



WE CONNECT CHIPS AND SYSTEMS

# Stencil Design Guidelines for Electronics Assembly Technologies

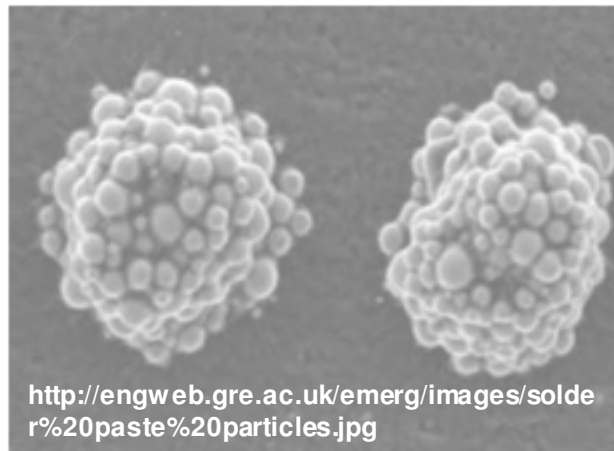
**Student professional contest The 22nd Edition, Brasov,  
24th-27th April 2013**



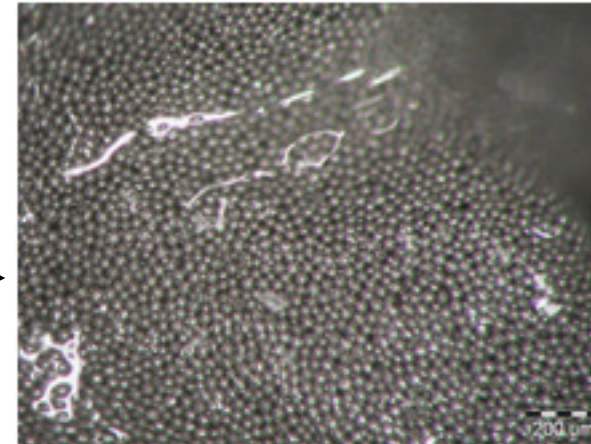
BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS  
DEPARTMENT OF ELECTRONICS TECHNOLOGY

# REFLOW SOLDERING - MATERIAL

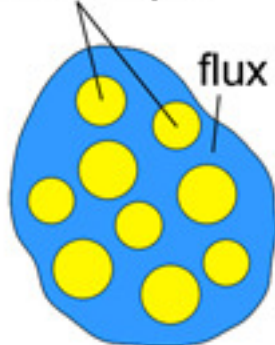
Solder paste is a combination of pre-alloyed spherical metal powder and flux medium.



Solder paste



solder particles  
 $d = 5...45 \mu\text{m}$



Solder paste



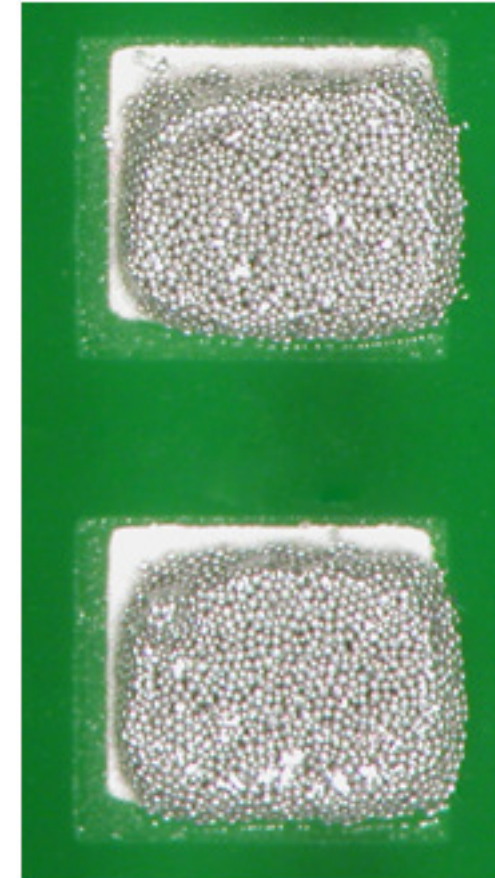
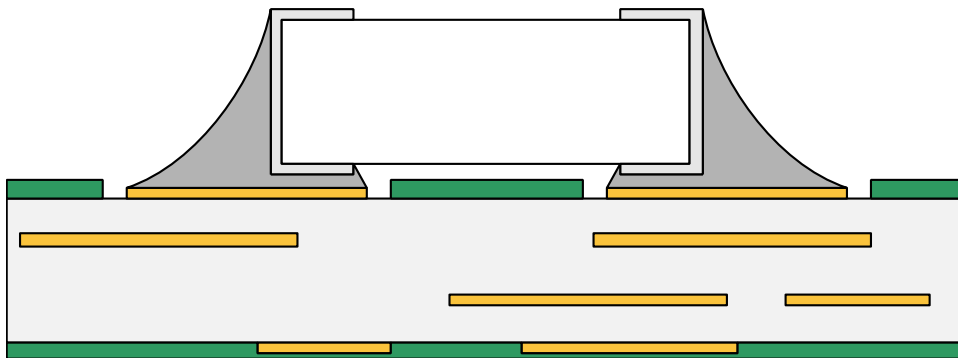
Packing of solder pastes: jar and syringe

# 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

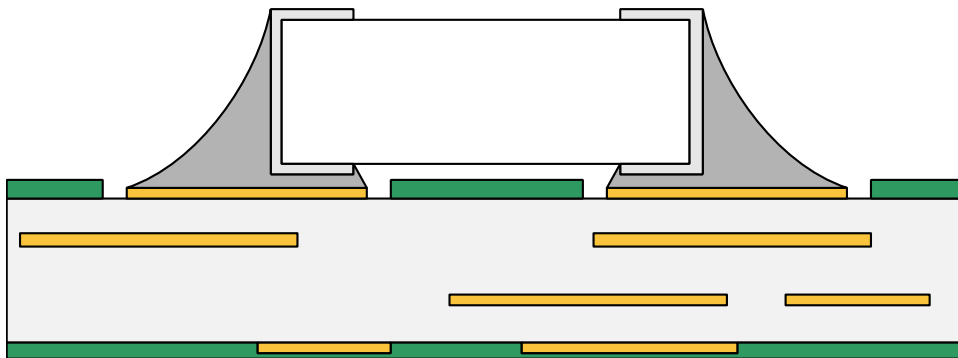


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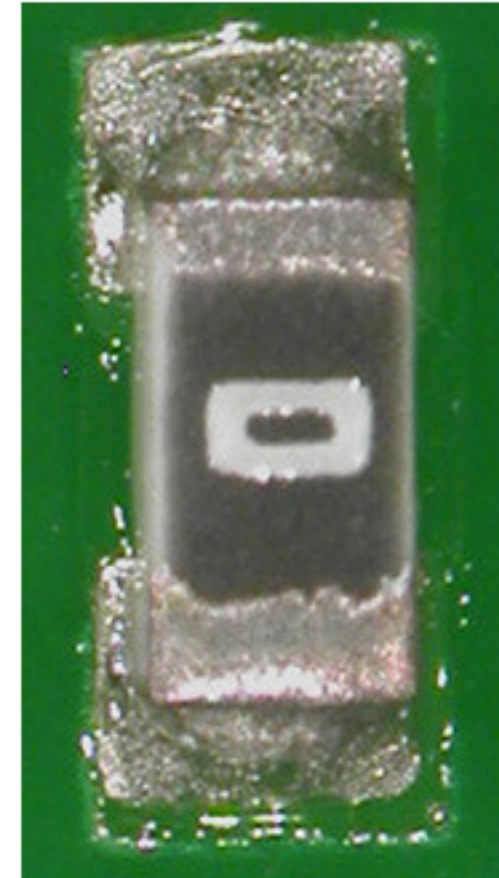
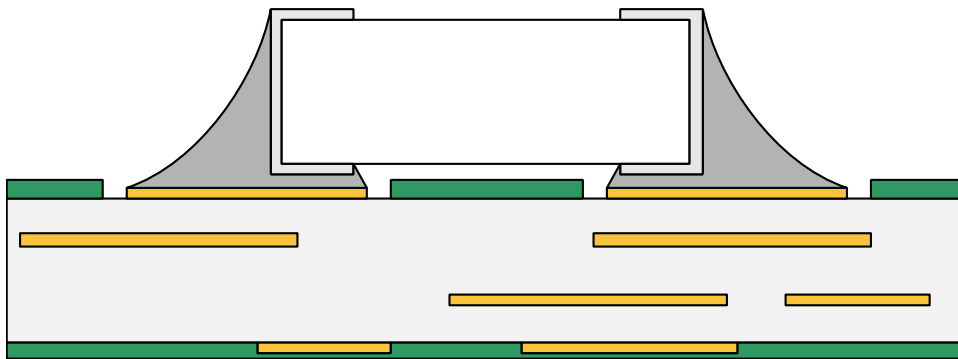


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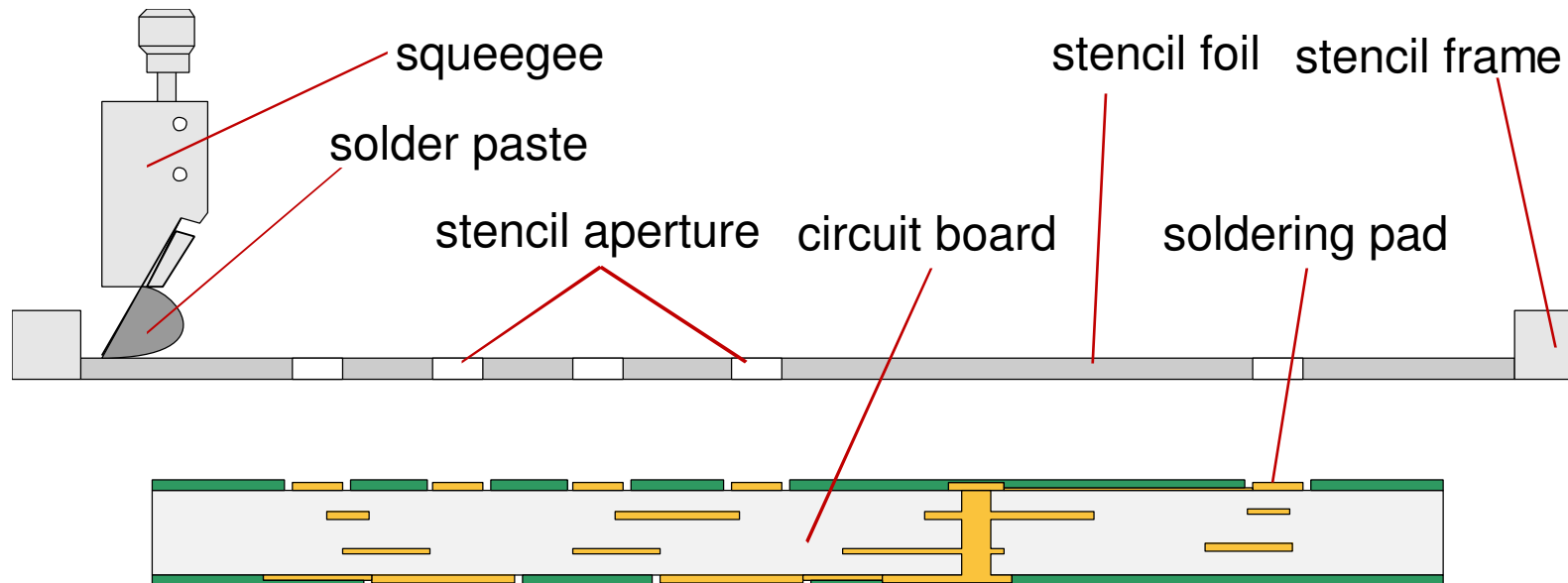
Surface mounted resistor





# THE STENCIL PRINTING

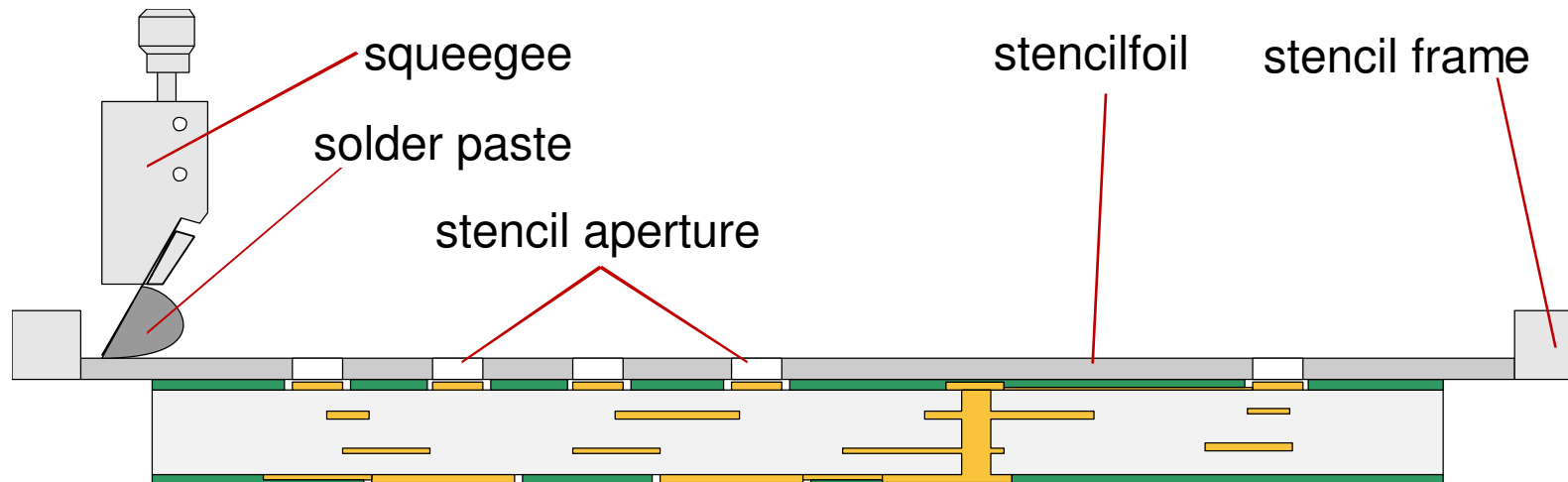
The **stencil** applied for depositing the solder paste is a thin, 75–200  $\mu\text{m}$  thick **metal foil**, on which **apertures are formed** according to the solder pads on the printed circuit board. **Stencil printing** provides a fast, mass solder paste deposition process; relatively expensive,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



# PROCESS OF STENCIL PRINTING

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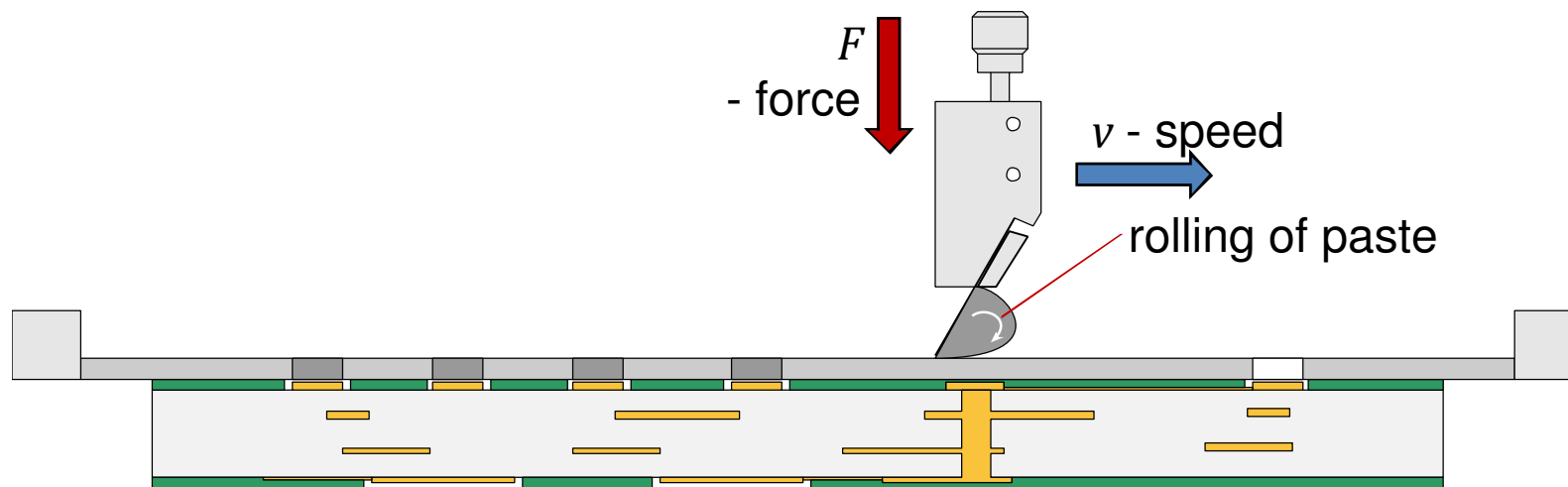
## 1. Aligning board to the stencil



# PROCESS OF STENCIL PRINTING

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## 2. Moving squeegee on the stencil – filling apertures

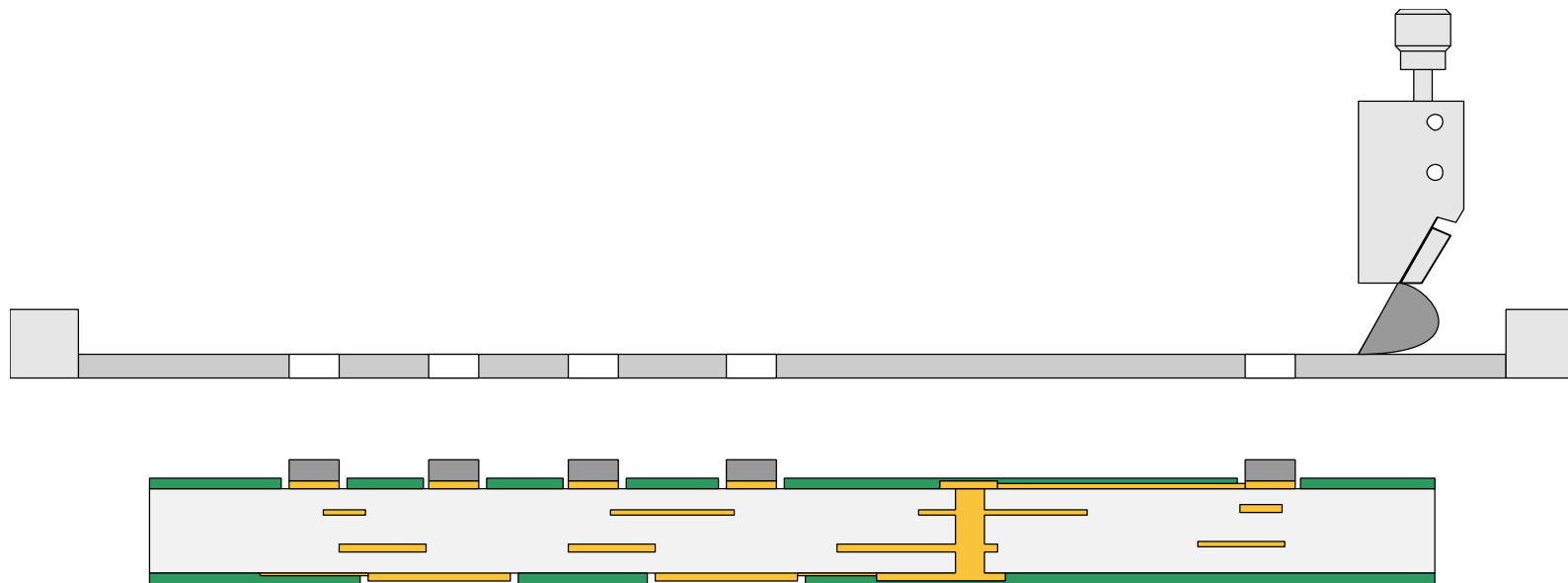




# PROCESS OF STENCIL PRINTING

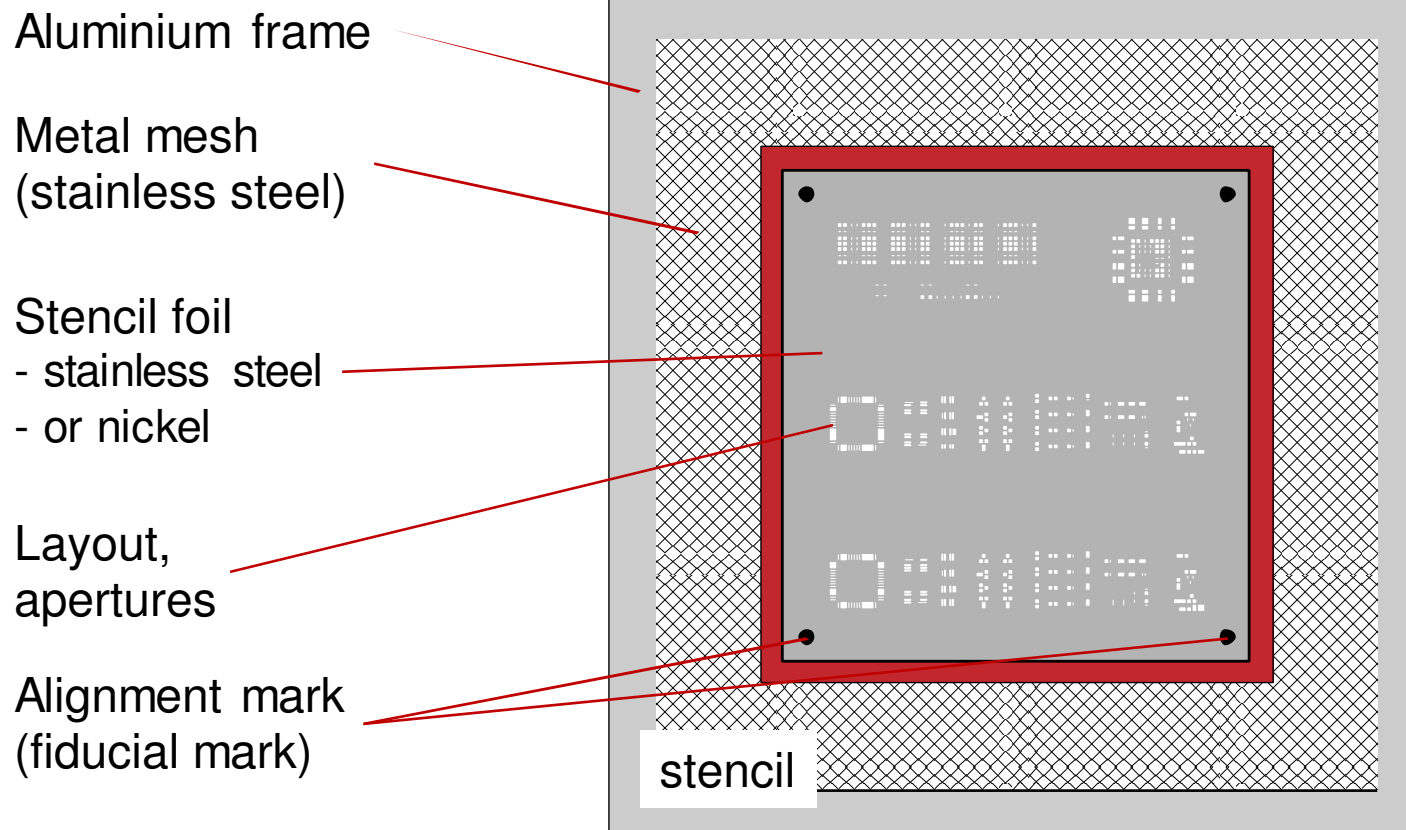
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## 3. Separating stencil from the board



# BUILD-UP OF STENCILS (TERMS)

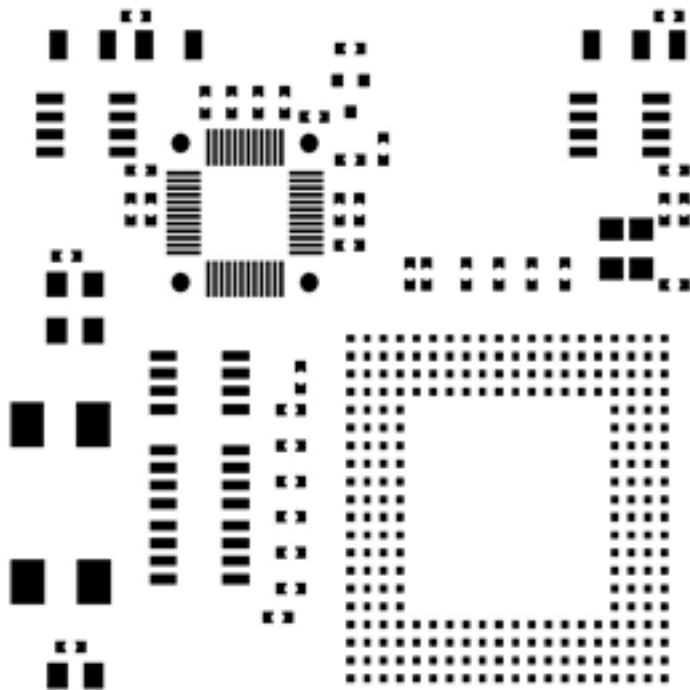
The stencil foil is tensioned and fixed to the frame by a metal mesh.  
The **tension of stencil foil** is around  $\sim 50 \text{ N/cm}$ .



# STENCIL MANUFACTURING TECHNOLOGIES

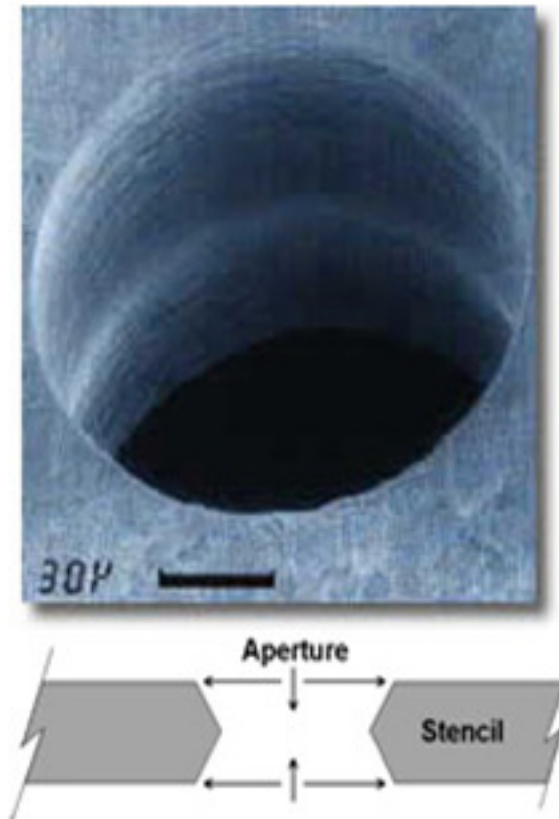
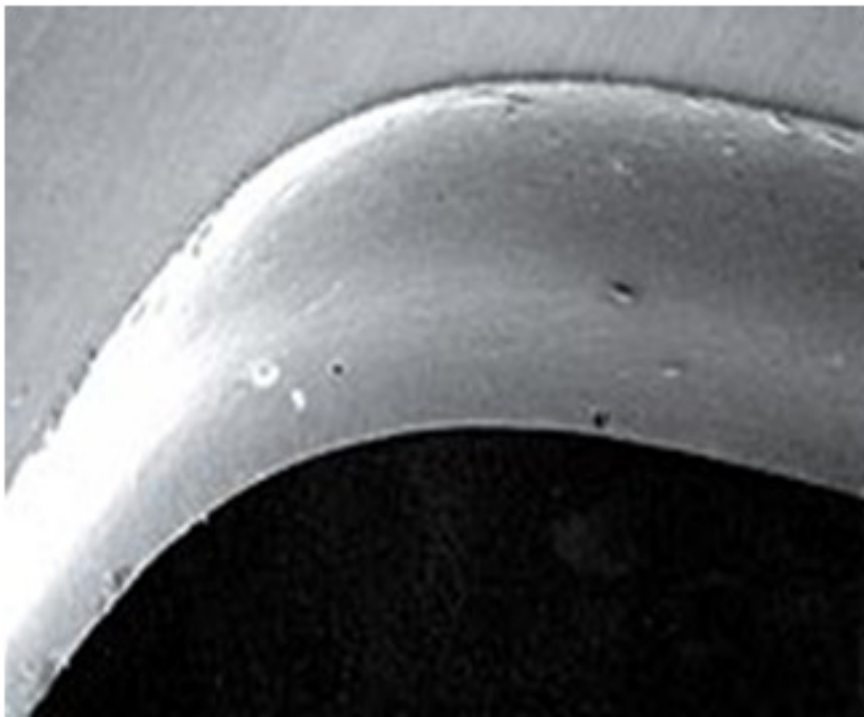
The main stencil manufacturing technologies are: chemical etching, laser cutting, electroforming.

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

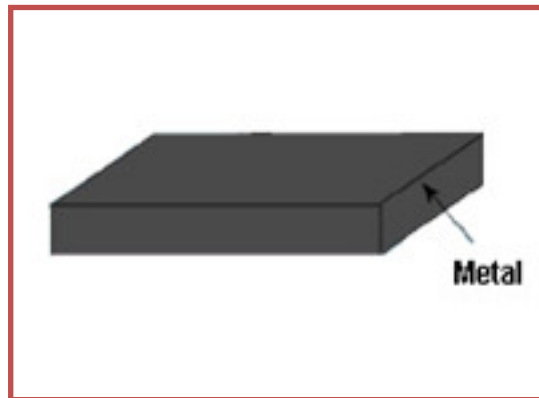


# CHEMICAL ETCHED STENCILS

- 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

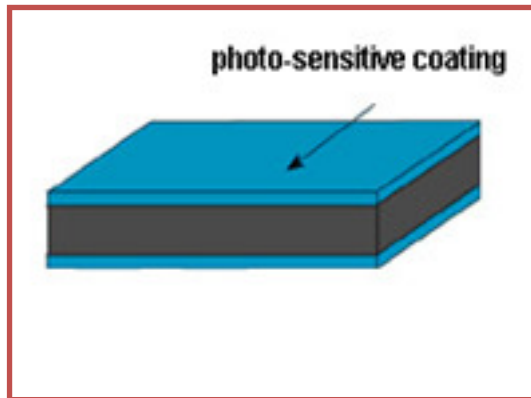
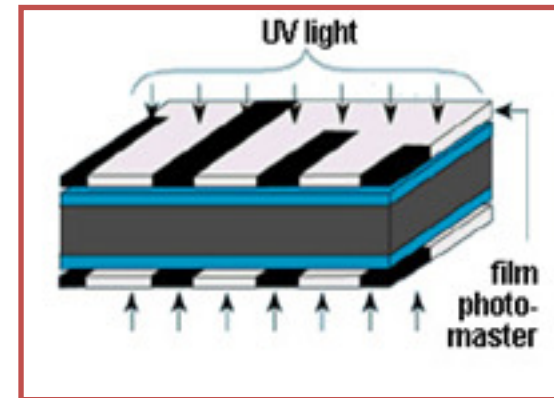
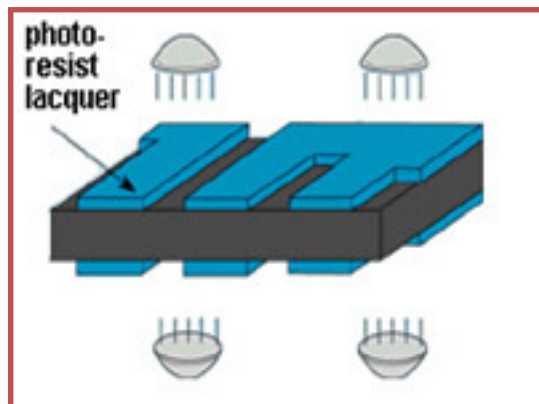


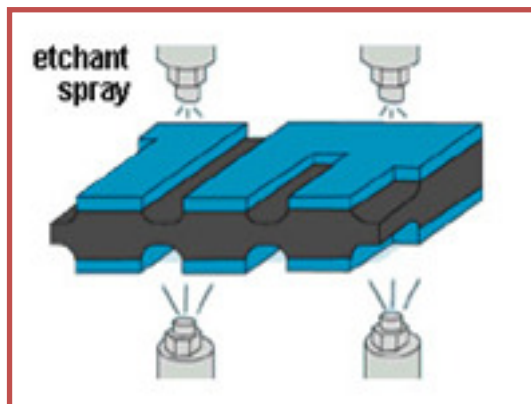
Photo sensitive coating applied to top and bottom



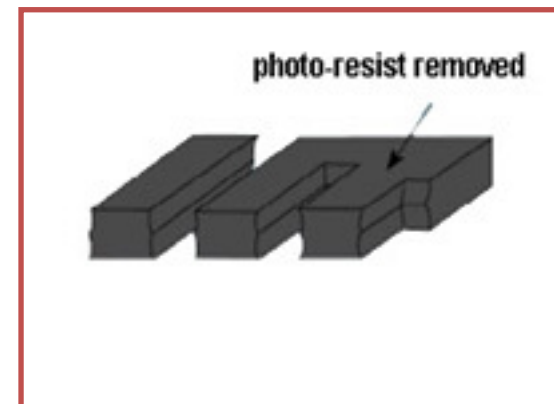
Developing solved photo-resist



Rinsing off photo-resist



Etching of metal



Complete etched product

# CROSS-SECTION OF CHEMICAL ETCHED STENCIL APERTURES



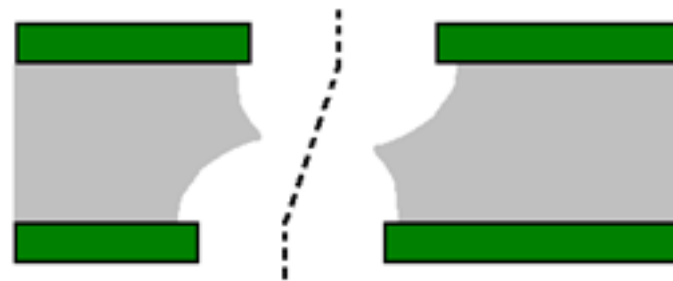
Single-side etching – high degree of undercutting



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



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

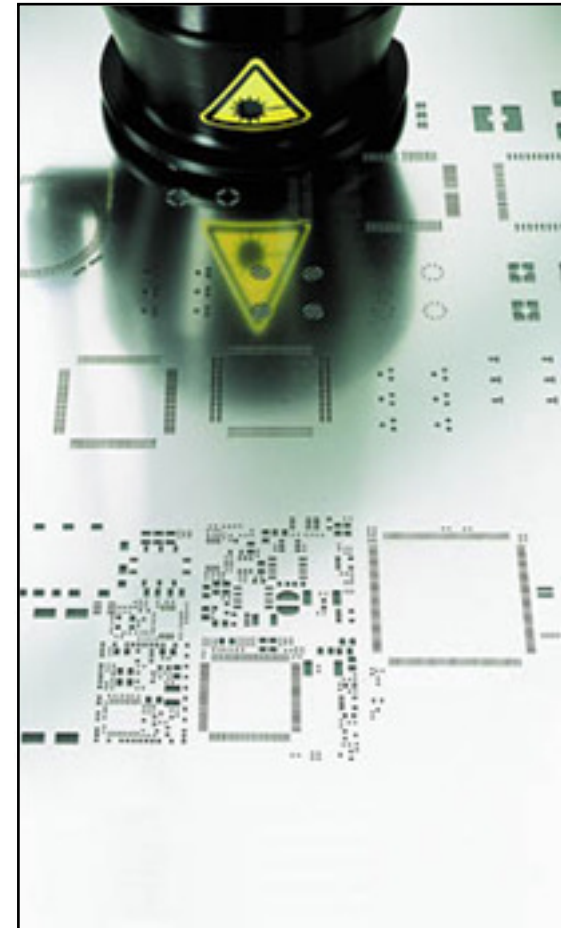
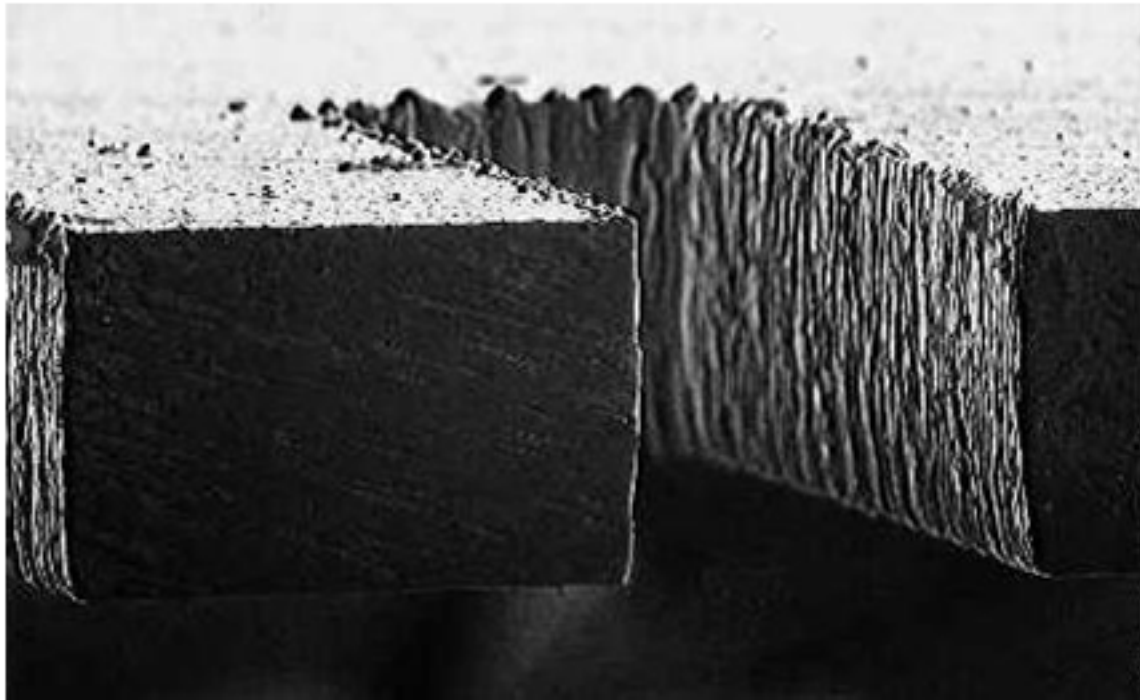


Misalignment of phototools between the two sides



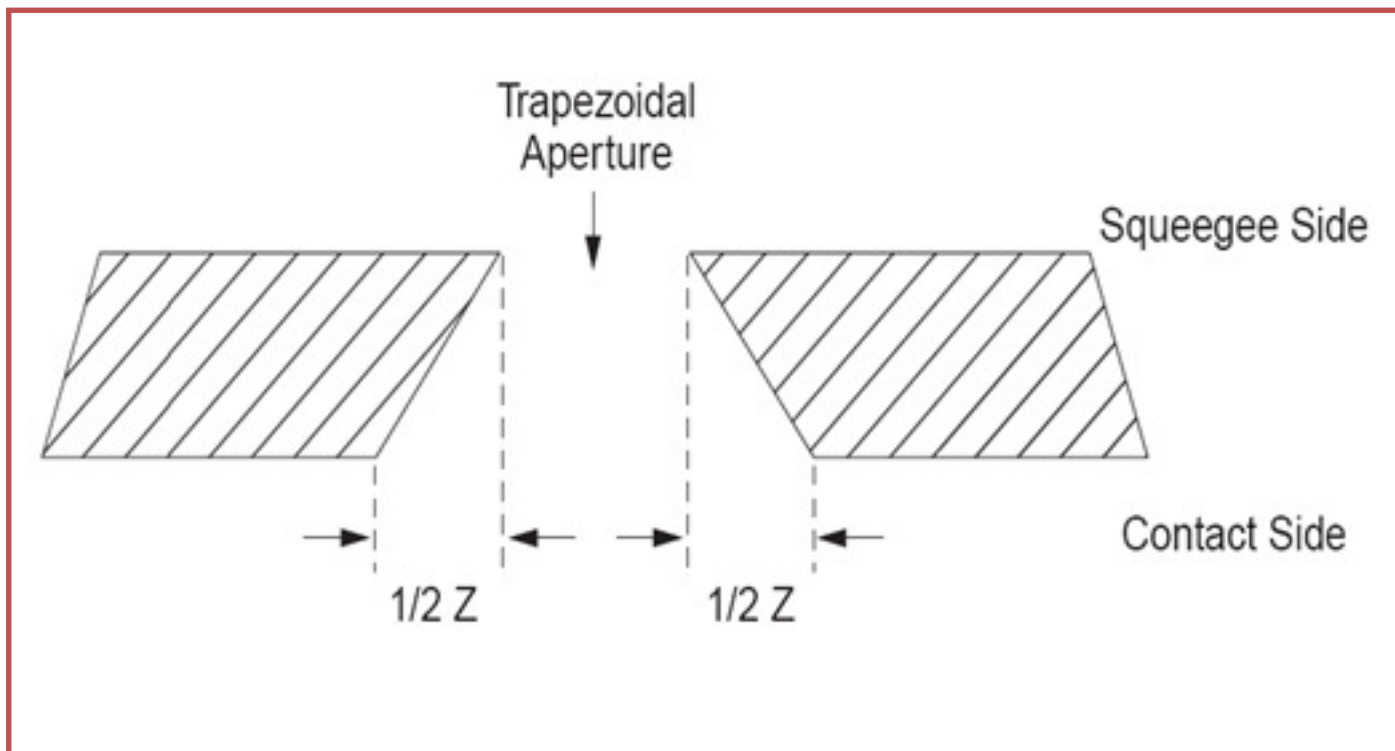
# LASERCUT STENCILS

- 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.

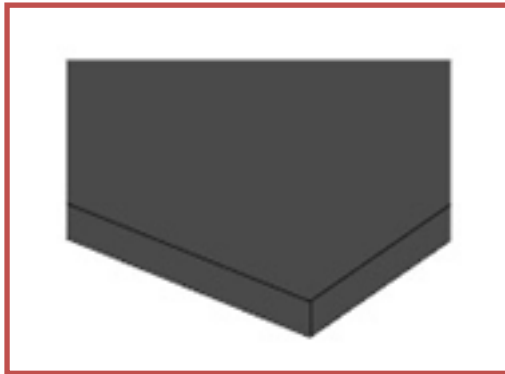


# ELECTROFORMED STENCILS

- 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

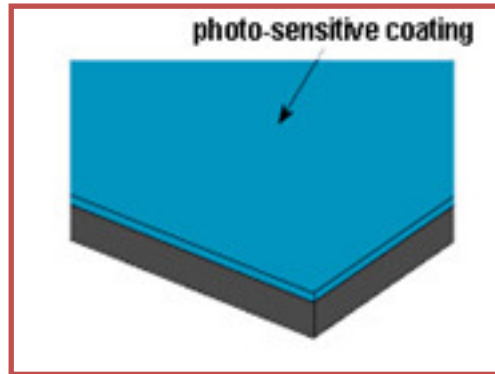
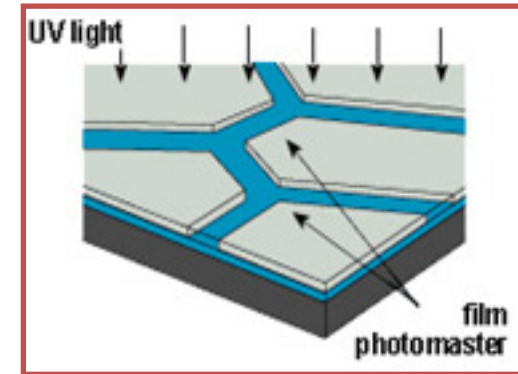
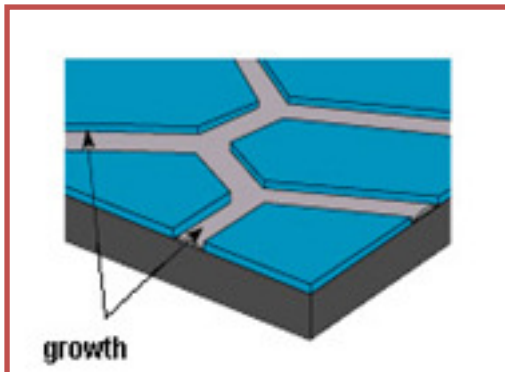


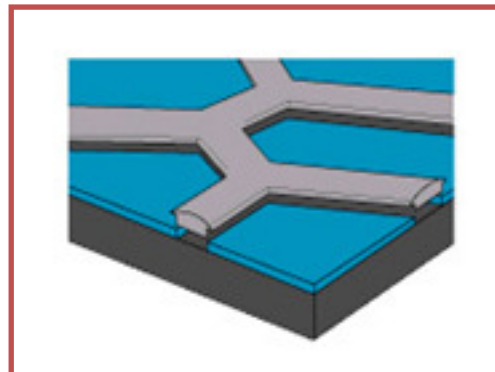
Photo-sensitive coating applied



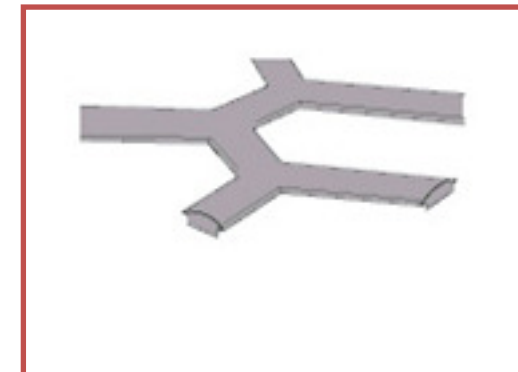
Developing and rinsing off solved photo-resist



Electro deposition of metal



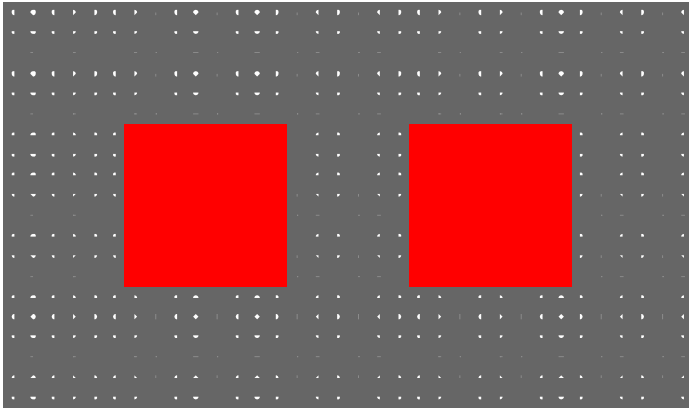
Separation of stencil



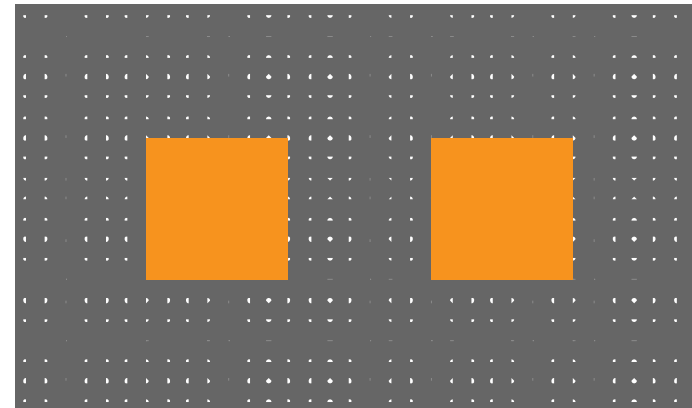
Complete stencil

# STENCIL DESIGN

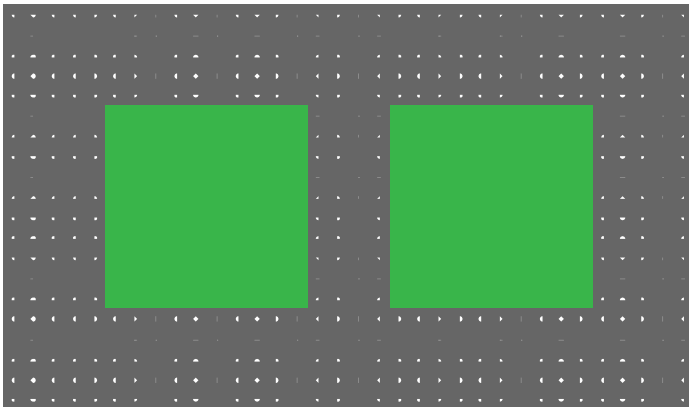
Top (Cu) layer – positive



Solder paste layer – negative



Solder mask layer – negative

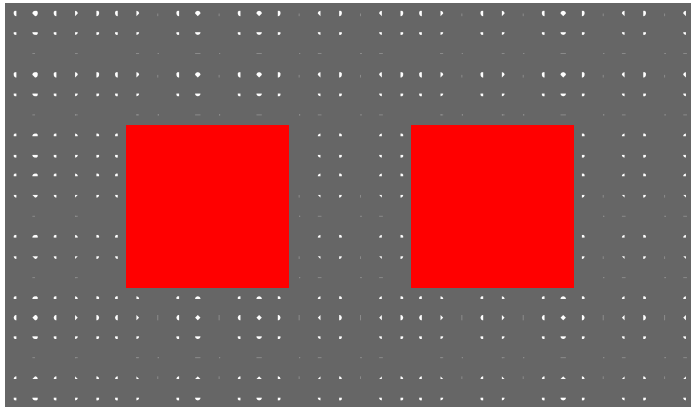


FR4 board with copper pads

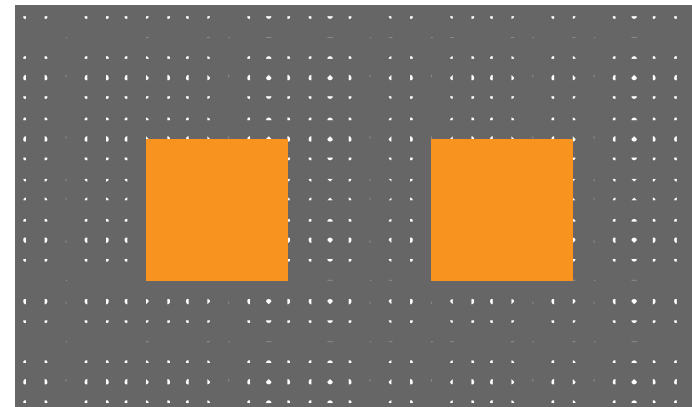


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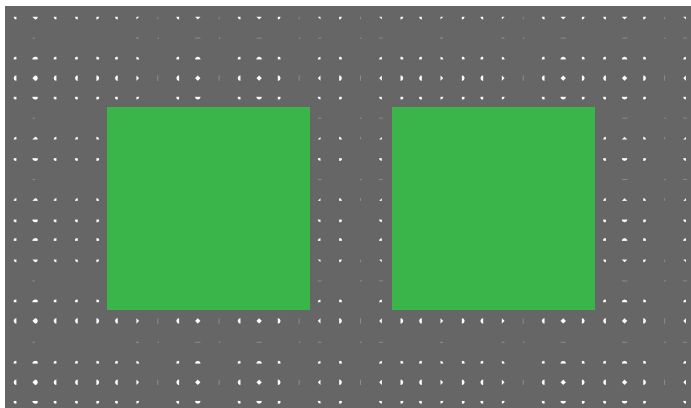
Top (Cu) layer – positive



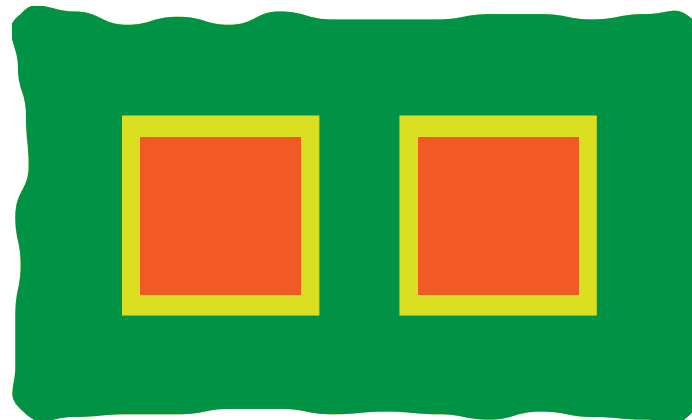
Solder paste layer – negative



Solder mask layer – negative

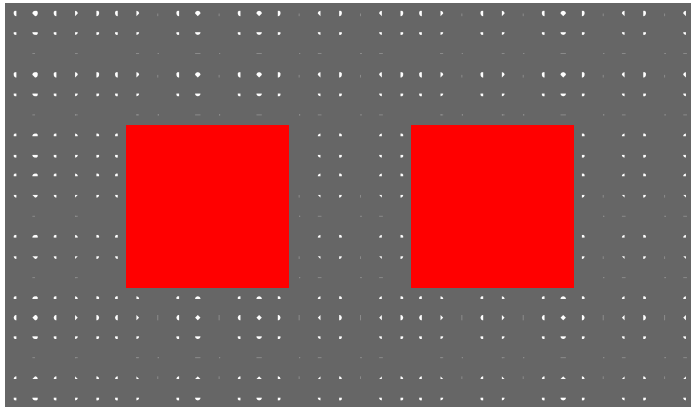


Copper pads and solder mask

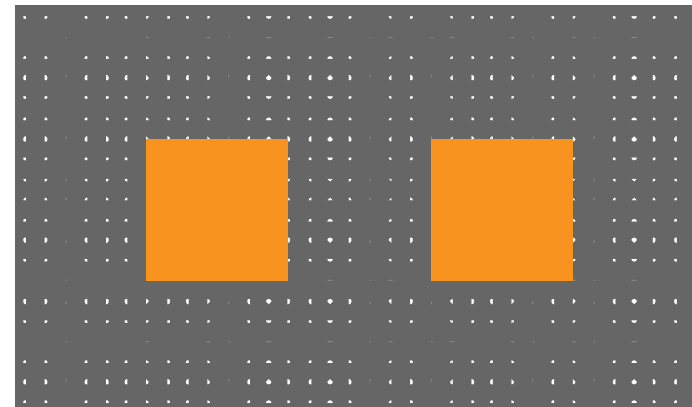


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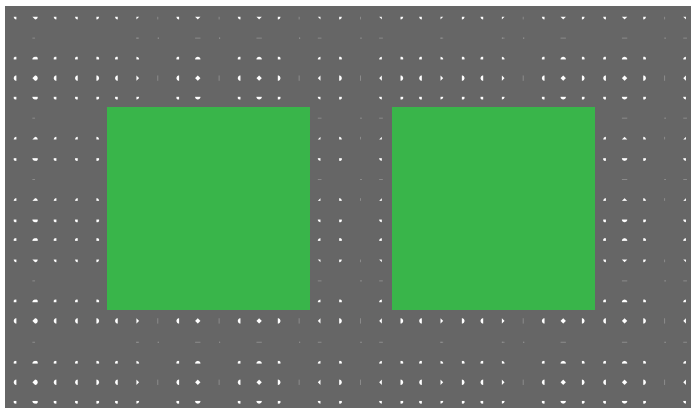
Top (Cu) layer – positive



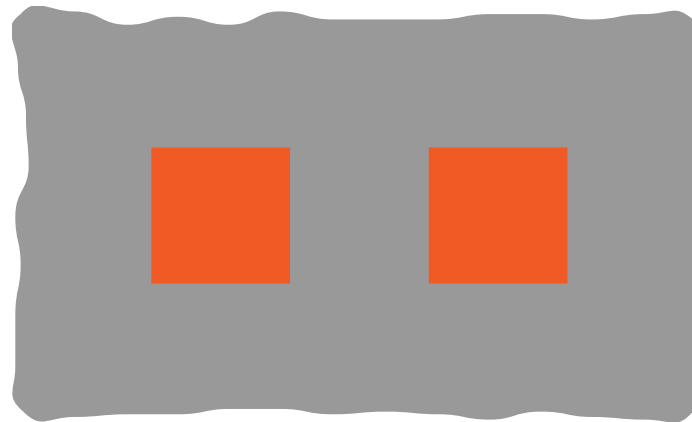
Solder paste layer – negative



Solder mask layer – negative

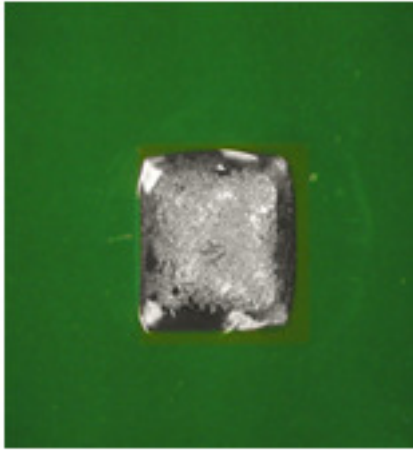


Copper pads with aligned stencil

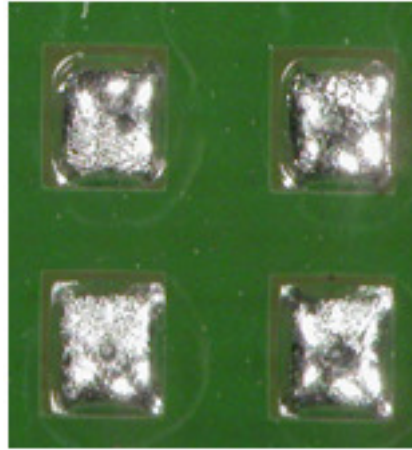




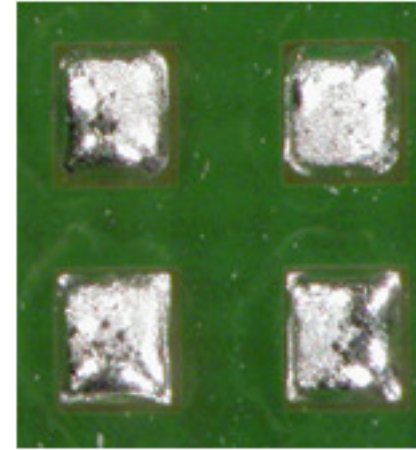
# BASIC STENCIL DESIGN GUIDELINES FOR SMD COMPONENTS



Ni/Au – 10% reduction



ImAg – 10% reduction

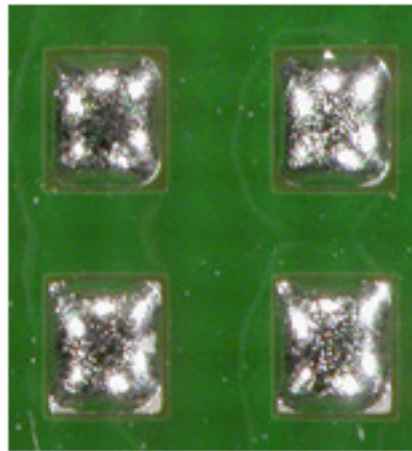


LF HASL – 10% reduction

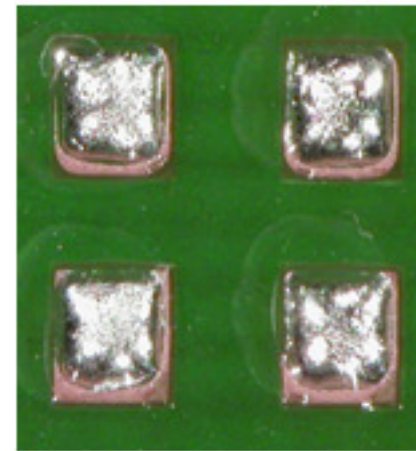
The possibility of aperture reduction depends on the solder alloy

Leaded alloy: reduction is always possible

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

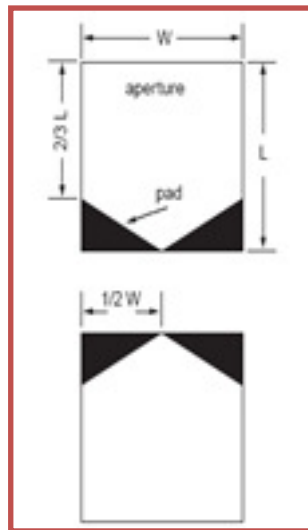
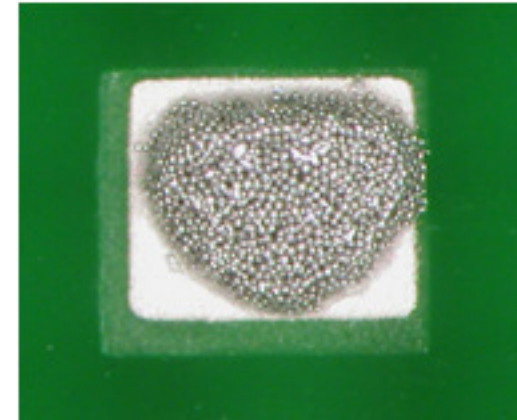
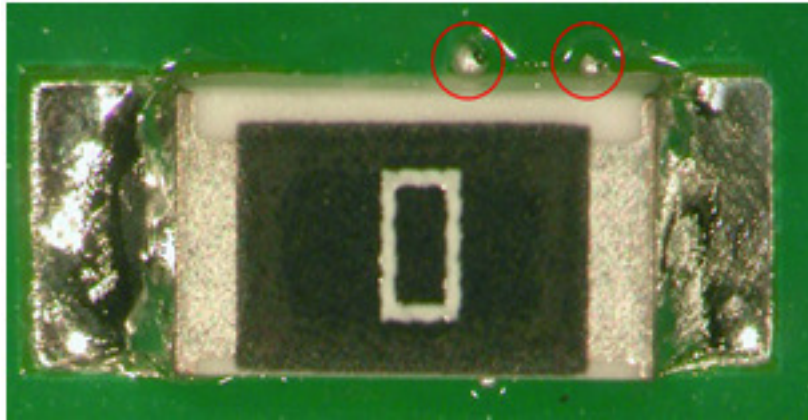


ImSn – no reduction

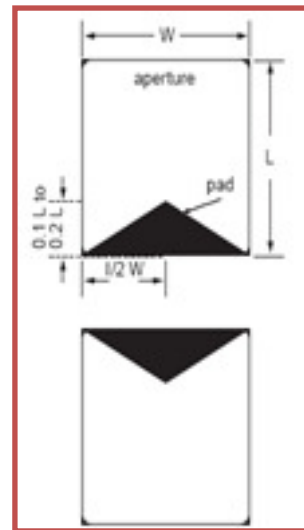


OSP – no reduction

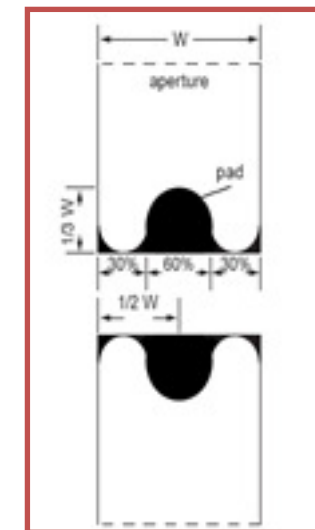
# STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



Home-plate

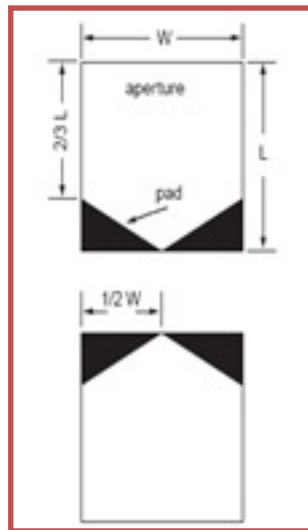
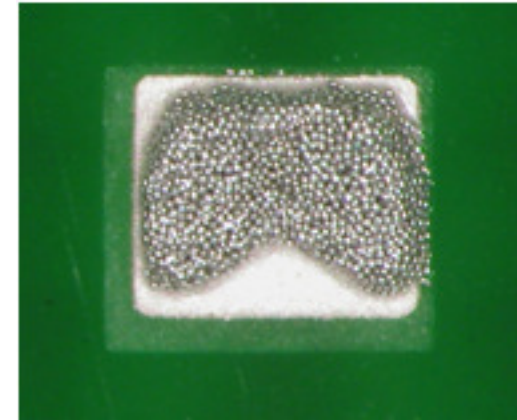
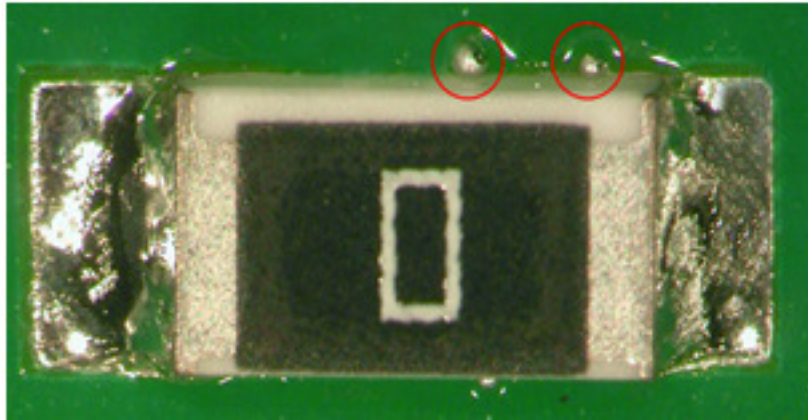


Inverse home-plate

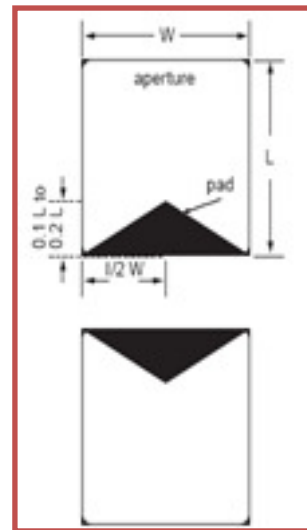


Rounded inverse home-plate

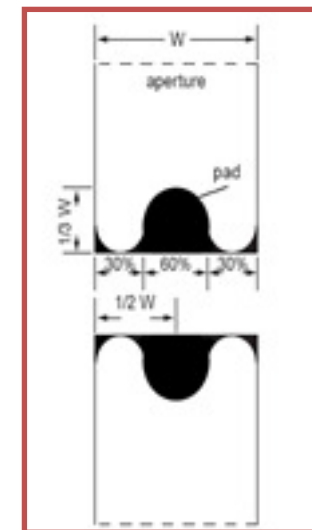
# STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



Home-plate

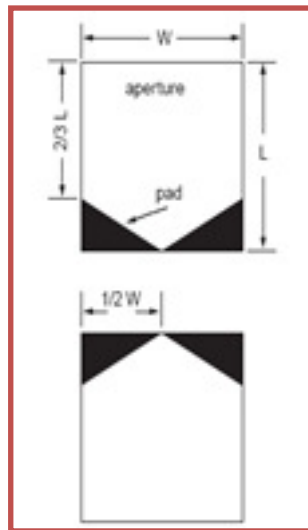
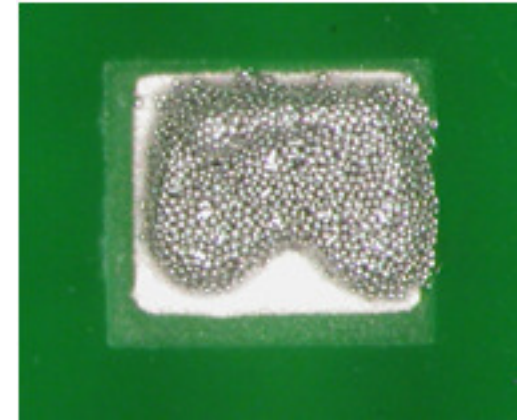
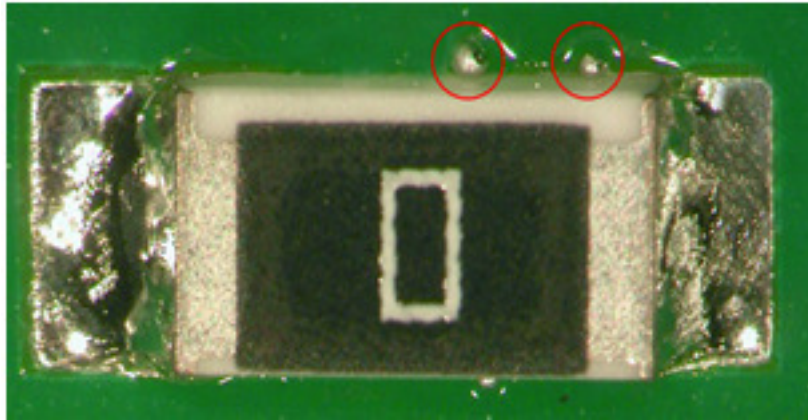


Inverse home-plate

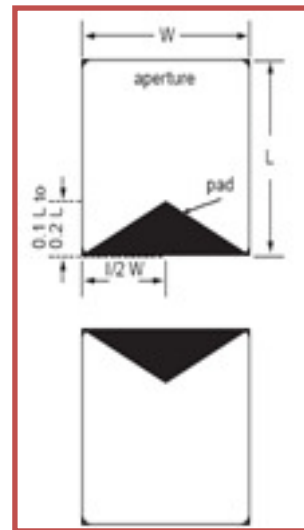


Rounded inverse home-plate

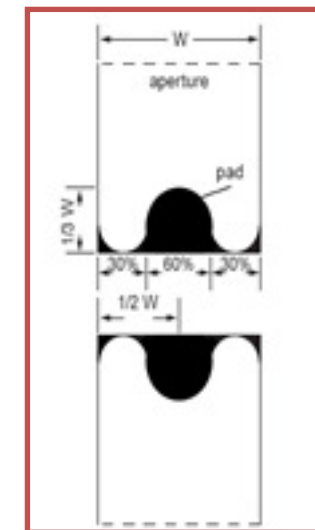
# STENCIL DESIGN FOR PASSIVE SMD COMPONENTS



Home-plate



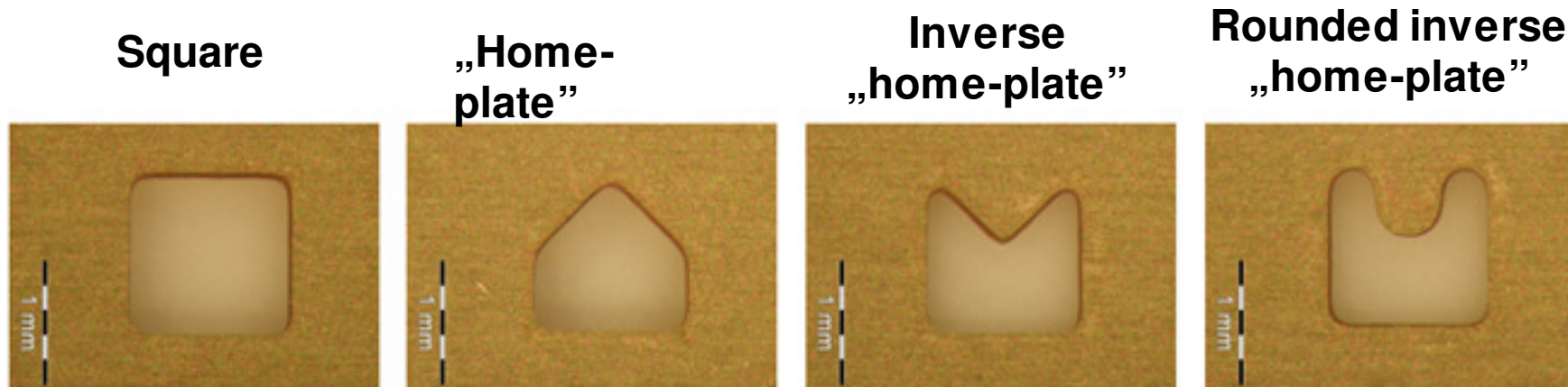
Inverse home-plate



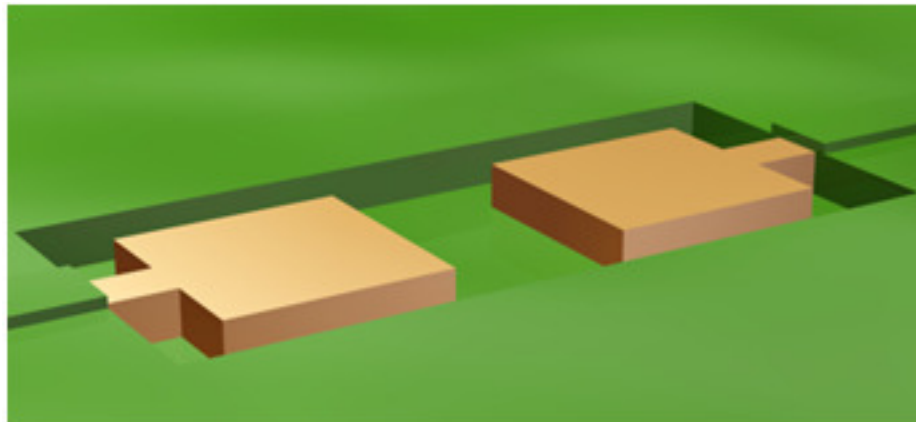
Rounded inverse home-plate



# EXPERIMENTAL ON SOLDER BALLING

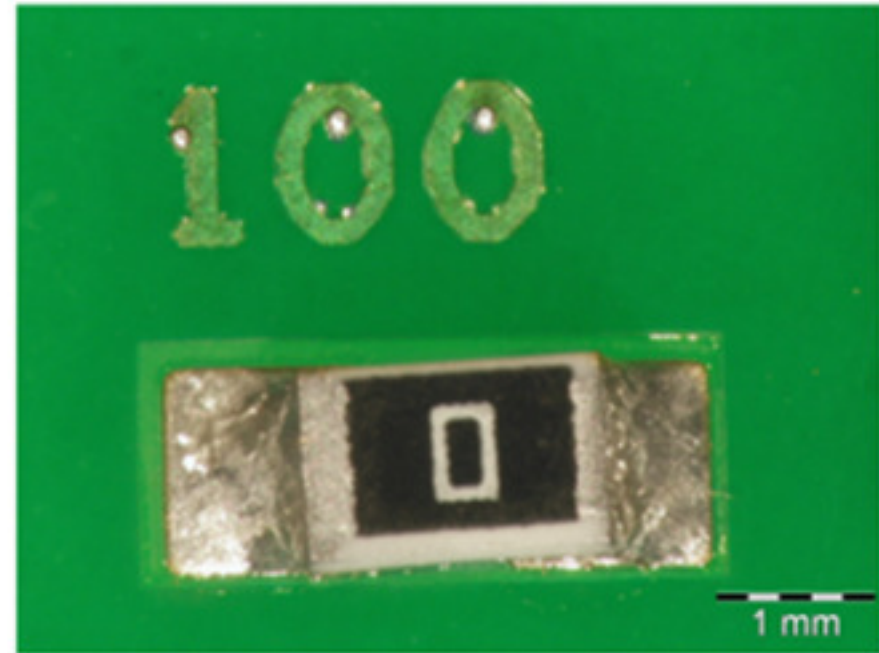
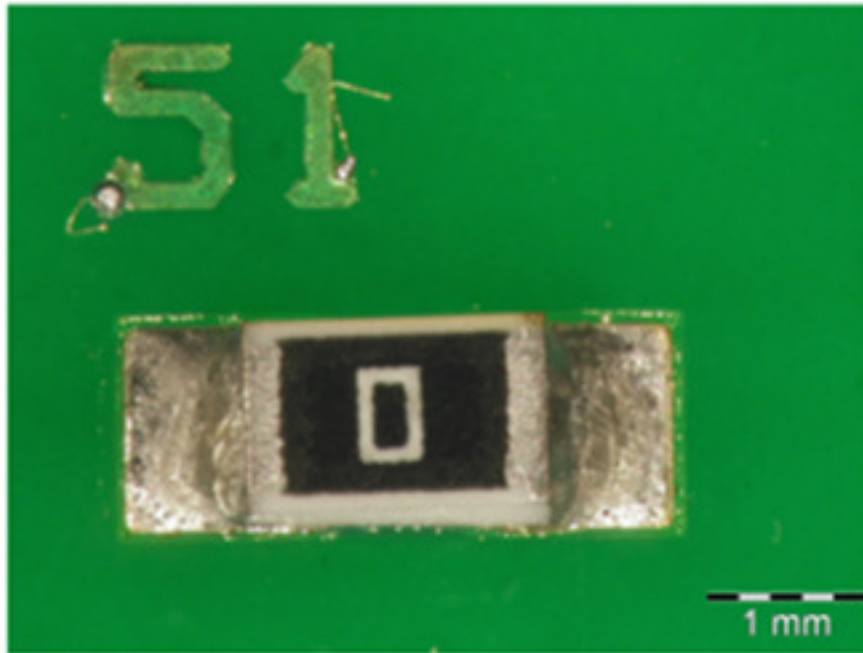


Stencil manufacturer's recommendation – no solder mask bridge between the solder pads



- 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                       |

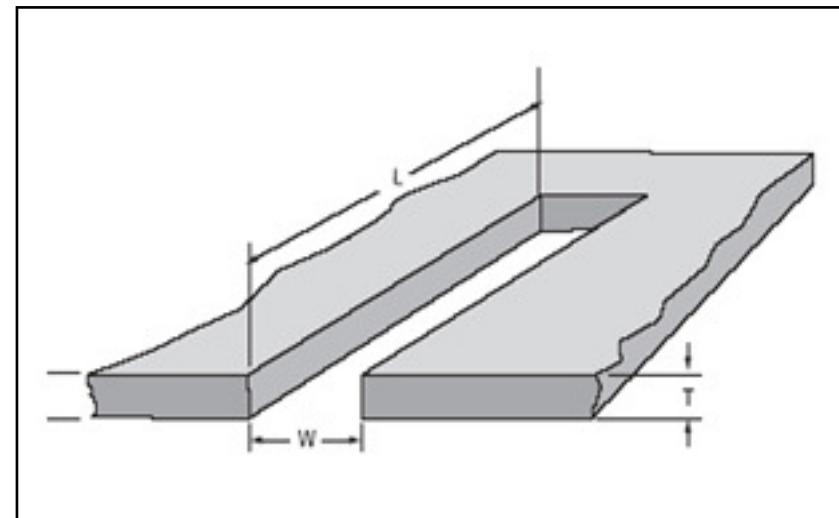
# STENCIL DESIGN FOR FINE-PITCH COMPONENTS

- 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

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

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

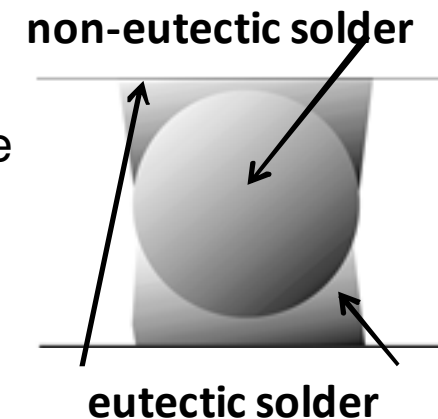
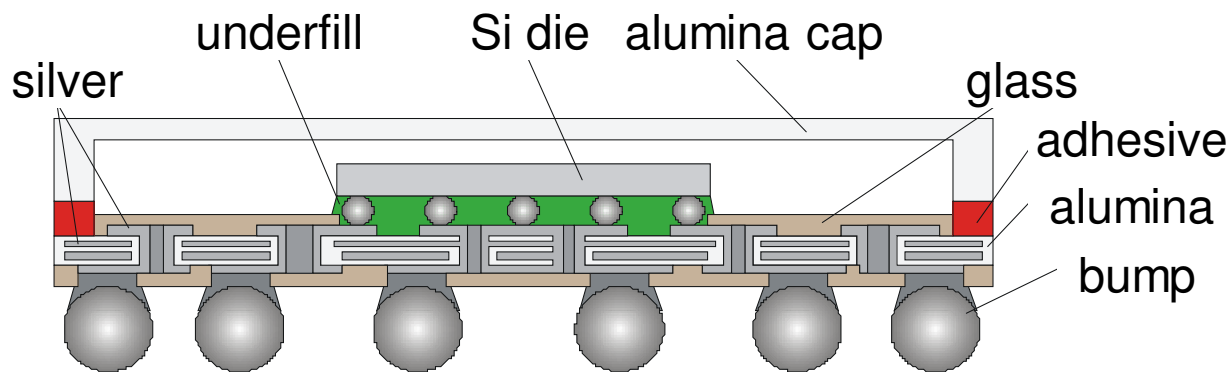
$$AS = \frac{\text{Aperture\_width}}{\text{Stencil\_foil\_thickness}} = \frac{W}{T}$$





# 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

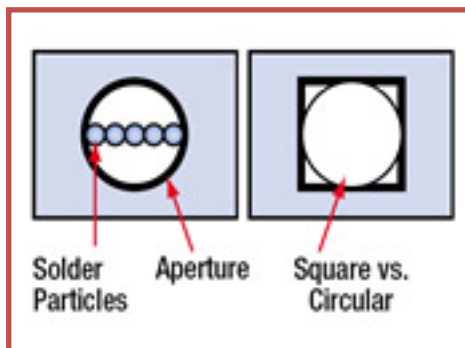
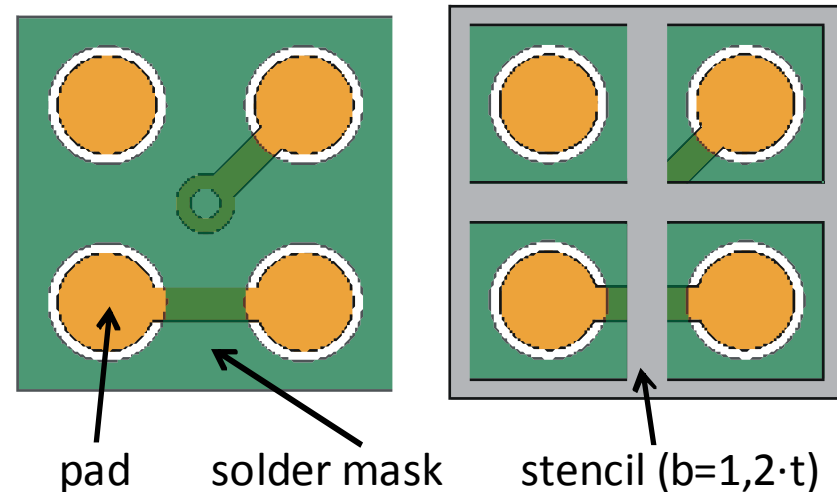
- Square aperture with side length equal to the diameter of pads
- Foil thickness considerations as below
- CSP – take care of particle diameter in paste

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

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

## CBGA package - overprinting

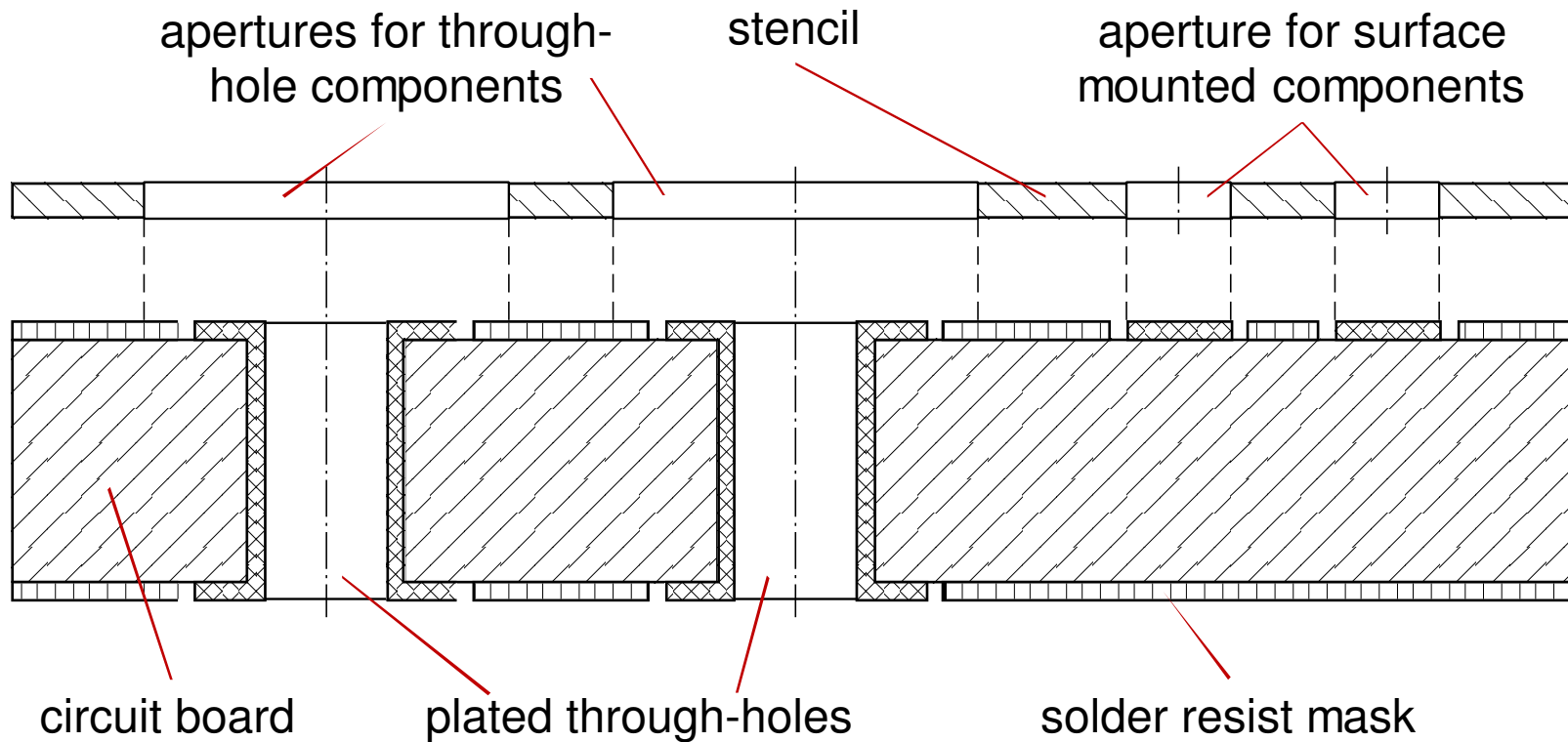
- Min. width of bridge between apertures:  $1.2 \cdot \text{foil\_thickness}$



| 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             |

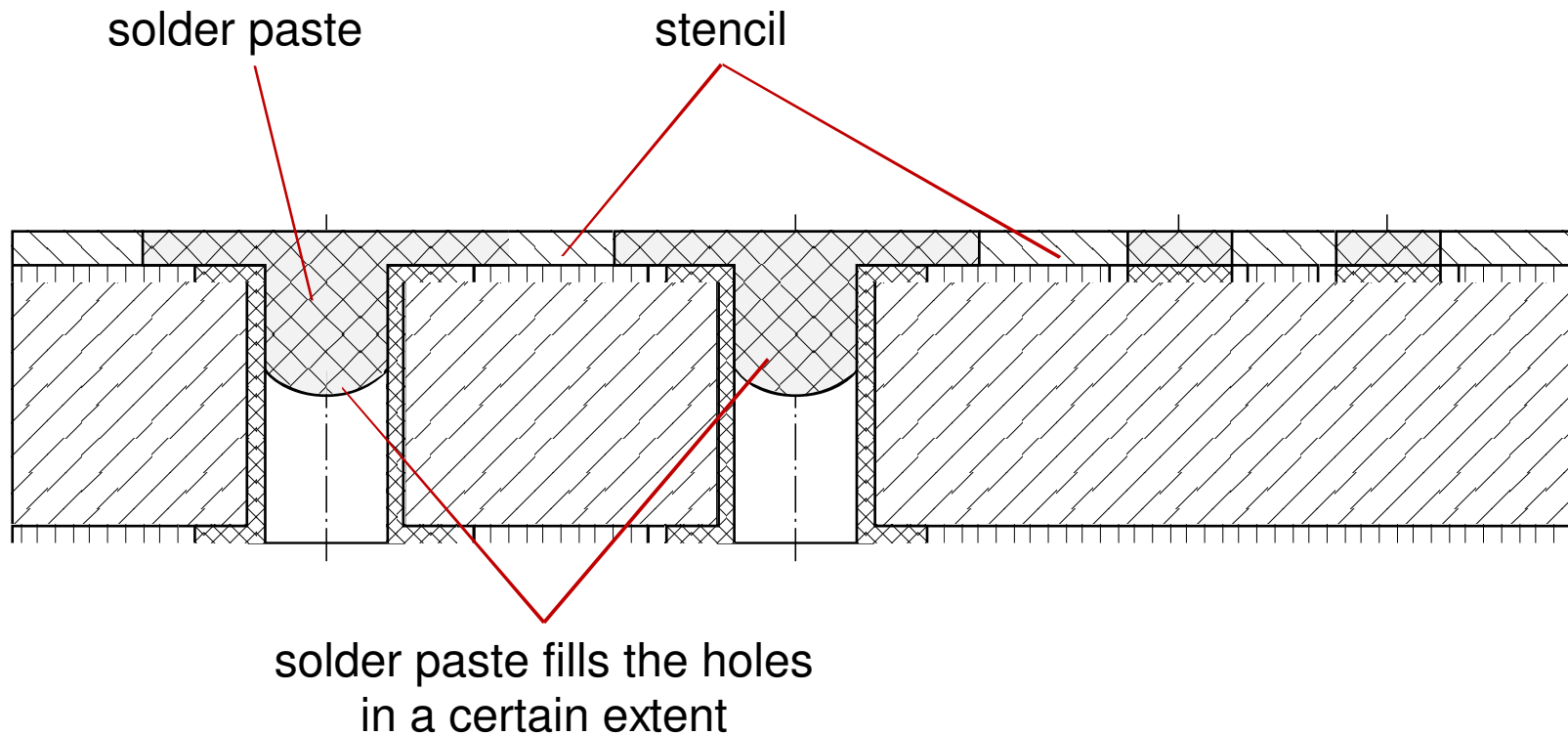
# STEPS OF THE „PIN IN PASTE” TECHNOLOGY

## 0. Starting



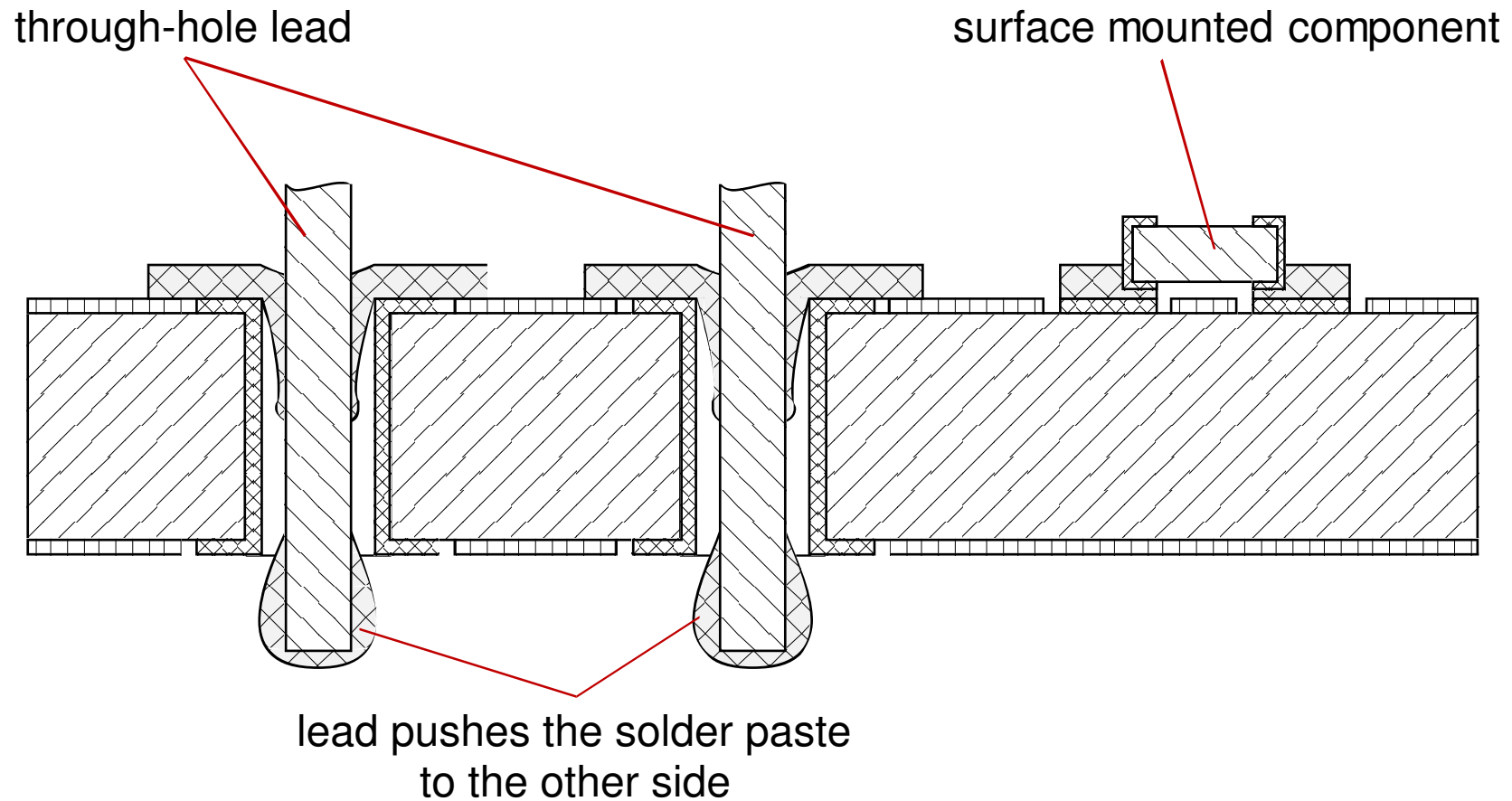
# STEPS OF THE „PIN IN PASTE” TECHNOLOGY

## 1. Stencil printing



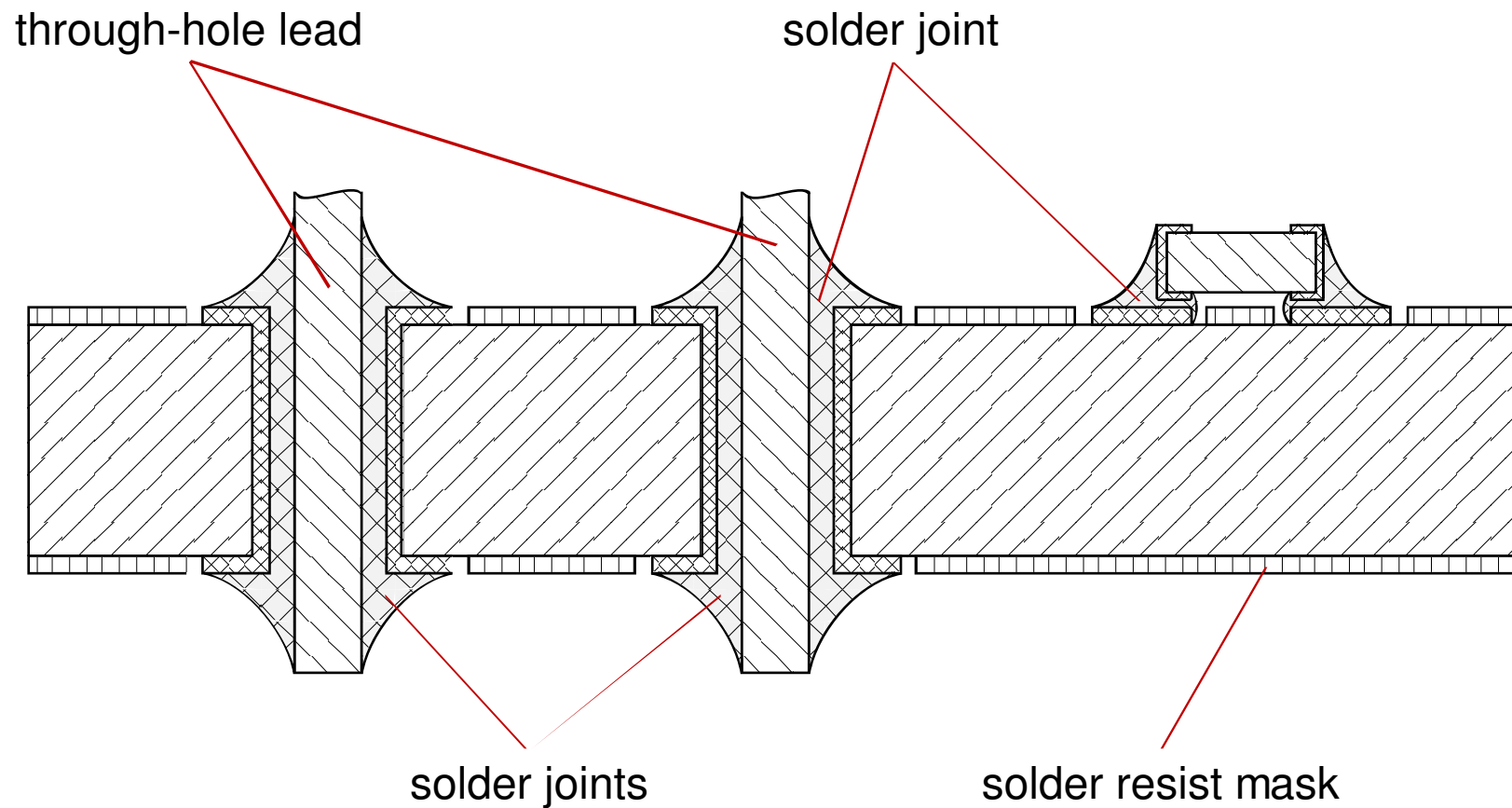
# STEPS OF THE „PIN IN PASTE” TECHNOLOGY

## 2. Component placement



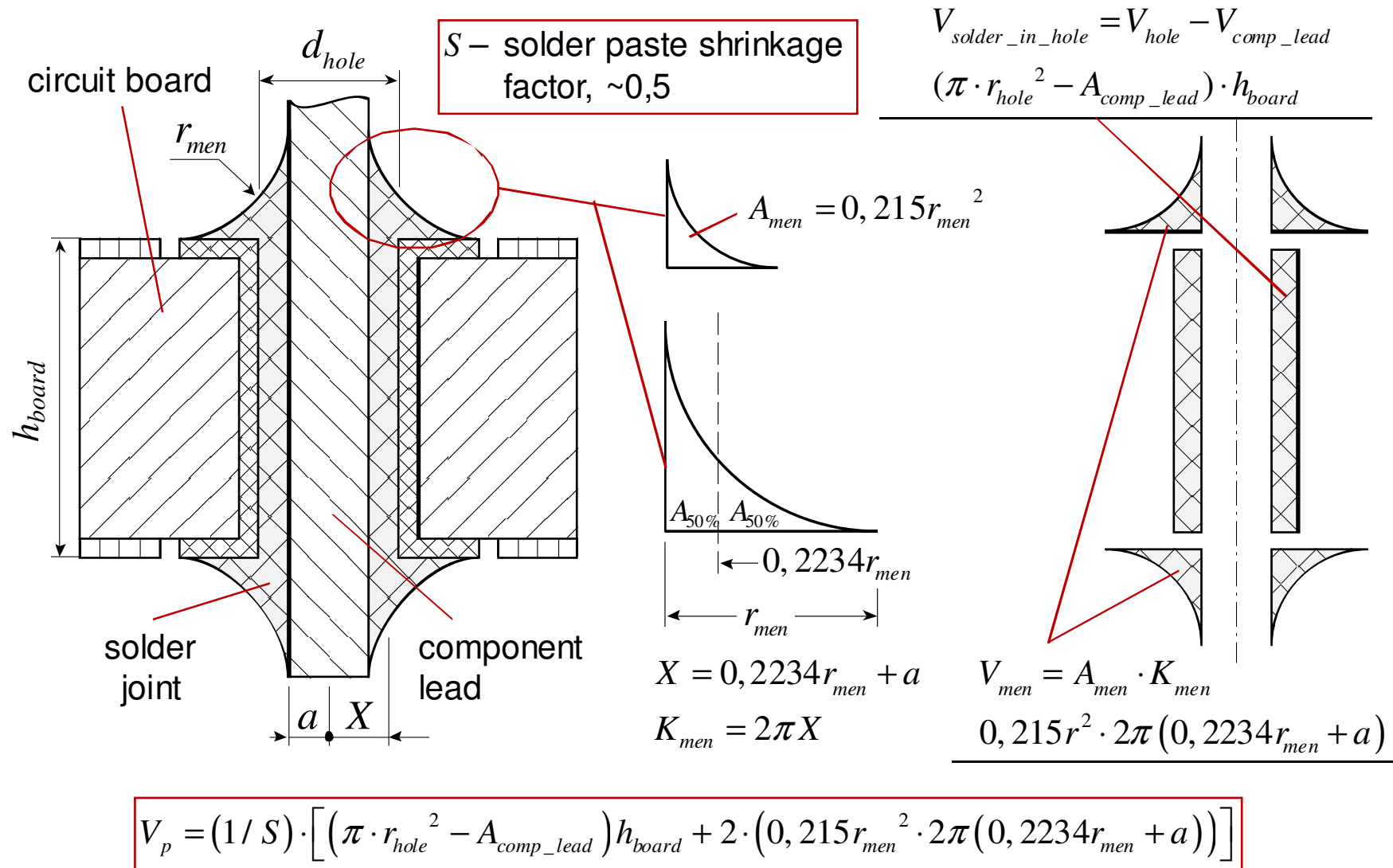
# STEPS OF THE „PIN IN PASTE” TECHNOLOGY

## 3. Soldering

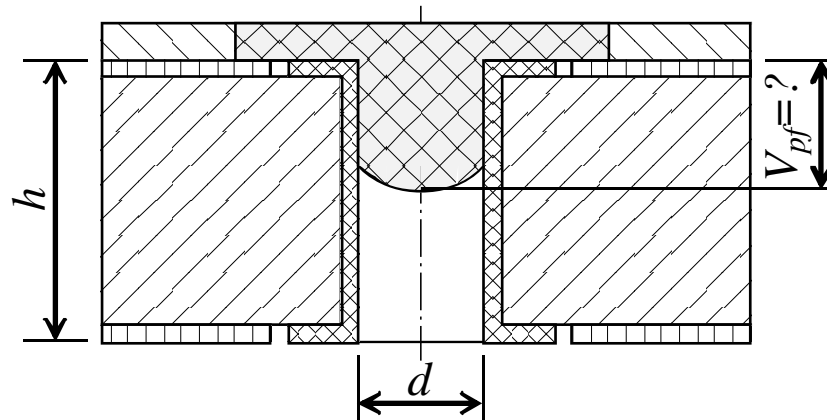




# SOLDER PASTE VOLUME NECESSARY FOR „PIN IN PASTE” TECHNOLOGY



# REQUIRED DEGREE OF SOLDER PASTE HOLE-FILLING



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

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

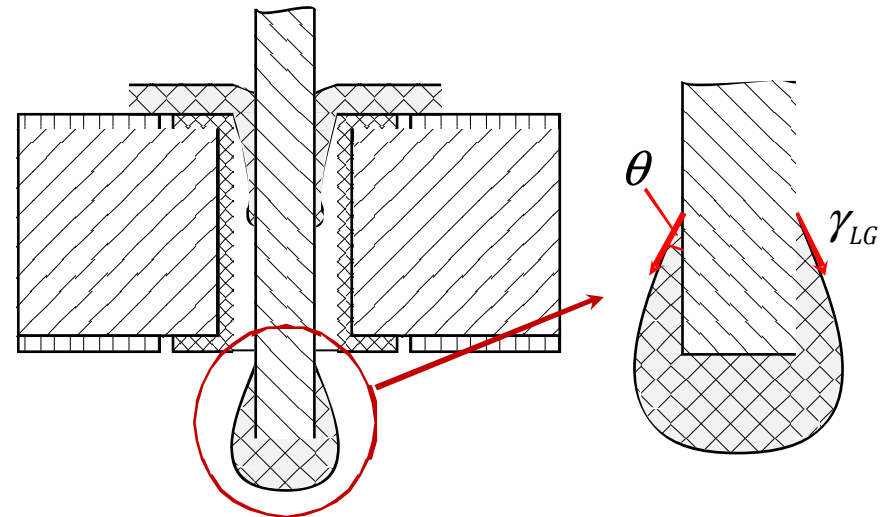
$$V_{pf} = V_{paste} - V_{aperture}$$

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

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

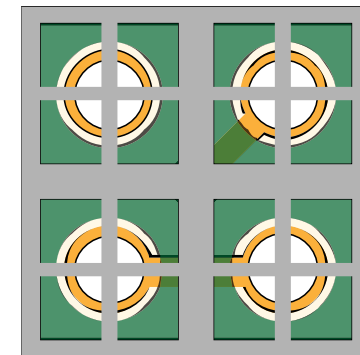
If  $\frac{d}{h} > \frac{2}{1}$ , then  $V_{pf}$  can be too high.

Boundary condition of the fusion:



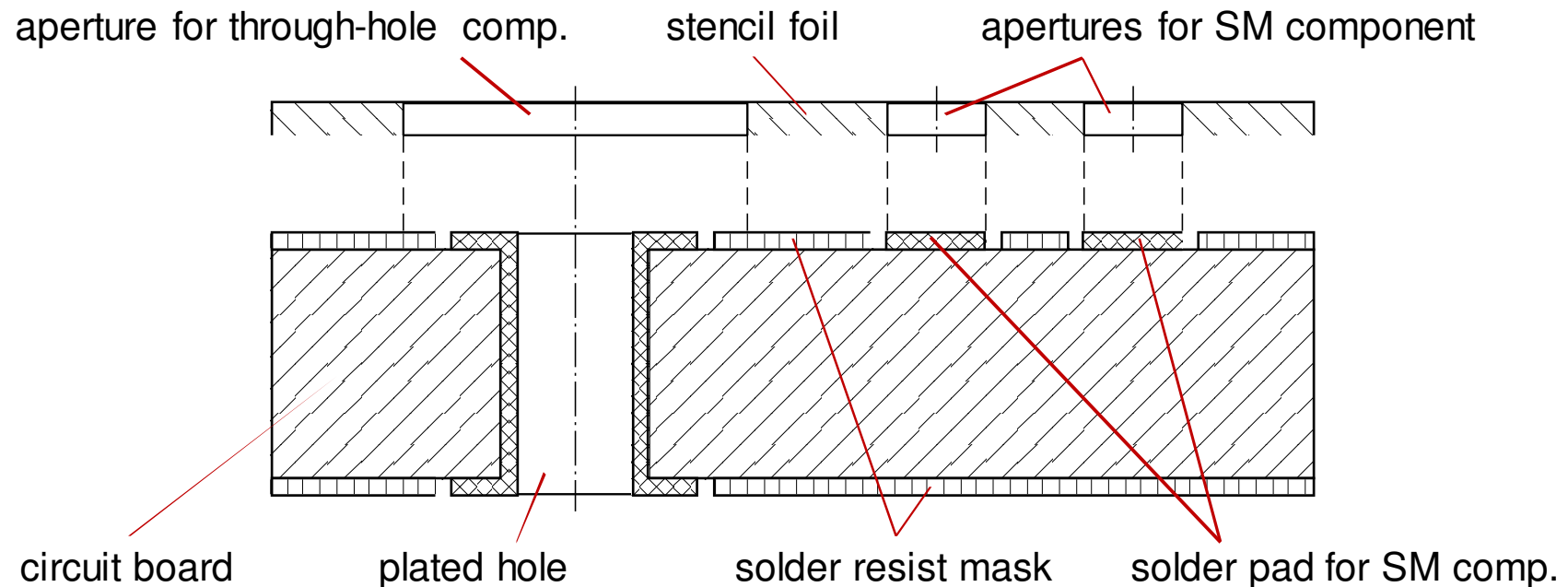
$$F_{grav} = \rho V g \ll F_{surf.tens.} = 2\pi r \cdot \gamma_{LG} \cdot \cos \theta$$

Cross apertures



# OVERPRINTING

|                   | Limits                               | Desirable                             |
|-------------------|--------------------------------------|---------------------------------------|
| Hole diameter     | 0.63...1.6 mm                        | 0.75...1.25 mm                        |
| Lead diameter     | Hole diameter minus 75 $\mu\text{m}$ | Hole diameter minus 125 $\mu\text{m}$ |
| Aperture diameter | Maximum 6.35 mm                      | Maximum 4 mm                          |
| Stencil thickness | 0.125...0.635 mm                     | 0.150...0.2 mm                        |

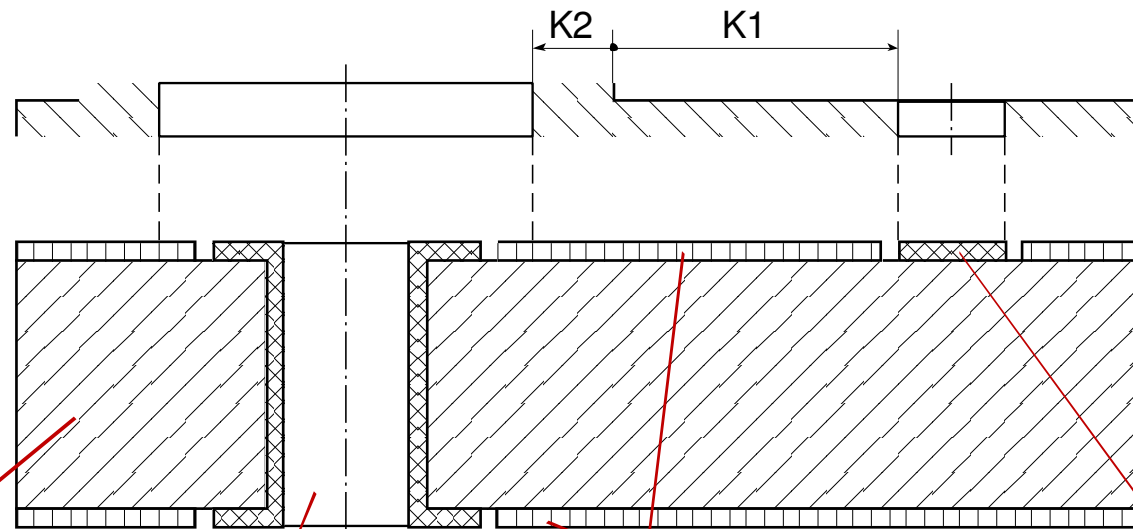


# STEP STENCILS

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

## Design rules:

- Step height is maximum 75  $\mu\text{m}$ .
- 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.



circuit board

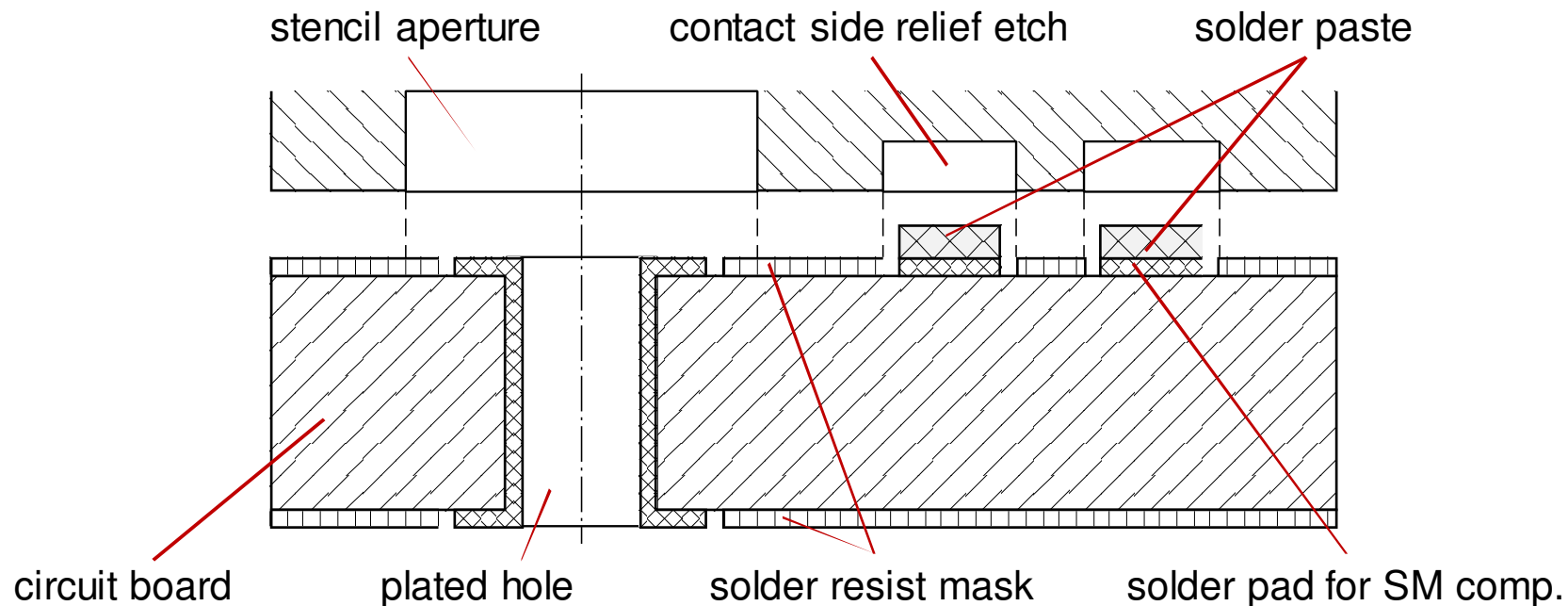
plated hole

solder resist mask

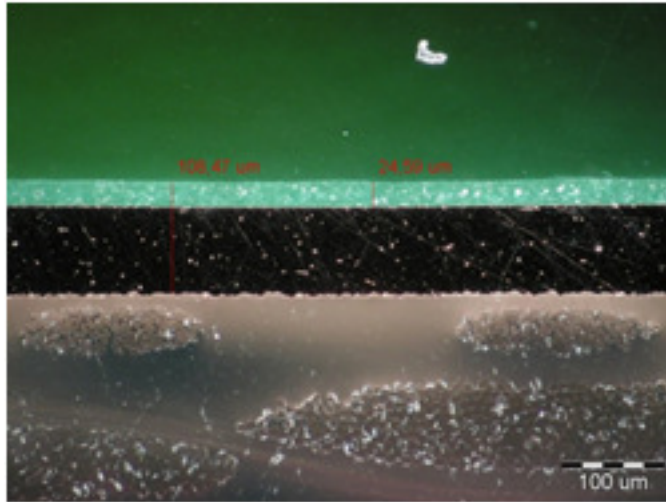
solder pad for SM component

# TWO-PRINT STENCILS

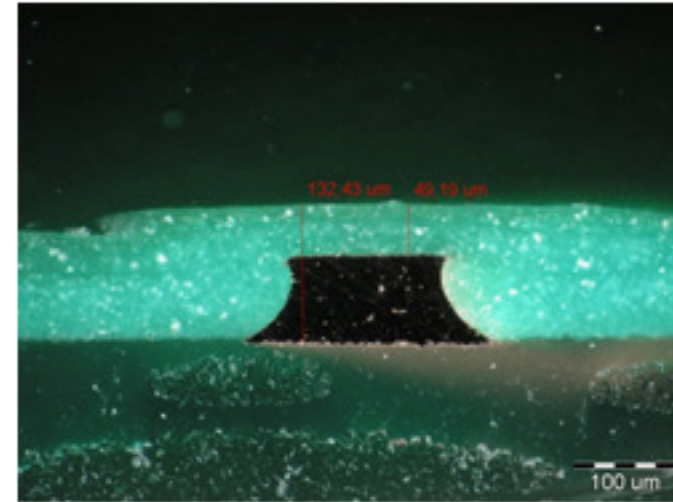
- **First printing** is performed by a thin stencil foil according to the fine-pitch SM components on the circuit (**125...175  $\mu\text{m}$** ).
- **Second printing** is carried out by a thick foil according to through-hole components (**400...760  $\mu\text{m}$** ), relief etch is formed on the contact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



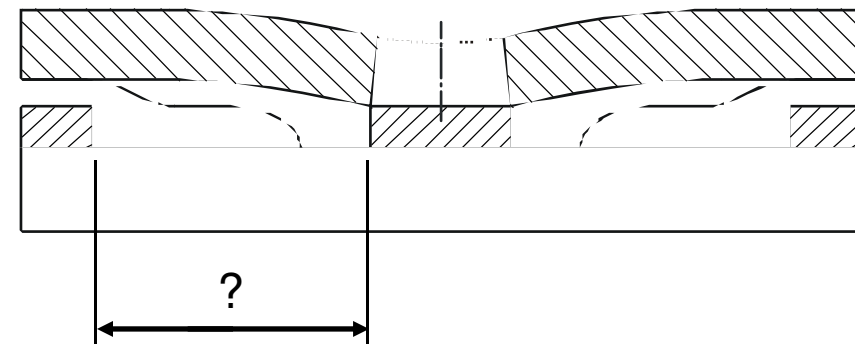
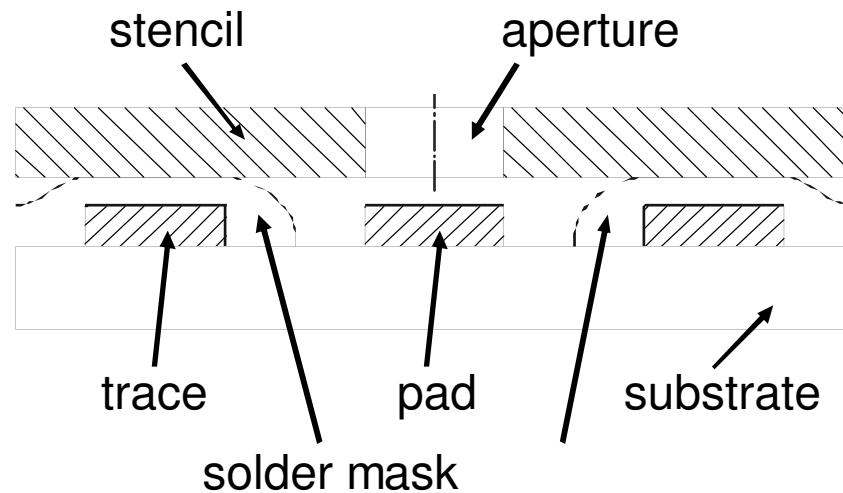
# INVESTIGATING STENCIL DEFORMATION DURING PRINTING



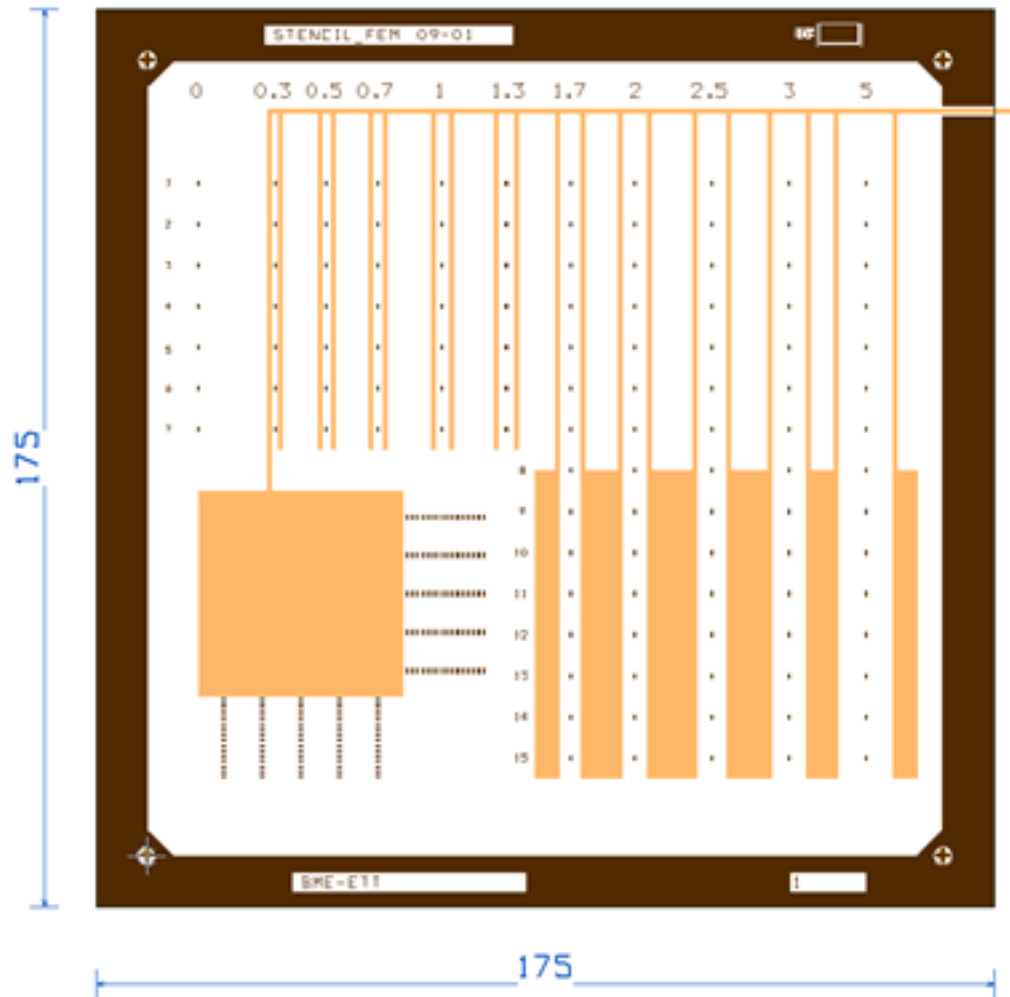
Thickness of solder mask: 25 µm



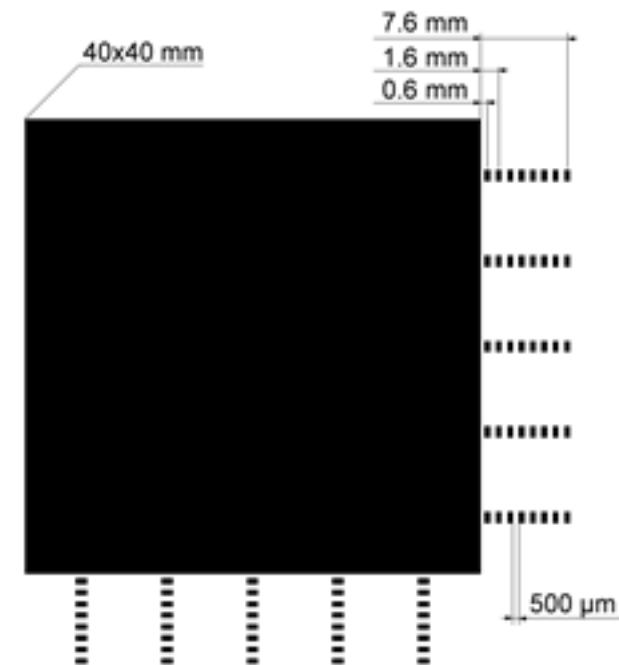
Thickness of solder mask: 50 µm



# THE TESTBOARD

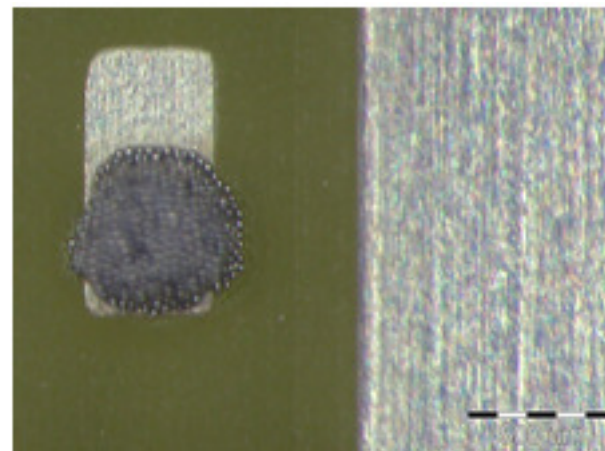
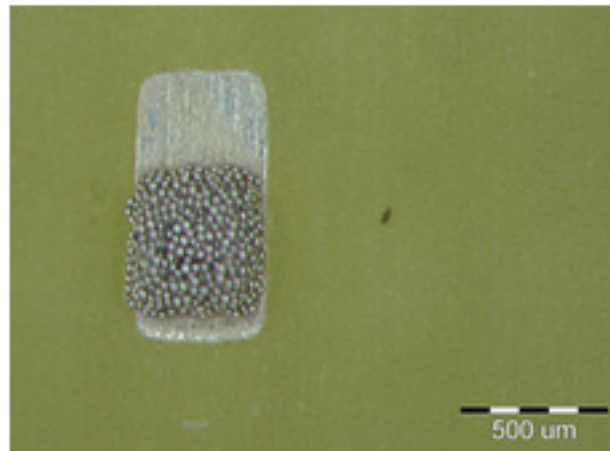


- Base thickness:  
contour and solder pads
- Protruding areas; thickened  
with electroplating



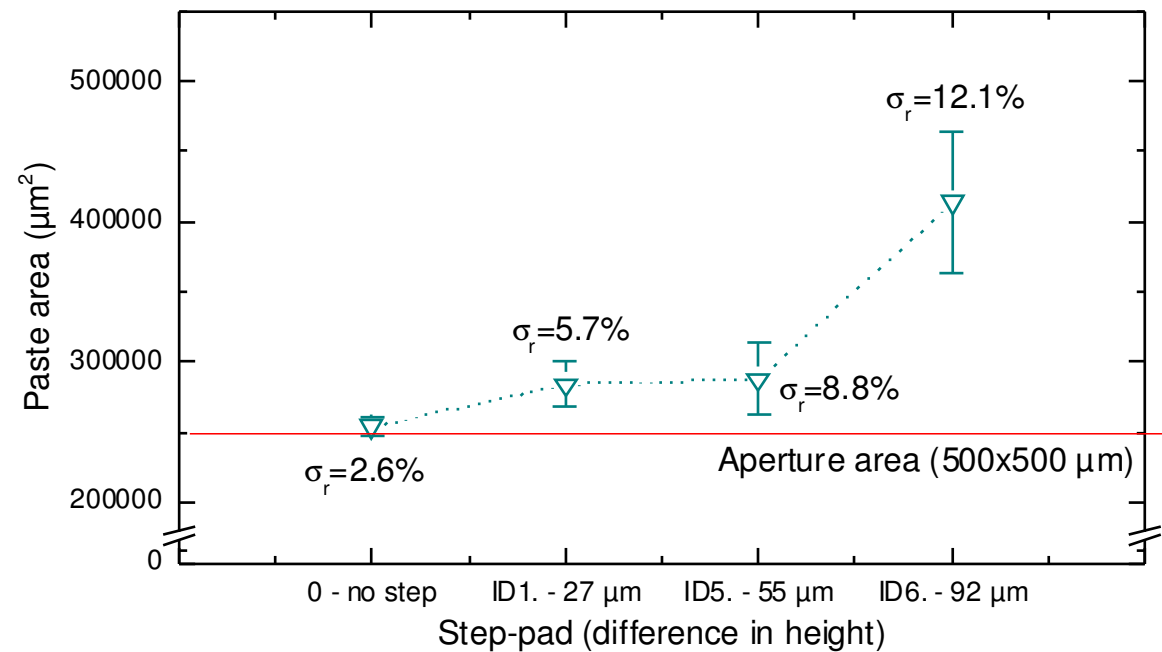


# AREA OF DEPOSITED PASTE



Left:  
ID. 1  
– no step nearby

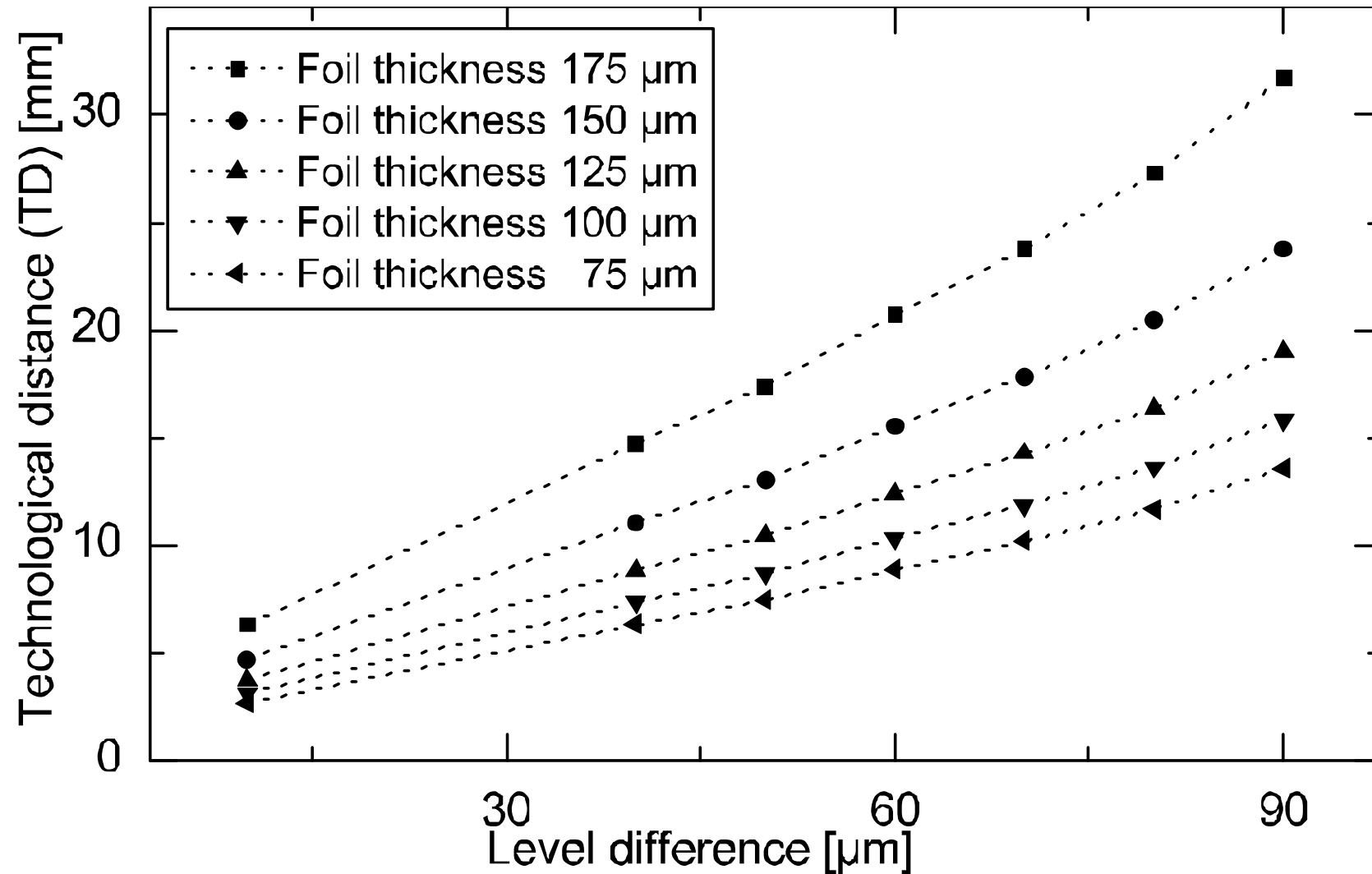
Right:  
ID. 6 – 0,5 mm  
step distance



# PARAMETERS OF THE FINITE ELEMENT MODELLING

- Squeegee length 30 cm
- Squeegee force 92 N
- Squeegee thickness 200  $\mu\text{m}$
- Squeegee angle  $60^\circ$
- Highest level difference 90  $\mu\text{m}$
- Simulated foil thicknesses: 75...175  $\mu\text{m}$ , in 25  $\mu\text{m}$  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  $36 \cdot \text{step\_thickness}$
- For contact side steps, recommended technological distance to the nearest surface mounted component is  $1.6 \cdot \text{step\_thickness} \cdot \text{foil\_thickness}$