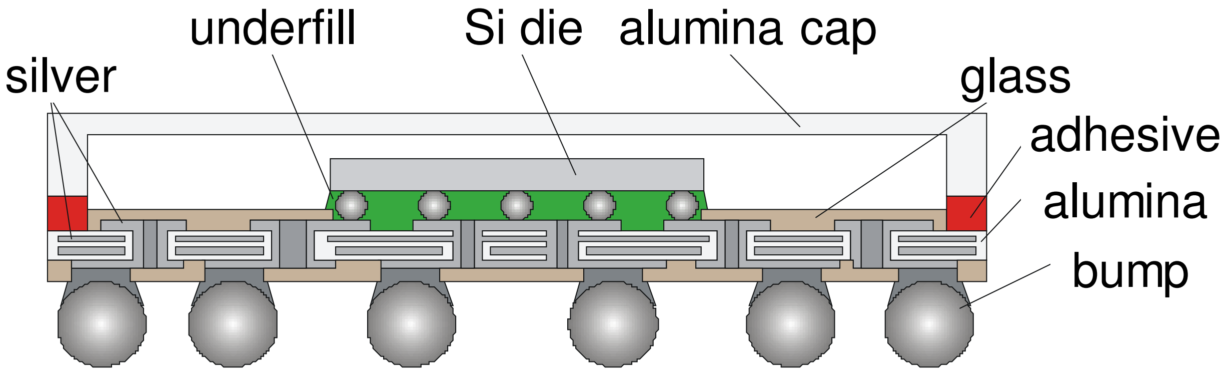
$$AR = \frac{Pad\_area}{Aperture\_wall\_area} = \frac{W \cdot L}{2 \cdot (W+L) \cdot T}$$

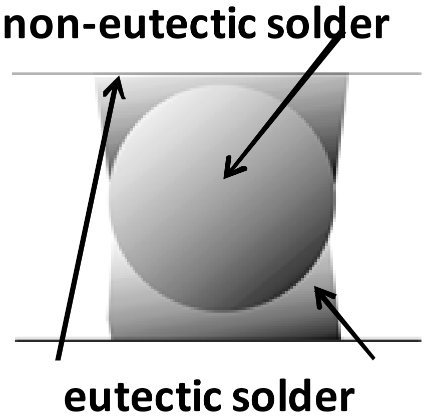
$$AS = \frac{Aperture\_width}{Stencil\_foil\_thickness} = \frac{W}{T}$$



BGA PACKAGES – PBGA, CBGA

- PBGA – Plastic Ball Grid Array
- Alloy of the solder bump is eutectic (Sn63Pb37, SAC305, SAC387)
- Material of the package is epoxy
- Interposer is FR4 or BT (Bismaleimide Triazin)
- Higher CTE mismatch to silicon, lower reliability (FR4, BT CTE ~14-18 ppm/°C)
- CBGA – Ceramic Ball Grid Array
- Alloy of the solder bump generally is non-eutectic (Sn10Pb90 – 302 °C , Sn80Au20 – 280 °C)
- Material of the package is ceramic or alumina
- Lower CTE mismatch, higher reliability (alumina CTE ~6 ppm/°C)





STENCIL DESIGN FOR BGA PACKAGES

PBGA package

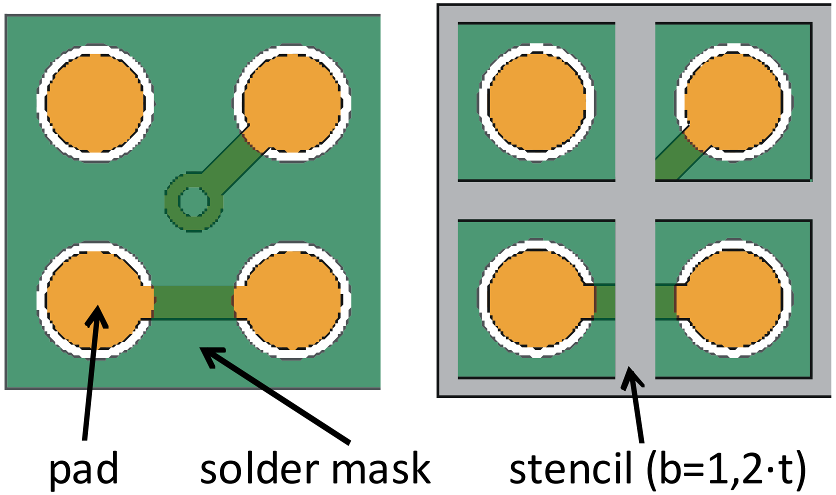
- Square aperture with side length equal to the diameter of pads
- Foil thickness considerations as below
- CSP – take care of particle diameter in paste

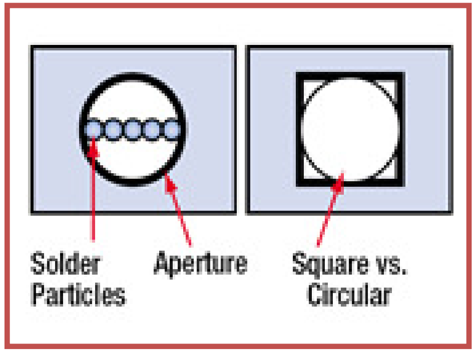
$$AR = \frac{W \cdot L}{2 \cdot (W + L) \cdot T} \geq 0.66$$

$$\Rightarrow T \leq \frac{W \cdot L}{2 \cdot (W + L) \cdot 0.66}$$

CBGA package - <u>overprinting</u>

- Min. width of bridge between apertures: 1.2·*foil_thickness*

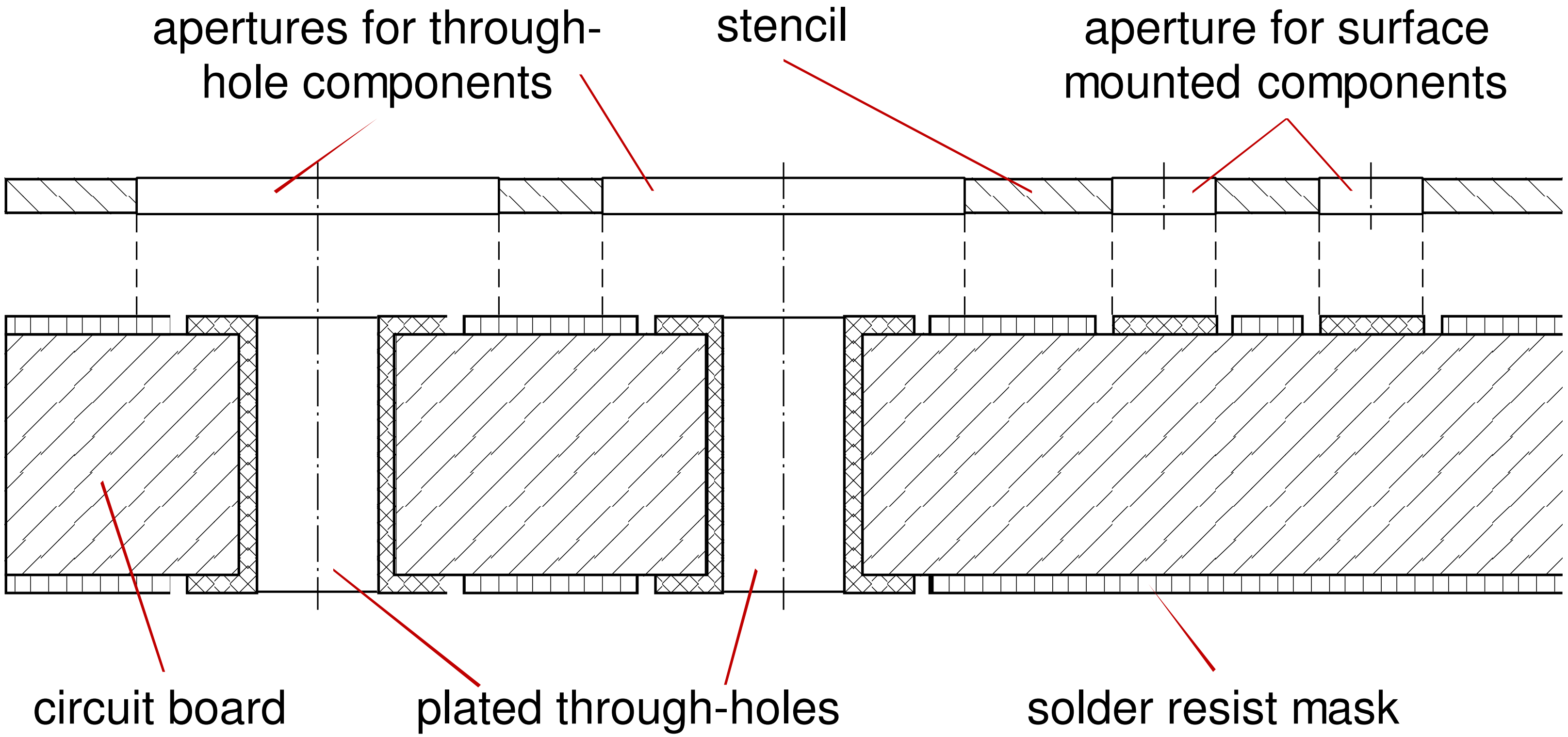




Type	Diameter of solder particles	
	>90%	<1% greater than:
Type 3	45 µm…25 µm	45 µm
Type 4	38 µm…20 µm	38 µm
Type 5	25 µm…15 µm	25 µm
Type 6	15 µm…5 µm	15 µm

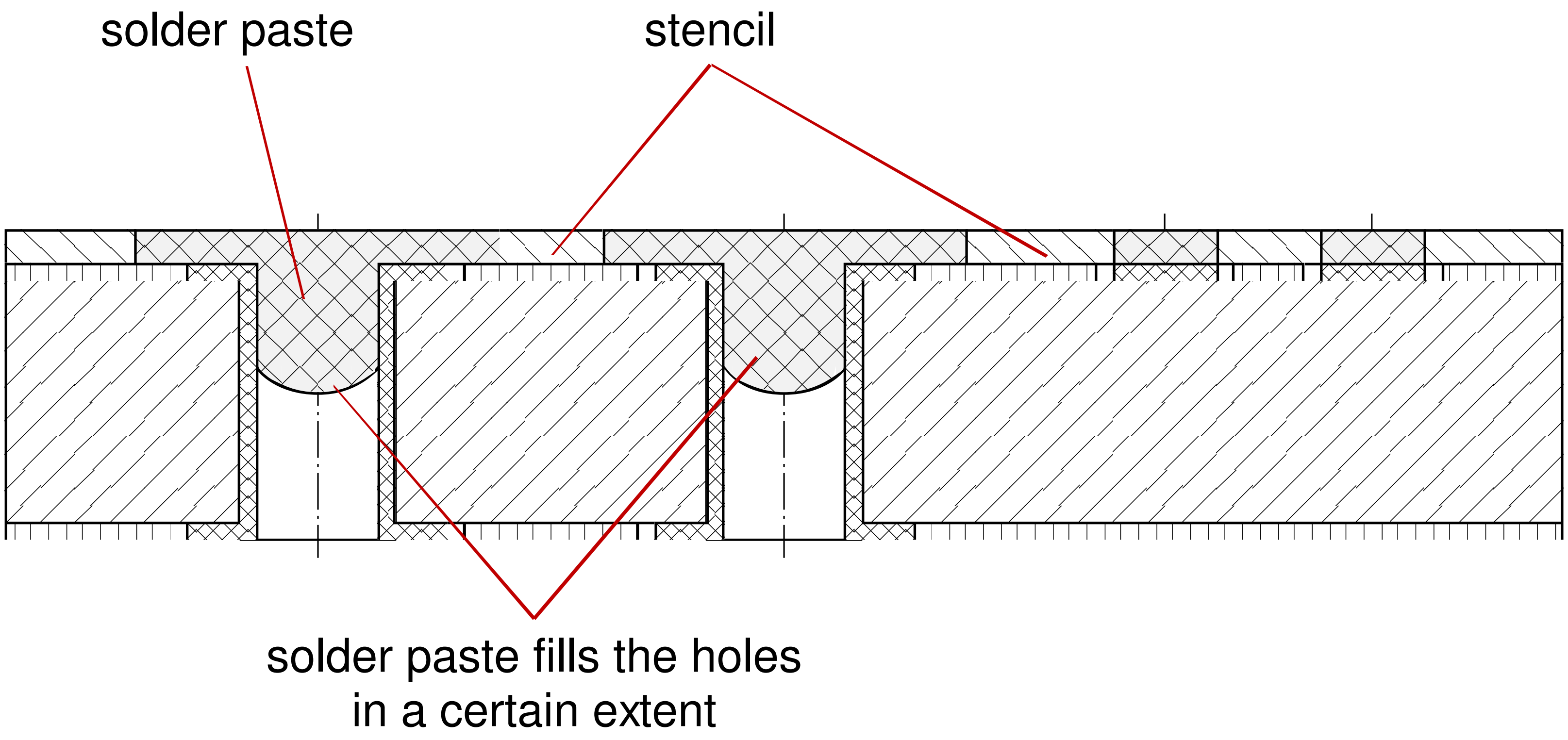
STEPS OF THE „PIN IN PASTE" TECHNOLOGY

0. Starting



STEPS OF THE „PIN IN PASTE" TECHNOLOGY

1. Stencil printing

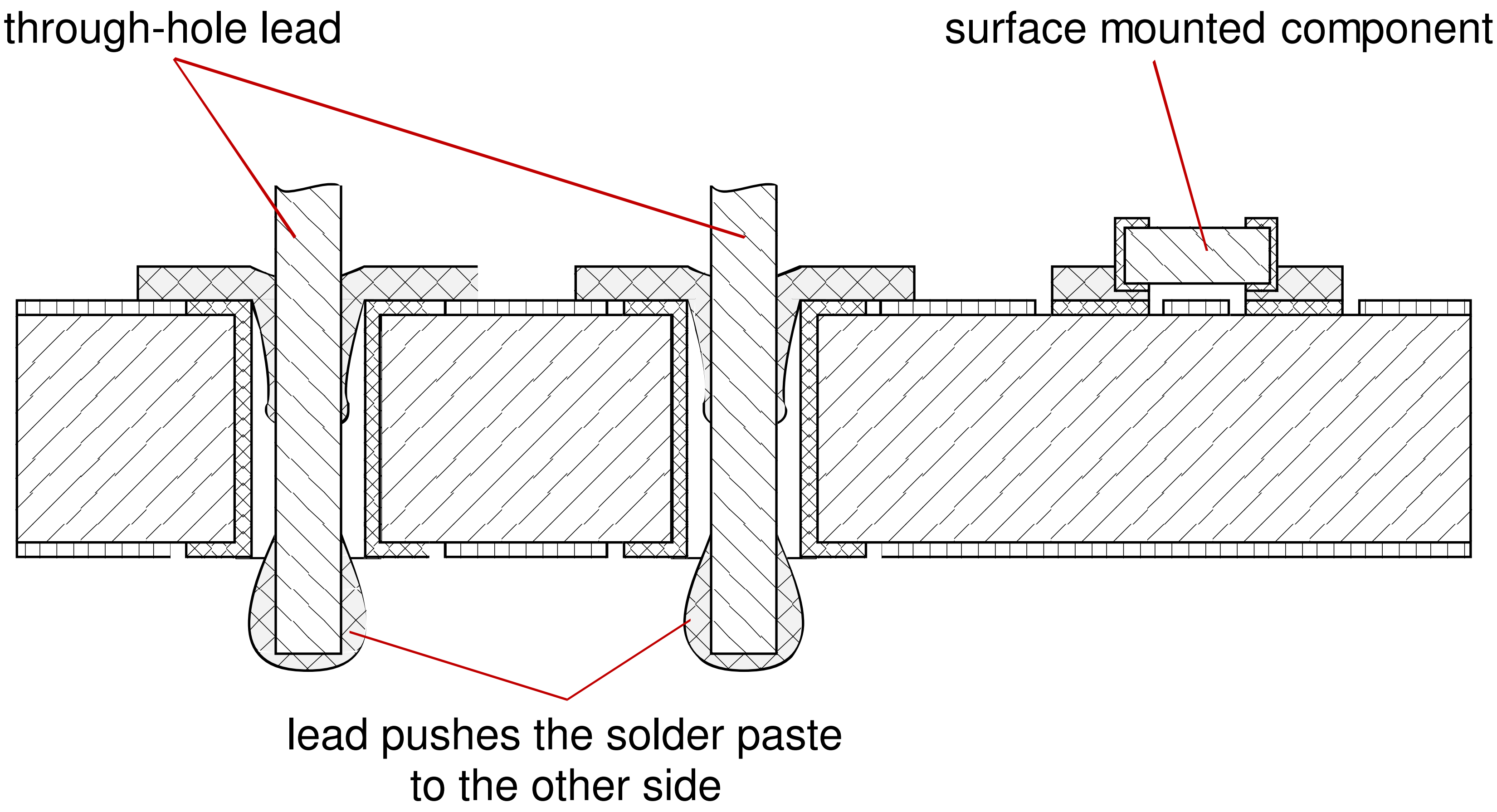

solder paste

stencil

solder paste fills the holes in a certain extent

STEPS OF THE „PIN IN PASTE" TECHNOLOGY

2. Component placement



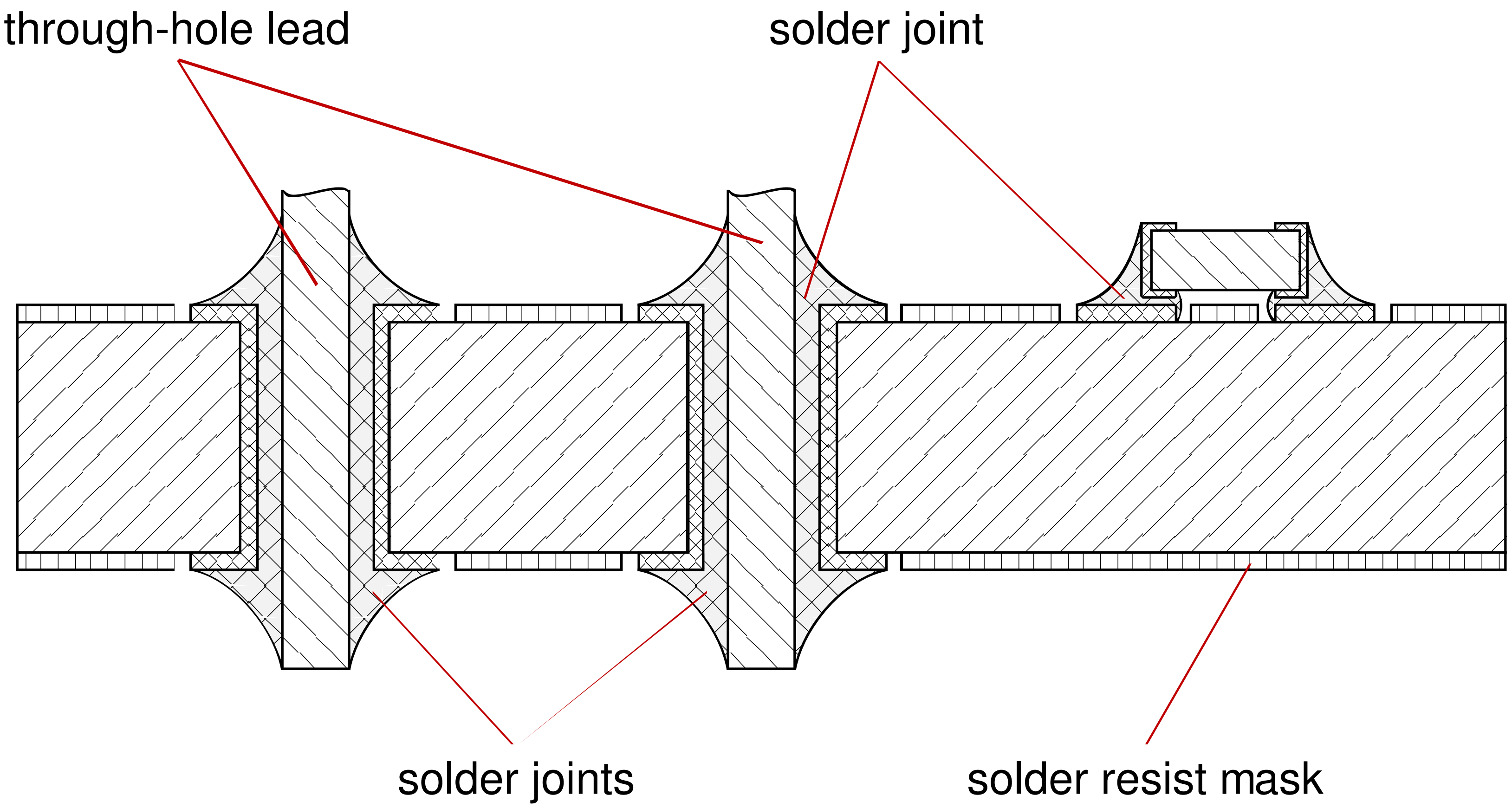
through-hole lead

surface mounted component

lead pushes the solder paste to the other side

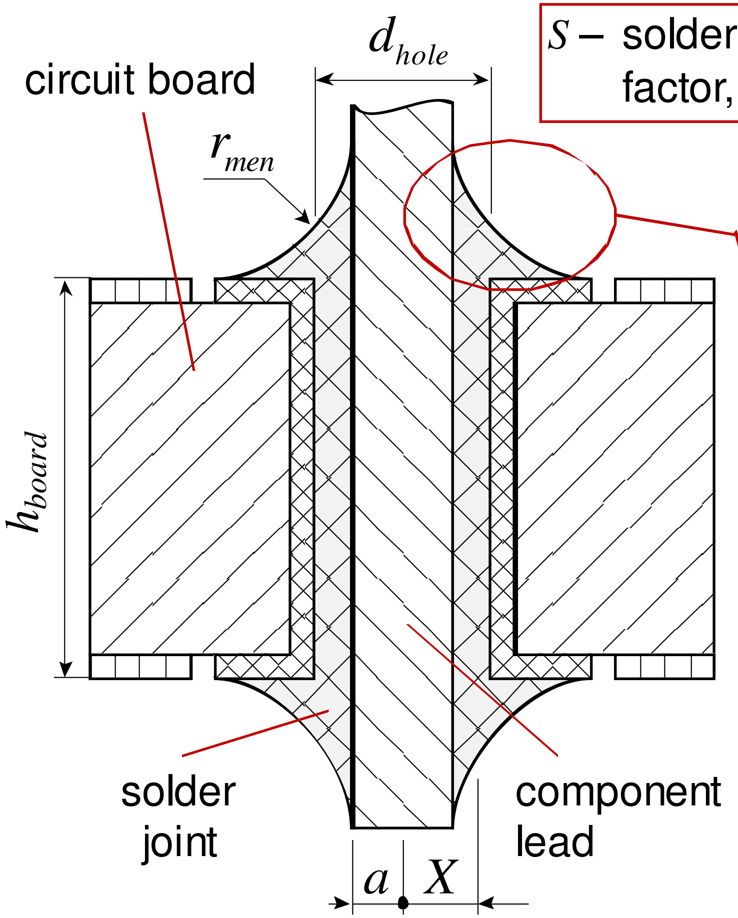
STEPS OF THE „PIN IN PASTE" TECHNOLOGY

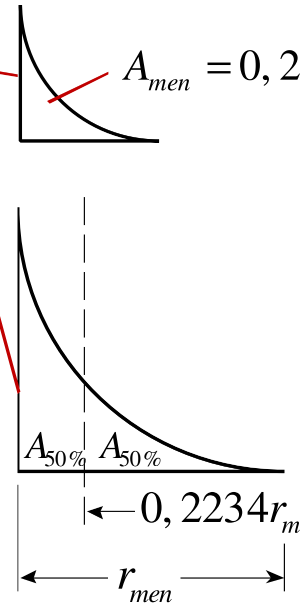
3. Soldering



SOLDER PASTE VOLUME NECESSARY FOR „PIN IN PASTE" TECHNOLOGY

S – solder paste shrinkage factor, ~0,5





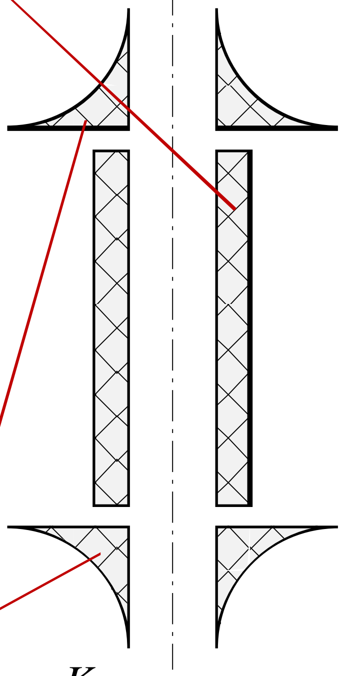
$$A_{men} = 0,215 r_{men}^2$$

$$X = 0,2234 r_{men} + a$$

$$K_{men} = 2\pi X$$

$$V_{solder\_in\_hole} = V_{hole} - V_{comp\_lead}$$

$$(\pi \cdot r_{hole}^2 - A_{comp\_lead}) \cdot h_{board}$$

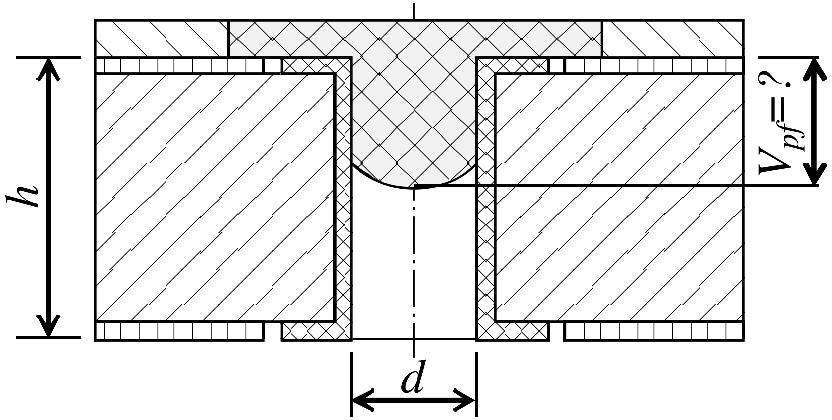


$$V_{men} = A_{men} \cdot K_{men}$$

$$0,215 r^2 \cdot 2\pi (0,2234 r_{men} + a)$$

$$V_p = (1/S) \cdot \left[\left(\pi \cdot r_{hole}^2 - A_{comp\_lead} \right) h_{board} + 2 \cdot \left(0,215 r_{men}^2 \cdot 2\pi \left(0,2234 r_{men} + a \right) \right) \right]$$

REQUIRED DEGREE OF SOLDER PASTE HOLE-FILLING



$$V_{paste} = (1/S)(V_{hole} - V_{comp\_lead} + 2V_{meniscus})$$

$$V_{aperture} = w \cdot l \cdot t$$

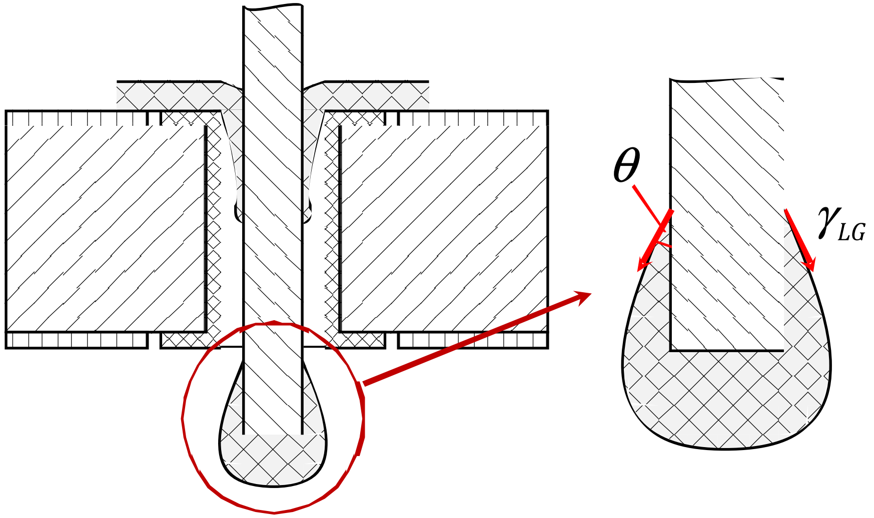
$$V_{pf} = V_{paste} - V_{aperture}$$

If $\frac{d}{h} < \frac{1}{2}$, then V_{pf} can be too low.

- Overprinting…
- Step stencils…
- Two-print stencils…
- *Preform* solders…

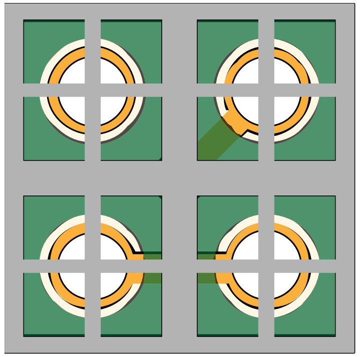
If $\frac{d}{h} > \frac{2}{1}$, than V_{pf} can be too high.

Boundary condition of the fusion:



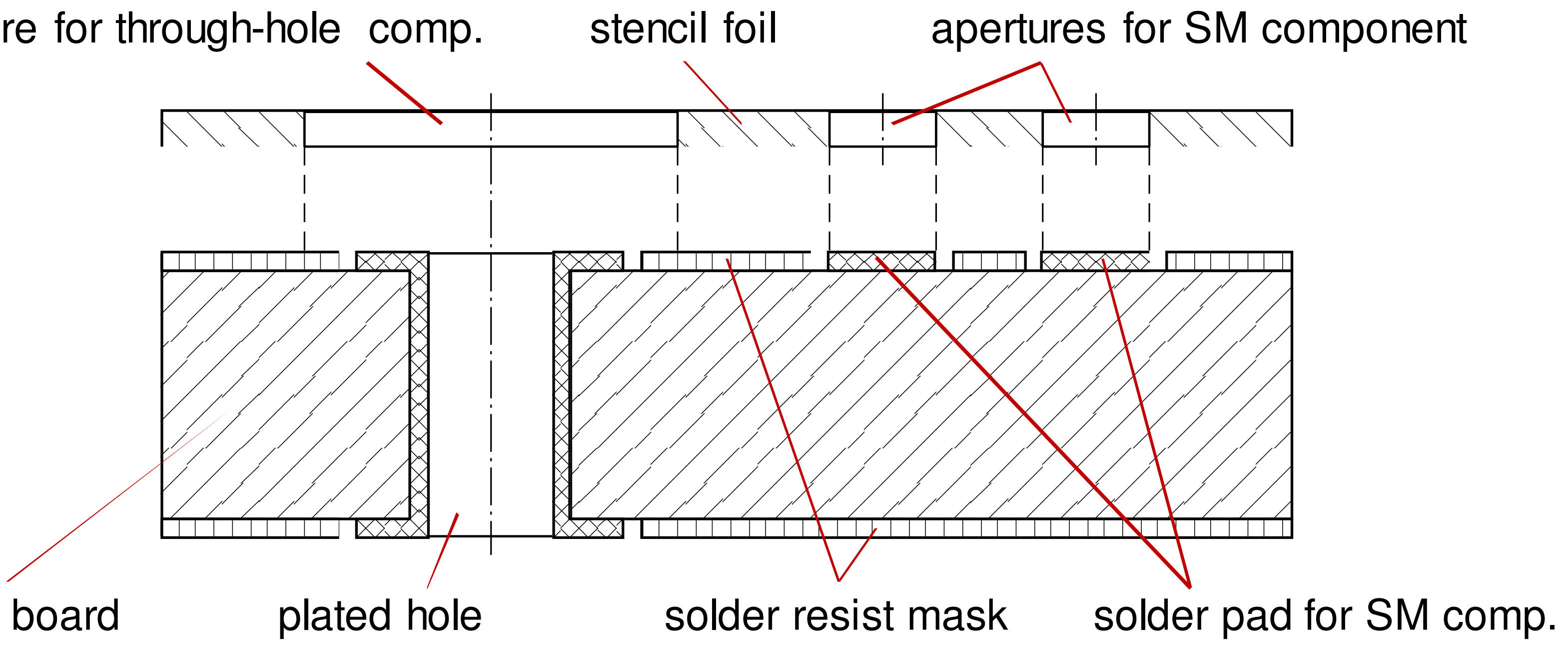
$$F_{grav} = \rho V g \ll F_{surf.tens.} = 2\pi r \cdot \gamma_{LG} \cdot \cos\theta$$

Cross apertures



OVERPRINTING

	Limits	Desirable
Hole diameter	0.63…1.6 mm	0.75…1.25 mm
Lead diameter	Hole diameter minus 75 µm	Hole diameter minus 125 µm
Aperture diameter	Maximum 6.35 mm	Maximum 4 mm
Stencil thickness	0.125…0.635 mm	0.150…0.2 mm

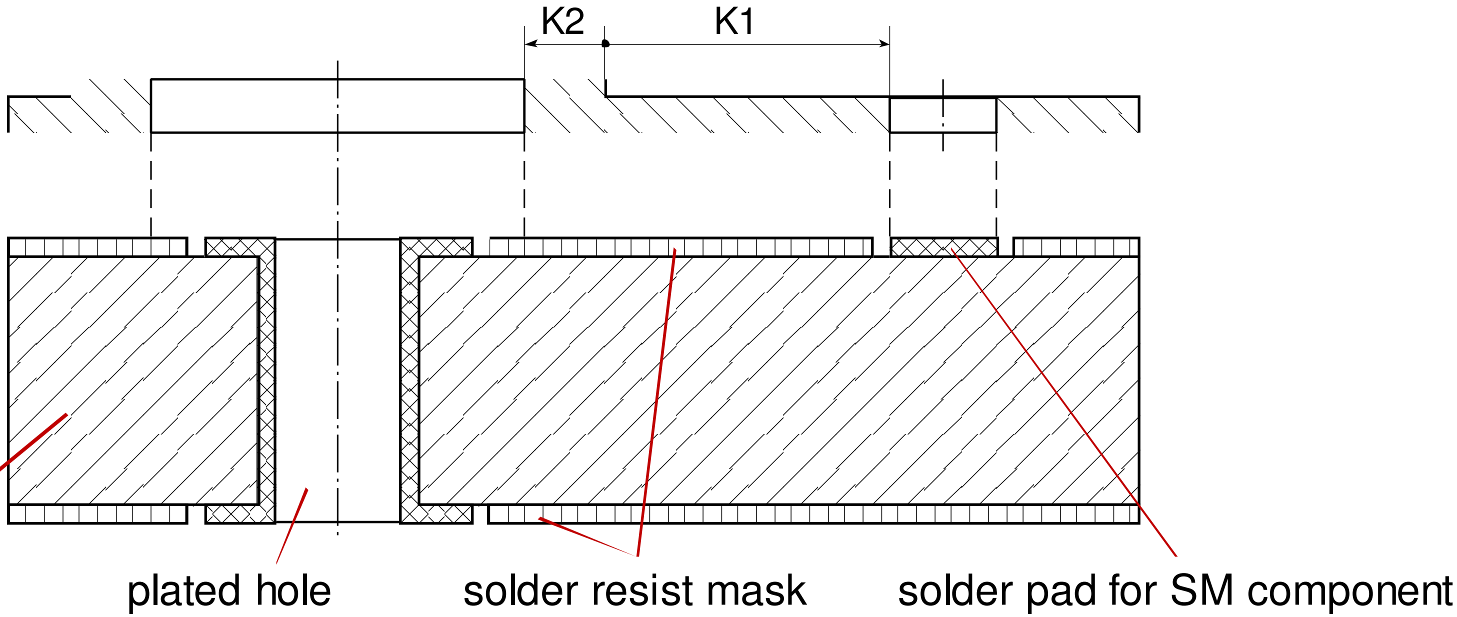


STEP STENCILS

Prepared using additive technology by electroplating, or subtractive process by chemical etching.

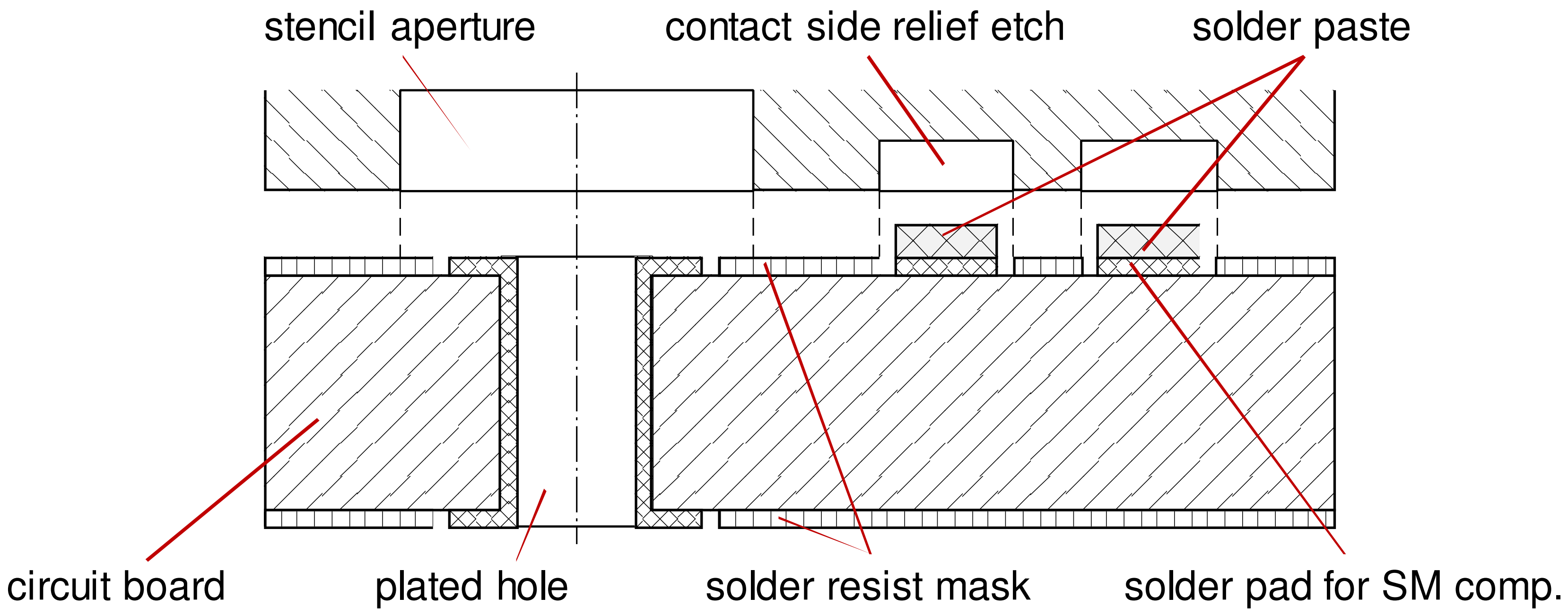
Design rules:

- Step height is maximum 75 µm.
- K1: distance between step and nearest aperture for SM component; should be at least 36 x step height.
- K2: should be at least 0,65 mm.

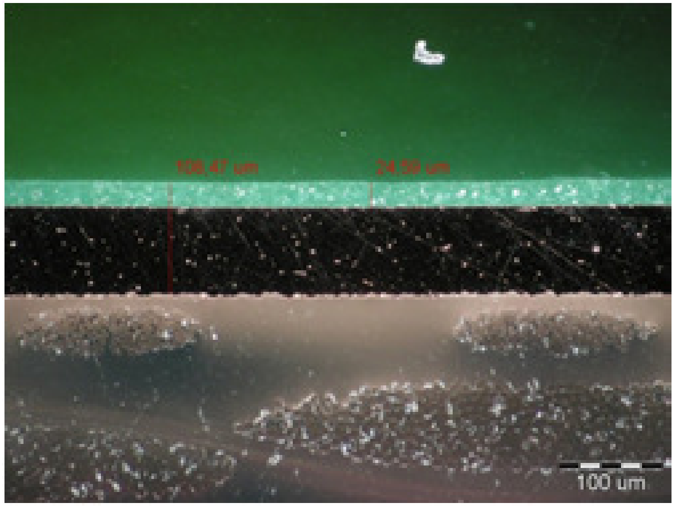


TWO-PRINT STENCILS

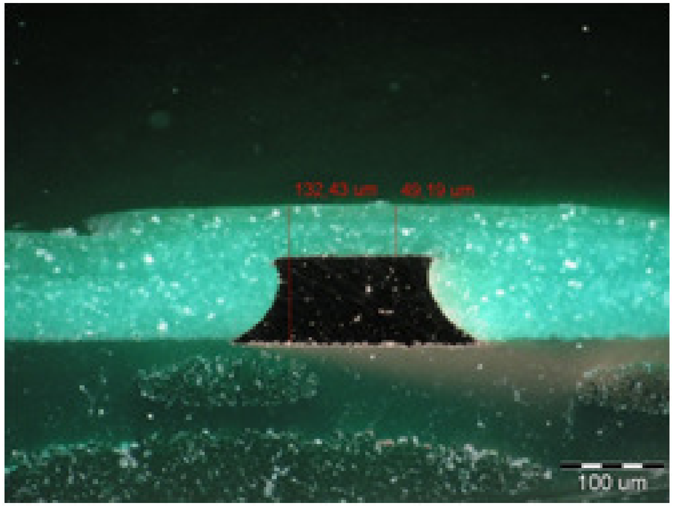
- First printing is performed by a thin stencil foil according to the fine-pitch SM components on the circuit (125…175 μm).
- Second printing is carried out by a thick foil according to through-hole components (400…760 μm), relief etch is formed on the contact side of the stencil at the locations of SM components to avoid solder paste smearing. Depth of relief etch should be at least 200 μm.



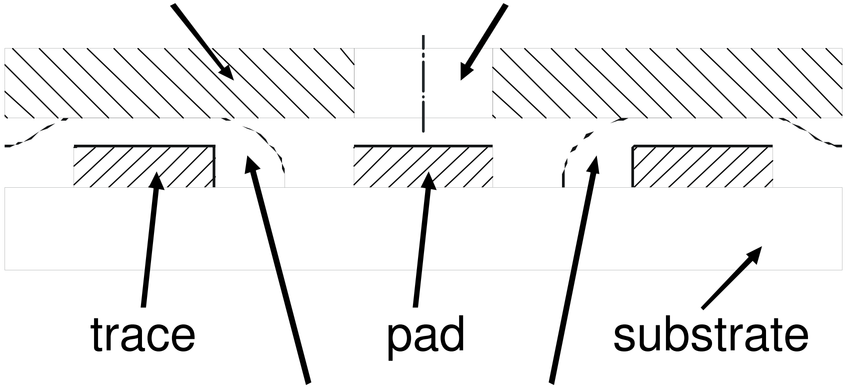
INVESTINGATING STENCIL DEFORMATION DURING PRINTING



Thickness of solder mask: 25 µm



Thickness of solder mask: 50 µm



stencil

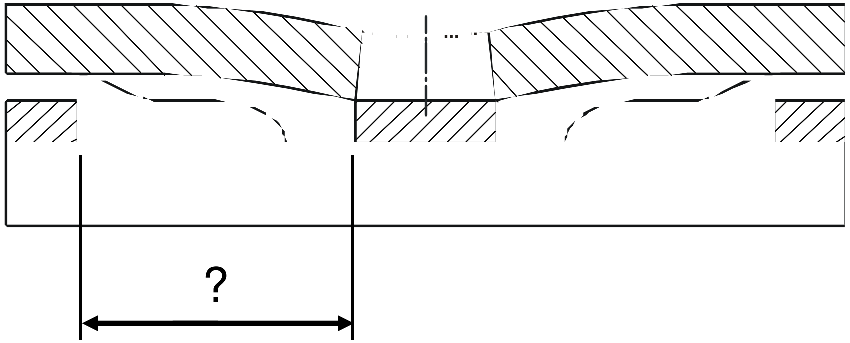
aperture

trace

pad

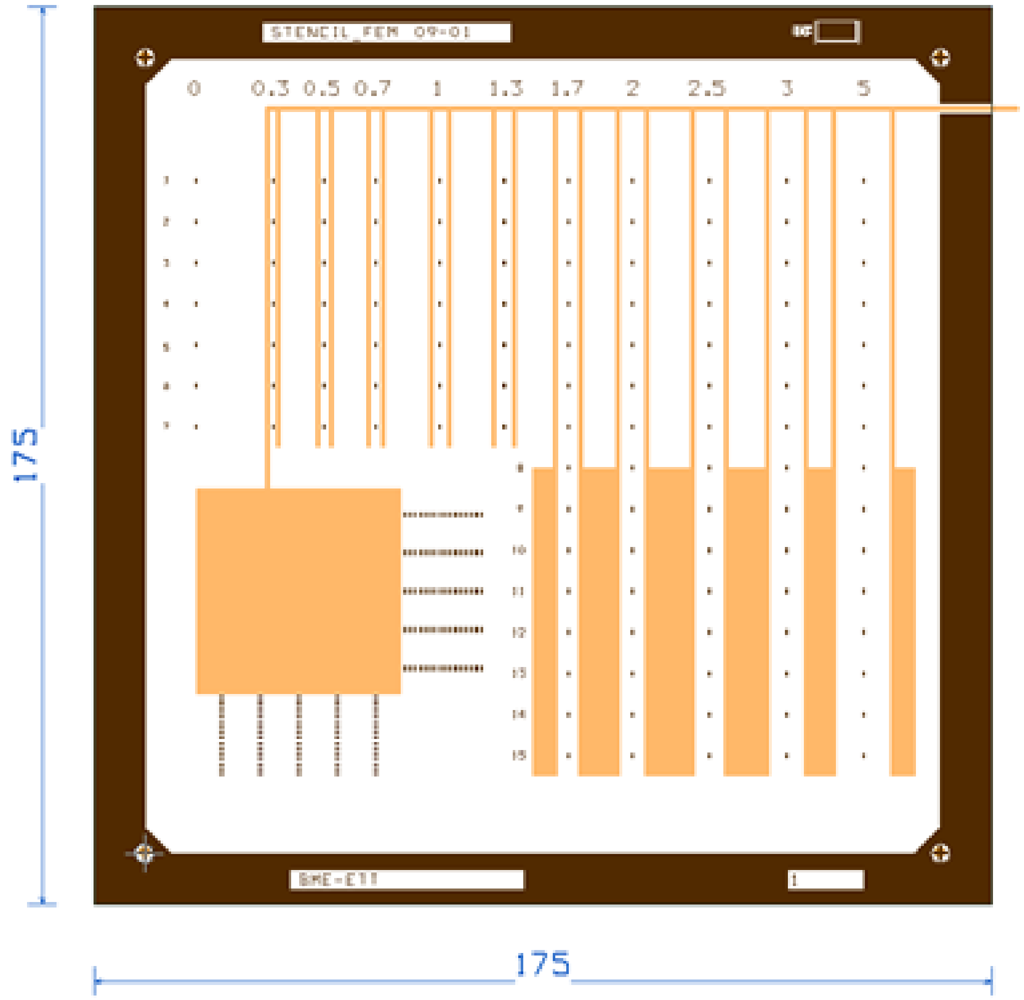
substrate

solder mask



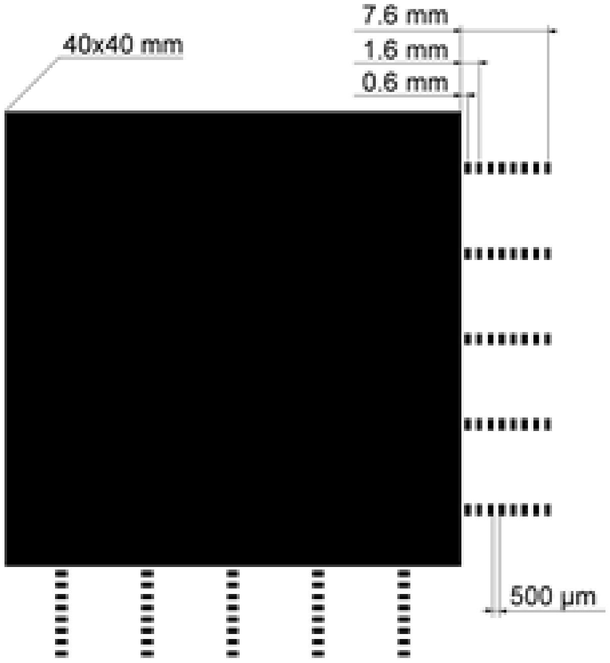
?

THE TESTBOARD

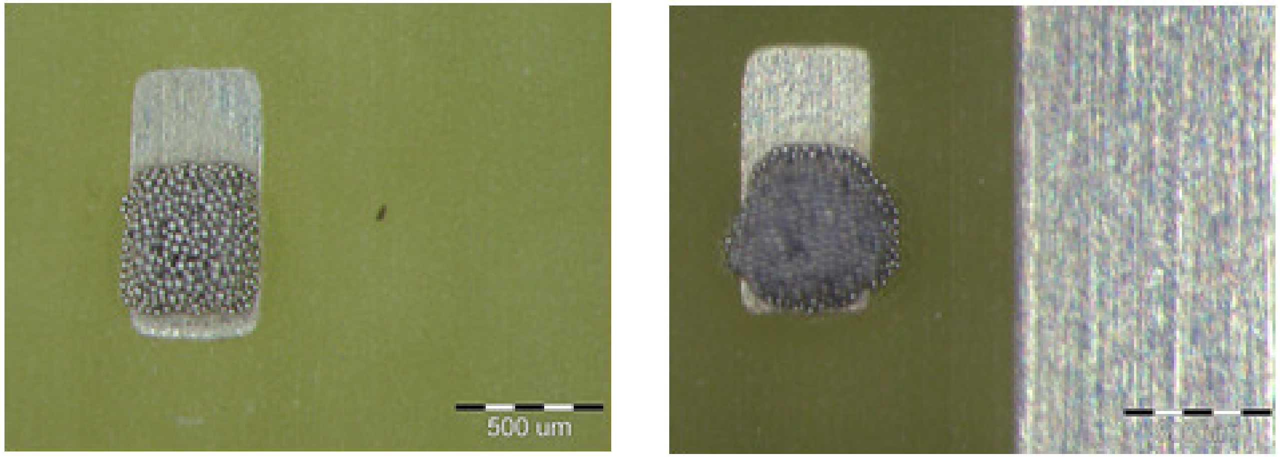


🟫 Base thickness:
contour and solder pads

🟧 Protruding areas; thickened with electroplating

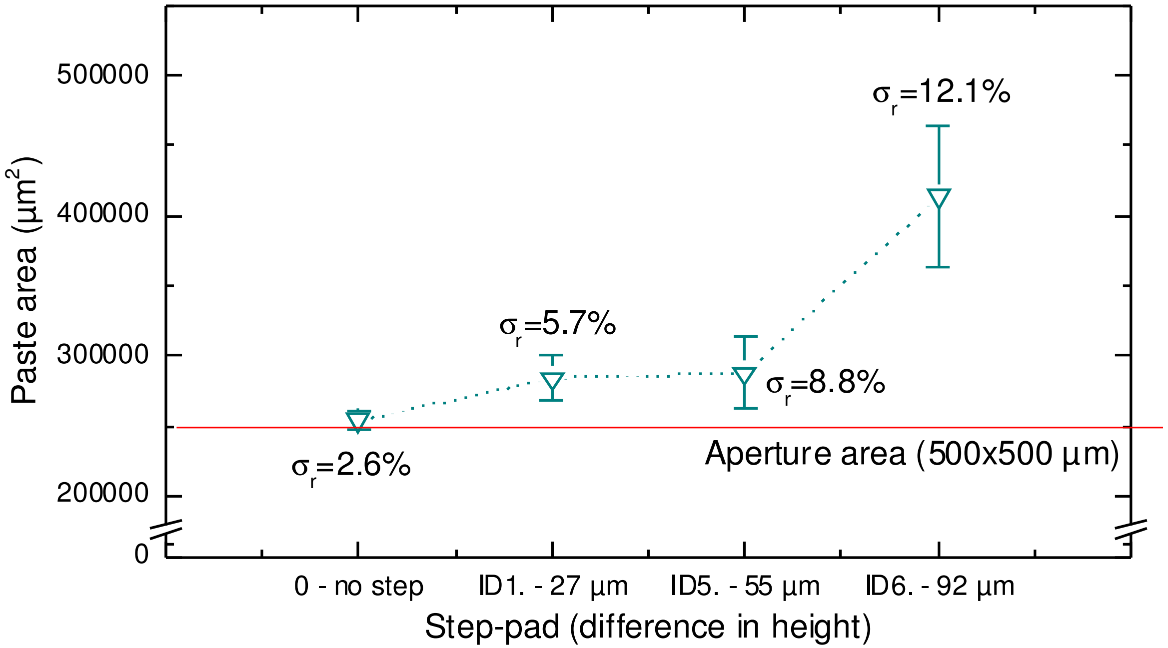


AREA OF DEPOSITED PASTE



Left:
ID. 1
– no step nearby

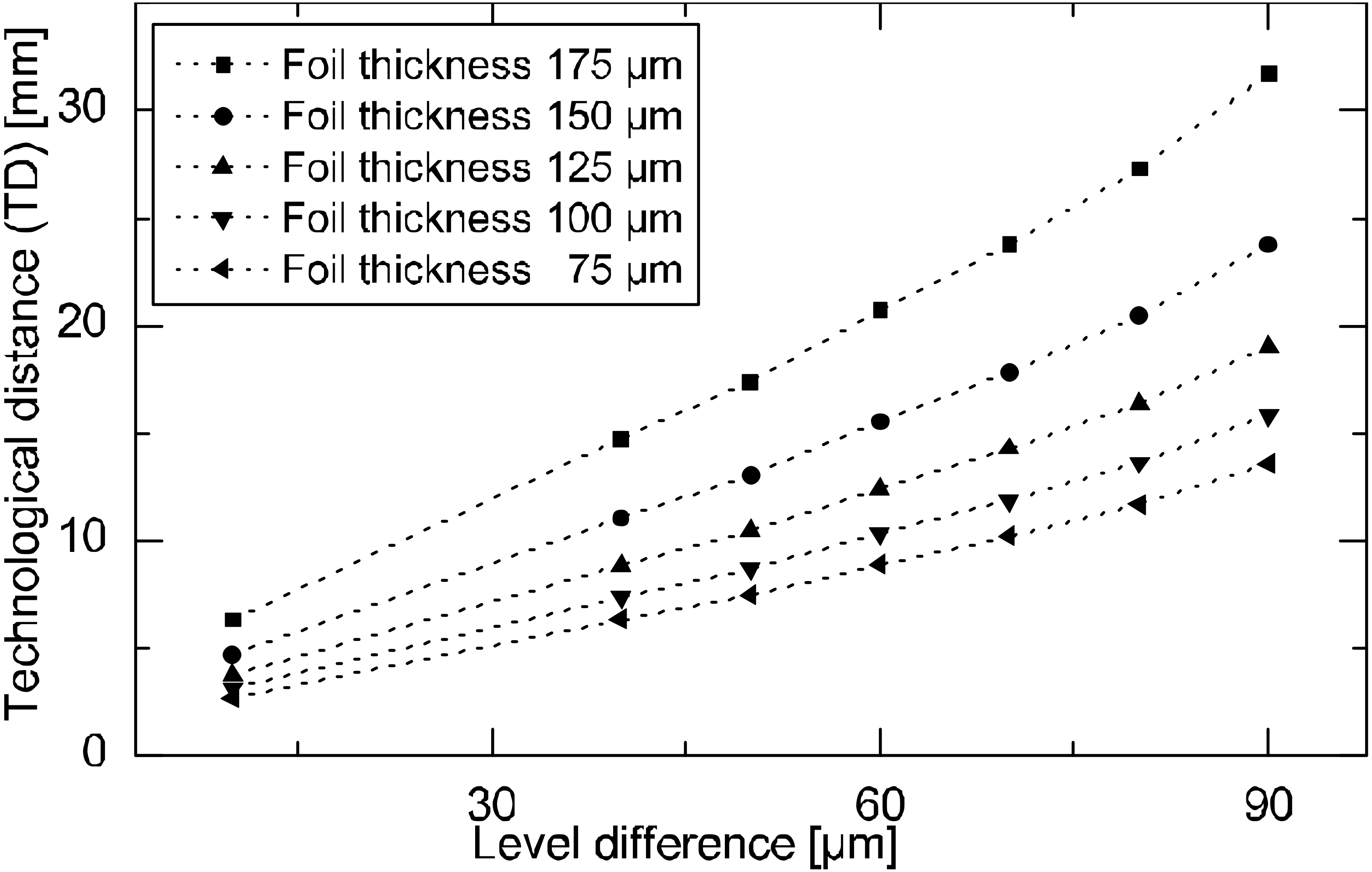
Right:
ID. 6 – 0,5 mm
step distance



PARAMETERS OF THE FINITE ELEMENT MODELLING

- Squeegee length 30 cm
- Squeegee force 92 N
- Squeegee thickness 200 µm
- Squeegee angle 60°
- Highest level difference 90 µm
- Simulated foil thicknesses: 75…175 µm, in 25 µm steps
- Size of stencil foil 50x50 cm

NECESSARY DISTANCE FOR COMPLETE STENCIL BEND-DOWN



SUMMARY

Basic stencil design:

- For surface mounted passive components aperture reduction rules apply
- For SM perimeter styles components (QFPs, QFNs) aperture reduction rules apply; foil thickness calculation is necessary
- For common plastic BGA packages (pitch>1.27 mm) round aperture is recommended with reduction considerations
- For fine-pitch plastic BGAs (pitch<1.27) square aperture recommended, aperture reduction rules do not apply

Step stencils for Pin-in-Paste technology:

- For squeegee side steps, technological distance to the nearest surface mounted component is $36 \cdot \mathit{step\_thickness}$
- For contact side steps, recommended technological distance to the nearest surface mounted component is $1.6 \cdot \mathit{step\_thickness} \cdot \mathit{foil\_thickness}$