Research of paste transition to substrate in LTCC-technology

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Abstract. The electronics development demands for accuracy of printed technologies, in particular, to screen printing. Under a flat blade operation the print form is deformed and the image is distorted relative to the original. A squeegee in a form of a smooth cylinder reduces distortion, but it allows obtaining satisfactory print quality only when using high density grids. The paper shows findings of using roller squeegee with dosed ink supply. The roller squeegee is provided with an elastic layer. Dosage is carried out due to the cells on the elastic layer surface. There were used meshes 100-31 and 120-34 for the stencil. The experiments were carried out with layers of photopolymers and rubber. The carried out calculations made possible to choose the optimum printing pressure. Under the selected conditions, the printed image had minimal distortion. The findings allow drawing a conclusion about the possibility of roller squeegee using in chips manufacture according to LTCC-technology.

Keywords – screen printing, electronics, roller squeegee, mesh surface.

1. Introduction

When printing a squeegee is usually used in an elastic plate form.

![Schematic representation of screen printing with flat squeegee.](image)

Figure 1. Schematic representation of screen printing with flat squeegee.

Screen printing allows obtaining a layer of paste with thickness of up to 100 μm. This feature made screen printing irreplaceable in manufacturing of microchips for thick-film technology, sensors and meters. The transition of paste to the substrate mainly depends on pressure in paste under the squeegee
operation. Studies of pressure distribution in paste and solder paste under a flat blade operation were carried out by Dietrich E. Riemer (1988) [1, 2], Ekere N. N. and Lo E. K. (1991) [3], Mannan, S. H. et al (1993) [4], Glinski G. P. et al (2001) [5].

Disadvantages of using a flat blade:

1. mesh deformation due to friction forces between screen and squeegee. The standard stencil elongation is approximately 100 μm for a 450×450 mm screen frame with an area of 150×150 mm [6];
2. of-contact, necessary to separate the mesh from the substrate.

I. J. Fox, T. C. Claypole and D. T. Gethin (2003) [7] examined the possibility of screen printing with a roller squeegee. The work revealed a lack of roller squeegee - a satisfactory print quality is obtained on a grid of 150-34 or more. If lower grid density is used, paste spreads on the substrate. Its reason is especially the pressure distribution in the printing paste when the roller squeegee moves. Figure 1 shows the pressure distribution obtained experimentally by Litunov S.N. (2007) [8]. Distance A is marked on Figure 2 where paste is forced through the mesh with the roller squeegee action. The distance is measured from the contact point B between the roller squeegee and the printing surface. Sagging paste is accumulated on the back side of the screen when roller squeegee moving and it is crushed along the substrate.

2. The object of study
A squeegee roller with paste dosing has been offered (Litunov S.N. et al., 2006) [9]. It is a metal cylinder with an elastic layer. There are cells on the surface of the elastic layer and they are filled with paste during the printing process. Excess paste is removed with a metal blade (Figure 2). Printing is carried out through the flow of paste through the stencil when the cells are deformed under the action of pressure. The object of the study is an experimental study of printing with this device and the transition of paste from the elastic layer cells to the substrate.

3. Methods
3.1. Roller squeegee material parameters
When printing the elastic layer deforms in the contact strip. The cell volume decreases and paste is forced through the screen (Figure 3). Thus, the quantity of paste passing through the screen depends on the cell deformation.

37 mm diameter steel roller was used in our study. Photopolymer materials ACE of BASF firm (Germany) and NS of TOYOBO firm (Japan) are used in flexographic printing. The cells on the photopolymer material were obtained using technology adopted in flexographic printing. Also oil-and-petrol resistant (OPR) rubber was used. Cells were obtained with laser engraving on the rubber. Cells on photopolymer material (A, C) and rubber (B, D) are shown on figure 4. Mechanical
characteristics were measured on a tensile breaker IP 5158. The cell size obtained with photographs was used to calculate the volume of the cells.

![Cells Image](image)

**Figure 4.** The image of the cells from the top (top) and the section (bottom): A and C are polymer material; B, D are rubber.

The characteristics of the selected materials are given in Table 1.

| Name of Material                        | Thickness, mm | Depth of the cell, mm | Elastic modulus, MPa | Poisson’s ratio | Cell volume, mm³ |
|----------------------------------------|---------------|-----------------------|----------------------|----------------|-----------------|
| ACE, BASF (Germany)                    | 1.52          | 0.16                  | 28                   | 0.485          | 0.0098          |
| NSF, TOYOBO (Japan)                    | 2.66          | 0.18                  | 37                   | 0.435          | 0.01103         |
| Oil-and-petrol resistant rubber        | 1.75          | 0.22                  | 7                    | 0.5            | 0.0229          |

3.2. Mechanical parameters of the elastic layer
To select the printing pressure experiments were conducted to determine the deformation of the elastic layer material depending on the load. The measurement scheme is shown in figure 5.

![Measurement Scheme](image)

**Figure 5.** Scheme of measuring the elastic layer material deformation.

The deformation dependence on the load for the materials under study is shown in figure 6.
Each chart has an inflection point. The deformation of the material develops linearly before and after this point. Mainly the cells on the material surface are deformed before the inflection point. After the inflection point, both the cell and the material are deformed as a unit. It is not clear in what range the optimal print pressure is. To select the printing pressure during the experiments, the deformation of the material with the cells on its surface was calculated.

The deformation was calculated for the element (Figure 7) considered an elastic rod on an elastic base. When calculating, it was assumed that the pressure was evenly distributed over the surface of the element; the material is isotropic and incompressible; each vertical end of the element can move only in a plane that coincides with it; the rigidity of the element and the elastic base are equal.

The deformation of the rod was determined with the equation:

$$\frac{dW}{dz} = \varepsilon_z,$$  \hspace{1cm} (1)

where \(W(z)\) is the longitudinal displacement of the cross section with the coordinate \(z\); \(\varepsilon_z\) is \(z\) cross sectional points elongation.

The equation of equilibrium of the rod element separated with two sections has the form \(N(z) = -P\), where \(N(z)\) is the normal force in the cross section \(z\); \(\sigma(z)\) is the normal tension at points of the cross section \(z\); \(F(z)\) is the cross-sectional area of the rod \(z\).

The accepted boundary conditions are:

$$W(0) = 0; \ \ N(z) = -W(c) / \delta,$$ \hspace{1cm} (2)

where \(\delta\) is the compliance of the base where the rod is located.

Rod relative deformation \(\varepsilon_z\) was determined using the system of equations (1) and (2). Using ratio \(\varepsilon_z = \nu \varepsilon_x = \nu \varepsilon_y\), where \(\nu\) is Poisson's ratio, the rod relative deformation \(\varepsilon_x, \varepsilon_y\) was defined in \(x\) and \(y\) directions respectively.

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**Figure 6.** Deformation dependence on the load of elastic layer materials.

**Figure 7.** An element for calculating the cell deformation.
Equation (1) in a form of finite differences is
\[ W[z(i+1)] = W[z(i)] + N[z(i)] \cdot \Delta c / (E \cdot F[z(i)]) \]
where \( W[z(i)] \) and \( W[z(i+1)] \) are displacements in the longitudinal direction of the cross-section at the \( i \)-th and \( (i+1) \)-th step; \( N[z(i)] \) is the force normal to the transverse \( i \)-th cross-section; \( F[z(i)] \) is the cross-sectional area at the \( i \)-th step. Newton’s method was used for the calculation. The calculation was carried out in the EXEL software. A trend line was obtained for each cell profile in a form of an exponential dependence. Having integrated from zero to the depth of the cell, considering the Poisson’s ratio, the volume of the deformed cell was obtained.

According to the results of calculations, knowing the amount of paste to be passed through the substrate during the cell deformation, the optimum load on the roller squeegee was determined. It was 0.11 kg/mm for NFS material, it was 0.07 kg/mm for ACE material, it was 0.02 kg/mm for oil-and-petrol resistant rubber. The cell profile on the ACE material deformed with a load 0.07 kg/mm is shown in figure 8.

**Figure 8.** Cell profiles on ACE material.

### 3.3. Printing devices

A printing device is shown in figure 9 it has a carriage 1, a roller squeegee 2 with an elastic casing 3, a metal blade 4, adjusting screws 5. The stencil is mounted in clamps and is not shown in figure 9.

**Figure 9.** Printing device with a roller squeegee.
The carriage speed was 148 mm/s, 193 mm/s, 232 mm/s. The diameter of the roller squeegee is 40.04 mm for ACE material, 42.32 mm for NSF material, 40.5 mm for oil-and-petrol resistant (OPR) rubber. The polyester meshes SAATI 100-31 нит/sm and 120-34 нит/sm were used. The net tension is 21 н/sm.

The image on the stencil test was a scale with lines 05-0.5 mm thick, that are along and across the roller squeegee movement and plots with raster fields.

During the experiments varied parameters were the elastic material layer, stencil mesh and carriage speed with a roller squeegee. As a paint, plastisol paint with a metallic pigment of viscosity 700 Pa∙s was used. Such paint by its properties is closest to the pastes used for the production of LTCC-microcircuits. On the obtained prints there were monitored changing line lengths along and line thickness disposed transversely roller squeegee motion. The measurements were carried out using a universally measuring microscope UIM-21. The substrate was organic glass sheets 4 mm thick.

**Results and experiments**

Increase in speed in the selected speed range slightly affects the change in the size (0.5-1.0%). The hardest of the subjects is the NFS material, it gives the least change in size, and the least hard is OPR rubber and it gives the biggest change. This is because the less rigid material is deformed more, and more paste passes onto the substrate. However, no dependence of the size change on the cell volume was detected. Hence, it can be concluded that the optimal print pressure is selected correctly. The deviation of the length of the lines on the print from the length of the lines on the original has been increased by 0.01-0.015 mm with a line length of 150 mm and a frame size 450 mm. This is less than the standard extension by 3-4 times. The deviations along the line width had the same values. It allows to conclude that the increase in the lines size does not occur from the deformation of the stencil during printing, but from the flowing of the paste under the whitewashed elements, and it is typical for screen printing as a whole. This defect is eliminated at the prepress stage. The findings allow to draw a conclusion about the possibility of using roller squeegee in the manufacture of microcircuits using LTCC-technology where the incompatibility between the layers of the chip should not exceed 20 % from the minimum diameter of the transition hole [10].

Among other features of the printing device operation with a roller blade type, the phenomenon of self-sticking, which allows to reduce of-contact to minimum can be noted. During the experiments, the gap was zero. At the same time, the substrate was on the printing table freely, without fixation.

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