PRINTED-CIRCUIT BOARDS. RELIABILITY OF INTERCONNECTIONS

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ABSTRACT

Stability of metallization of holes to thermomechanical pressure is provided with durability and plasticity of galvanic besieged copper.

Distinctions in factors of thermal expansion of copper and the dielectric bases of printed-circuit boards create powerful thermomechanical factors of rupture of metallization of apertures, destructions of internal interconnections in multilayered structures of printed-circuit boards. Standard norms of requirements to a thickness of metallization of apertures, its durability and plasticity of copper were established in the course of manufacture of ordinary printed-circuit boards with reference to use of traditional technologies of the soldering by tin-lead solders. Return to consideration of a problem of plasticity of copper is caused first of all by transition on the Lead-free solders, initiated by the all-European Directive RoHS [1], rations different by a heat. More heats create the big deformations of metallization of holes those forces to reconsider requirements to plasticity of copper. At the same time, the tendency to reduction of diameter of the metallized holes, so also to reduction of the area of cross-section section of metallization is everywhere observed. Smaller sections have smaller resistance to rupture. Therefore, along with good plasticity, metallization of holes of printed-circuit boards should provide and higher breaking strength. In this connection deformation of metallization of holes at heating to soldering temperatures has been investigated. The purpose of researches - revision of norms on plasticity of copper in holes of printed-circuit boards. It is shown that plasticity copper deposition in holes of modern printed-circuit boards should not be less than 6 % [2]. Modern cupper electrolytes allow to receive plasticity of copper of 12-18 % [3].

Keywords: PCB, Interconnection, Reliability, Plasticity of copper

Essence of problem

The elements of interconnections exposed to thermal loads in the process of manufacturing, assembling and cyclic changes in temperature during operation of the equipment. Differences in temperature coefficient of linear expansion (TKLR) conductive structures and dielectric in electrical connections are the thermomechanical tension of various intensity. In longitudinal reinforced fiberglass patches, differences in TKLR are so small that they do not affect the strength of the connections of the longitudinal structure.

In the transversal direction perpendicular to the plane of the reinforcement, the differences are so significant in linear expansion ($17 \cdot 10^{-6}$ for copper (100…400) ·10 -6 for dielectric basic) that occur when thermal loadings are able to destroy the thermomechanical tension interlayer connection.

Es's know that resistance of metallized holes to the thermal-mechanical loads are thick and plasticity of metallization. Standard requirements for metallization on these quality criteria have been established during the years of practice manufacturing and operation of electronic devices with printed with a thickness of boards to the diameter of the hole from 1: 1 to 3: 1. When the amount of through holes less than 0.3 mm is the ratio can be as high as 10:1 current. 20:1. In such constructions for multilayer printed circuit boards (MLB) metallization aperture ratio results sections and the surrounding material of the bottom board is not in favor of metallization in conditions of thermal effects increases the deformation of metallization of vias (fig. 1). This phenomenon is exacerbated by the decline in copper metallization of plasticity with increasing temperature.

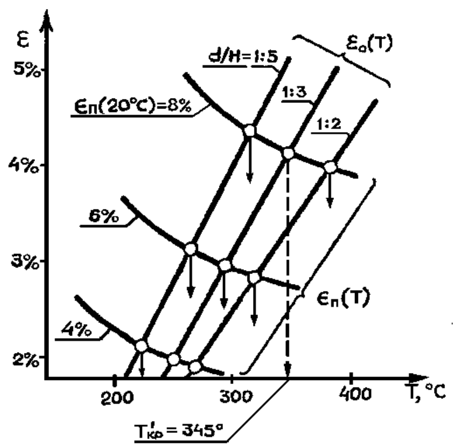

Figure 1. Ehe toughening of requirements to the plasticity of metal as the diameter of the hole.

Statistics show that especially big bounce stream observed in interlayer connections, systematically exposed to cyclic changes in temperature (Thermo-cycles). According to the long-term operation of aviation systems printed circuit failures are distributed as follows: metallized holes-24%, inner joins-72%, printed conductors internal layers-0.1%,-2%, 2.5%, breakages of solder wire-0.3%,-0.6%. Comparing the number of refusals of MLB in the stationary equipment operators in relative constancy of temperature, and airborne show the difference in nearly three orders of magnitude, that has convinced us that, if the level of variable tensile exceeds a certain limit of thermo-mechanical, is in the process of gradual accumulation of damage, which concludes with a fatigue destruction.

Model of Thermo-mechanical stressing

Thermomechanical stress during heating cause the stretching along the axis of the hole metallization (axial) and flex contact pads, with the largest concentration of which focuses on the junction with metal cylinder bores (tensile drop). A typical distortion of holes form when heated schematically shown in figure 2 and photos of microsection in figure 3.

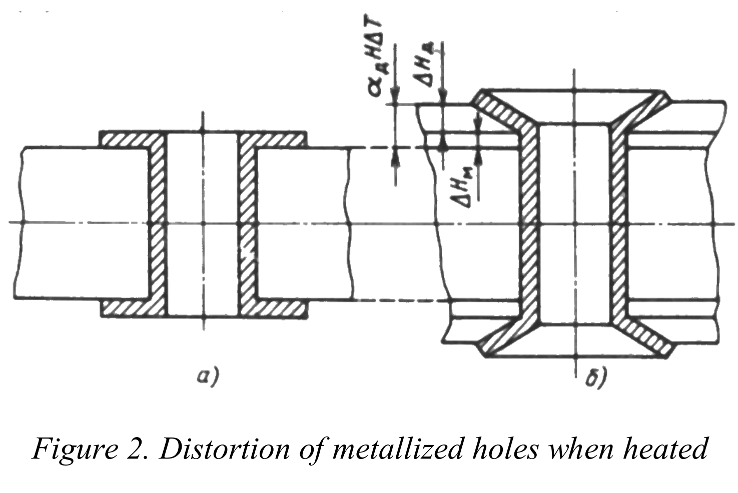

Figure 2. Distortion of metallized holes when heated

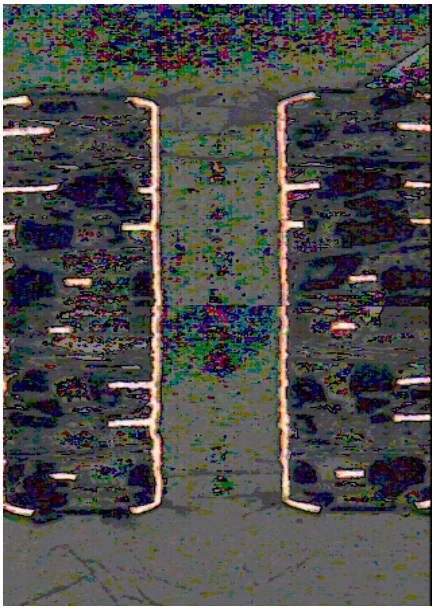

Figure 3. Microsection of metallized holes after thermo shock

In general, the relative deformation at temperature influences σ_Z plating can be represented as the sum of the elastic ε_Y and of the thermal deformations ε_T. Elastic deformation of the $\varepsilon_Y = \sigma E$ (E- elastic modulus). Thermal deformation of $\varepsilon_T = \alpha(T\text{-}T_0)$. Hence the thermomechanical stress $\sigma = E\,[(\sigma_Z - \alpha(T\text{-}T_0)]$. Thermomechanical efforts in each of the elements of metallized holes:

$$F = E[(\sigma_Z - \alpha(T\text{-}T_0)]\ h\ dZ.$$

To determine the characteristics of Thermo-mechanical deformation equilibrium equation we write metallization of the condition that the sum of all thermo-mechanical effort, resulting in components of "metallization-wall holes ", must be zero (Figure 4):

$$\int_0^{h_M} E_M[(\varepsilon_Z - \alpha_M(T - T_0)]hdZ + \int_{h_Д}^{0} E_Д[(\varepsilon_Z - \alpha_Д(T - T_0)]hdZ = 0$$

After integration and transformation it can be shown that deformation of copper in transversal Z-direction is:

$$\varepsilon_Z = (\alpha_Д - \alpha_M)\ (T - T_0)\ (1 + J_M/J_Д)^{-1} \qquad (1)$$

Here $\alpha_Д$ and α_M - thermal expansion coefficient, J_M and $J_Д$ -conventional hardness of copper and dielectric.

If ε_Z exceeds the limit of ductility of copper sludge in the hole (or $\sigma_P > \sigma_{ПЧ}$) annular gap metallization.

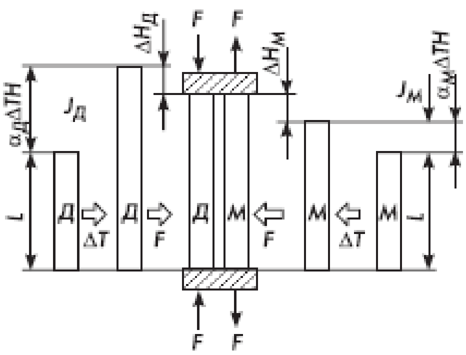

Figure 4. Thermo-mechanical stress analysis model of axial

If the forces of adhesion plating machines with small holes can be realized in the shear fracture of inner joins. Shear stress, obviously, should increase with increasing distance from the neutral axis interface 0- -0 (figure 5). The nudge distance, if it occurs, you can determine, on the basis of public views. But if the coupling forces hold metalizing on joints, holes developing temperature increases shear stress equals $\sigma_{Сдв} = G(\alpha_Д - \alpha_M)\Delta T$. Value destructive shear stress is determined based on the experimental values of hole metallization breaking efforts. In Figure 6 shows a picture of destruction resulting from an inner join on the walls of the hole metallization shift.

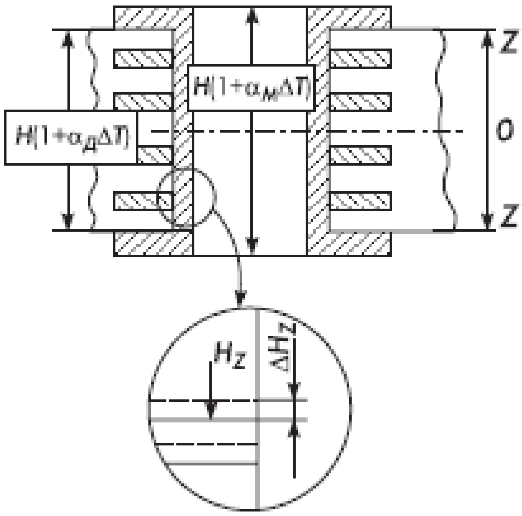

Figure 5. Shift metallization with the edges of contact pads inside layers

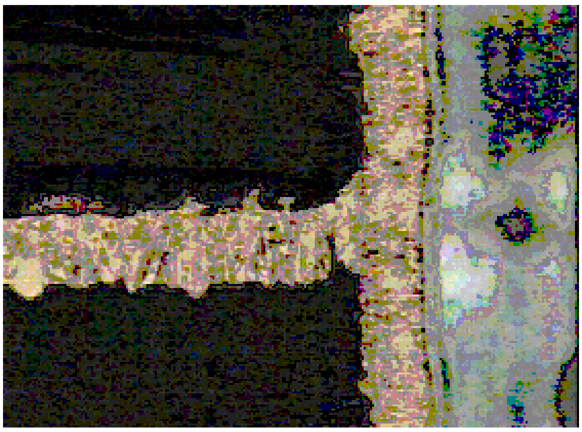

Figure 6. The photograph of the ruined inner join microsection

In Figure 7 shows chart of the temperature deformation freely expanding cylinder of copper, polymeric dielectrics and the resultant temperature deformation together, as in Figure 8 deformation-strain. Thermal expansion curve has a fracture at the base of the dielectric glass transition temperature *Tg.* zone of elastic deformation of copper is limited to the value of the ε_Y

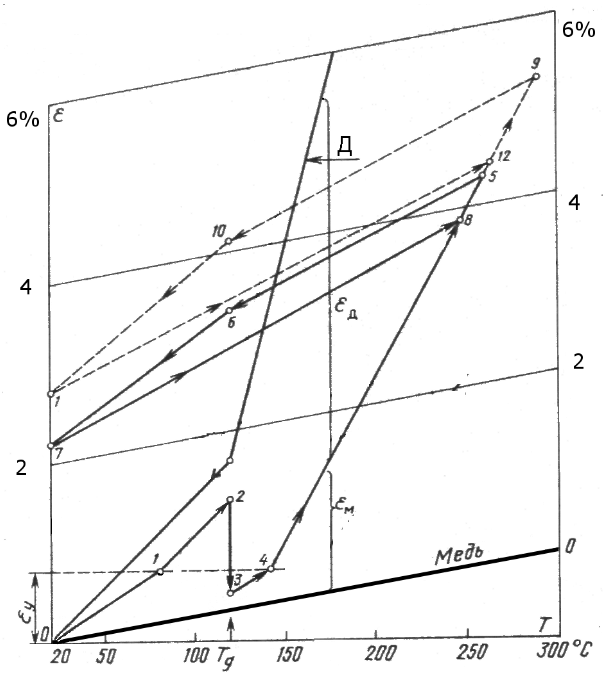

Figure 7. Graph temperature deformation of metallization aperture received grapho-analytical method

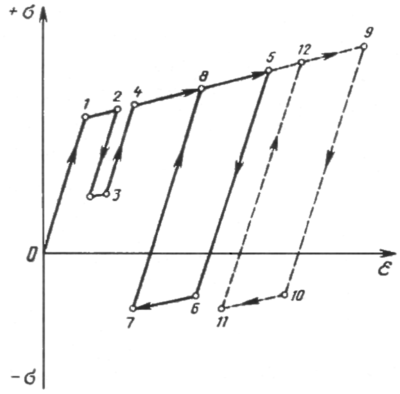

Figure 8. Figure deformation-strain

On the 0-1 the shear modulus of copper is part of elasticity, i.e. G_M, is the shear modulus of the dielectric is $G_Д$. Distribution of deformation of dielectric and copper is the ratio: $\alpha_Д/\alpha_M = G_M S_M/ G_Д S_Д$, here S_M and $S_Д$ -loading cross sectional area of the copper cylinder and dielectric around hole wall. When at the point 1 deformation of copper goes to a plot point (1-2), the module is reduced, so the hole metallization deformed almost following the free expansion of the glass transition temperature dielectric. *Tg* dielectric substrate loses its stiffness through the copper cylinder is unloaded. The deformation is a value that corresponds to the point 3. When you move the glass transition temperature *Tg* dielectric begins to grow intensively. However, initially, this does not result in a large increase of copper, while its deformation does not exceed the limits of elasticity (section 3-4). Correlation of deformation of dielectric and copper on the plots:

$$\alpha_Д/\alpha_M = G_M' S_M/ G_Д' S_Д \qquad (2)$$

Curves of 5-6-7-8-5 and 9-10-11-12-9 show the changes of the linear dimensions of the metallized holes on cooling and heating-cooling cycle again for soldering temperatures 260° and

290° c, respectively. The presence of hysteresis in thermal deformation diagram reveals a certain percentage of plastic deformation of copper-a harbinger of fatigue damage under cyclic temperature stress.

Methodology of experimental research

Es' know the basic principles of studies stresses in the metallization of through-holes using the micrometrical sensor of motion, registering growth of thickness of dielectric and metal cylinder through openings as the heating of the MLB. Increasing the accuracy of measurements in a wide temperature range by using a quartz sample holders and rods passing movements. There were attempts to use overhead strain micro-sensors for measuring small elongations (extensometer) for the study of deformation of metallization of through holes during soldering. Comparison of measurement results of thermal expansions of the two methods obtained by different authors, demonstrates their ambiguity due to the uncertainty of the reference database in the first case and low sensitivity of tensometry to small samples, what are the openings of the MLB in the second case.

The author has used its own methodology to the study of Thermo-mechanical stresses that it be analyzed hole is used as a load cell to measure its temperature deformations. For this they proceeded from the following prerequisites. Link changes with deformation: the resistance $\Delta R/R = k\varepsilon$, where k is the tensosensitivity of element (in this case, the metallized holes) Since $R = \rho H/S$ differential form of expression $\Delta R/R$ has the appearance of $dR/R = d\rho/\rho + dH/H - dS/S$. (here ρ - the electrical resistivity of metallic coating, H - the thickness of the Board (length of metallized cylinder hole), S-cross-sectional area of cross-section of holes in perpendicular to its axis. At low relative lengthening $d\varepsilon = dH/H$ the relative change in cross-section $dS/S = -2\mu(dH/H)$. So $dR/R = d\rho/\rho + \varepsilon + 2\varepsilon$ (here μ –Poisson coefficient). Then the tensosensitivity of metallization element - the metallization of holes:

$$k = (dR/R)\,\varepsilon^{-1} = (1 + 2\mu) + (d\rho/\rho)^{-1} \qquad (3)$$

The expression (3) consists of two parts: the geometry of the dependent by ρ and displaying electrical resistance change due to changes in the size of the metal cylinder due to its longitudinal deformation and physical part connected with the change of resistivity of metallic coating when extending: $d\rho/\rho\; dV = B/V$ and reflecting the linear dependence between the change in resistivity and the relative change in volume dV/V-coefficient of Bridgman. In the case of uniaxial loading hole metallization generated during heating,

$$d\rho/\rho = B\,(1 - 2\,\mu)\,\varepsilon \qquad (4)$$

Combining (3) and (4), we get:

$$k = 1 + 2\mu + B(1 - 2\mu) \qquad (5)$$

The direct effect of temperature on resistance of the metallic coating is taken into account, based on known relationships: $\Delta R/R = (+\ 234)^{-1}$. For pure copper $B = 1$, at least for the temperature range from 0 to 300° c. From here on (5) numeric expression tensosensitivity of metallization of vias is 2. I.e. elongation of metallization on the 1% change of resistance of metallization holes on 2%. The research of deformation within the 6% from 0.1% in where the required accuracy of measurement of resistances to almost four-probe method with precision class instrument. For contacting the four probes wire to pin bonded cold Ga-soldering sites that after the formation of solid solutions can withstand without fracture temperature up to 800° c (Figure 9).

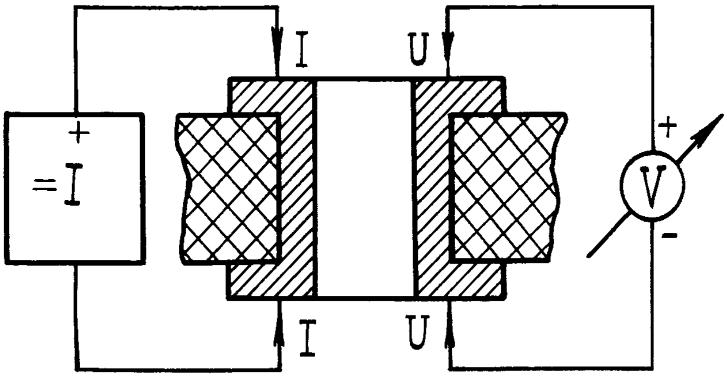

Figure 9. Circuit of resistance measurement metallization by four-probe method

The results of experimental research of deformation

Measurement of deformation of metallized holes with a diameter of 0.8 mm and 1.6 mm thick, MLB is shown in Figure 10, give good agreement with results of graphic-analytical analysis based on Nonlinear model of Thermo-mechanical deformation of through metal holes.

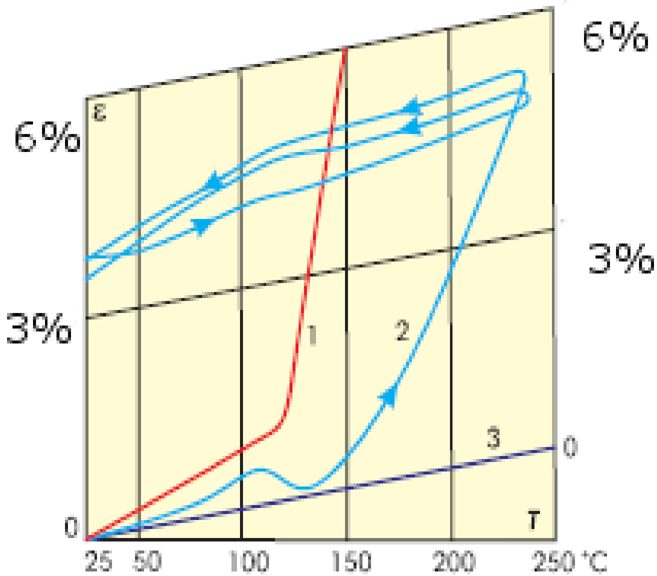

Figure 10. Experimentally obtained diagrams of temperature deformation of metallized holes: 1 and 3 – chart of free expansion of dielectric and copper; 2-experimental deformation diagram metallized holes.

The combination of large deformations of the metallization of vias in thermal loads and reduced ductility of copper may in certain circumstances lead to rupture hole metallization of metallization or the shift of the walls of the holes, if not to take measures to increase the plasticity of galvanic deposition at temperatures relevant to possible overheating of the MLB. Table 1 shows the threshold temperature value destruction interconnections in MLB.

Table 1. Threshold temperature of the beginning of destruction

The ratio of thickness of MLB to the size of the holes, the H/d	2:1	3:1	5:1	10:1	20:1
Plasticity of metallization, %	Threshold temperature, °C				
4	290	250	220	210	190
6	320	290	260	240	220
8	380	350	320	280	260

In high temperature deformations, plasticity of metallization and shaky grip of metallization with walls through holes, MLB may destroy internal connections. To identify such defect enough after thermal shock (reflow) provoke oxidation (humidity + heat) surfaces of physical contact metallization of vias with ends of internal contact pads and internal resistance measurement of compounds to diagnose reliability of MLB.

Fatigue fracture low-cycle damages are only possible when moving in the area of plastic deformation. And the deeper the temperature deformation in the area of plastic deformation, the earlier start connection failures during operation. The proposed means of monitoring the status of connections in the MLB started the plastic deformation is detected as the emergence of hysteresis in low-resistance of the circuit. Studies to quantify the influence of thickness of metallization of through holes at the temperature corresponding to the start of plastic deformation (table 2)

Table 2. Start of plastic deformation during heating

The thickness of metallization of the MLB in the hole, μ	MLB thickness ratio to diameter through-holes metallized (*H/d*)		
	2:1	3:1	5:1
	The temperature beginning of the plastic deformation, °C		
10	75	60	50
15	85	73	55
20	95	80	60
25	100	85	65
30	110	90	70

Local defects, particularly in the form of thinning ring, significantly reduce the stability of the metallization of vias to cyclic temperatures.

These studies demonstrate the futility of thermal cycling for grading and installation of products by identifying the weak elements of the cyclic load connections: destroy defective cells and create fatigue weaken the connections, close to the border of the differences of quality or defective items. This is due to the fact that the boundary of quality between defective and qualitative elements of blurred. Between them there are always intermediate states that characterize the opportunity to bounce connections due to fatigue phenomena.

Conclusion

Reliability of interconnections in modern electronic equipment technology is provided by the high level of plasticity of metallization of PCB resistant to by low-cycles fatigue destruction provoked group heat when soldering and manual many-stage soldering by repair print sites.