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Electrically Conductive Adhesives in Electronics

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Anotace:
Elektricky vodivá lepidla jsou materiály, které se v některých případech montáže v elektronice užívají namísto bezolovnatých pájek. Jsou to kompozitní materiály složené z izolační matrice a vodivého plniva. Matrice je většinou tvořena epoxidovou pryskyřicí, ale je možné použít i jiný typ pryskyřice, např. silikonové pro lepidla určená pro vyšší teploty, polyamidové a jiných. Plnivem bývají zpravidla kovové částice, nejčastěji stříbrné šupinky pro lepidla s izotropní a stříbrné mikrokuličky pro lepidla s anizotropní elektrickou vodivostí. Článek se v prvé části zabývá popisem základních vlastností elektricky vodivých lepidel a jejich aplikací. Ve druhé části je sledován odpor adhezních spojů vytvořených z izotropně vodivých lepidel při různých typech jejich zatěžování. Jako nejvýznamnější se pro odpor spojů ukázalo zatěžování v kombinaci zvýšené teploty a vlhkosti.

Abstract:
Electrically conductive adhesives are materials that are sometimes used in electronics assembly instead of lead-free solders. These are composite materials consisting of an insulating matrix and a conductive filler. The matrix is usually comprised of an epoxy resin, but it is possible to use another type of resin, e.g. silicone one for higher temperatures, polyamide resin, and others. Fillers are usually metallic particles, silver flakes with adhesives having isotropic and silver microspheres for adhesive having anisotropic electrical conductivity. The article in the first part describes the basic properties of electrically conductive adhesives and their basic applications. The second part is focused on the examination of the resistance of adhesive joints made of isotropic conductive adhesives for different types of loading. It has been found that the maximum changes of the joint resistances are caused with combined humidity-heat treatment.

INTRODUCTION

The massive development of electrically conductive adhesives started in parallel with the development of lead-free solders. It has been found that the development of lead-free alloys directed for substitution of lead-tin solders still used in electronics assembly has met with many problems dominantly joined with the too-high melting temperature of these alloys. Therefore, it has been has been necessary to find another way as well, that would allow the conductive joining in electronics at significantly lower temperatures than the temperatures required for soldering. This way has been joining by means of electrically conductive adhesives.

TYPES OF ELECTRICALLY CONDUCTIVE ADHESIVES

Electrically conductive adhesives are nature-friendly materials used for conductive joining in electronics. Electrical, mechanical, and other properties of these materials are worse in comparison with solders [1-3]. The price of these composites is substantially higher than the price of lead-free solders.
Electrically conductive adhesives (ECA) are composed of the insulating matrix and electrically conductive filler. The matrix is formed of different types of resins. Mostly epoxy resin is used, but other types, such as silicon, polyimide, and many others can also be used. The type of resin depends on the application of adhesive. Adhesives with an epoxy matrix are used for temperatures up to 90 °C. For higher temperatures, up to 200 °C, a silicone matrix is used. The resins also vary with resistance to weather conditions, particularly moisture, with the mechanical properties, etc. Therefore, it is necessary to choose a proper adhesive for every type of load [4-6].

The conductive particles are mostly silver flakes with adhesives having isotropic electrical conductivity or silver microspheres with adhesives having anisotropic conductivity. Other shapes, such as trees, wires, grains, and others are also sometimes used for isotropic adhesives. As for the anisotropic ones the plastic spheres covered with the metal, usually silver, film are used instead of silver spheres.

Adhesives with isotropic electrical conductivity have a concentration of filler particles between 60 and 80 wt% usually. The concentration of filler particles in adhesives with anisotropic conductivity is low, 7 – 25 wt% usually. The concentration of the conductive particles in these adhesives must be so low as not to exceed the percolation threshold [7, 8].

The basic material of filler particles is silver, as mentioned already. Other metals, such as gold, nickel or palladium can also be used. Sometimes the filler paricles are formed from an insulating nucleus covered with the conductive metal film [9-11].

The adhesive assembly based on using isotropic adhesive is very simple. The bump of the adhesive is applied on the pad of the PCB and a contact or terminal of an SMT component is placed on it. The process is the same as the process of application of the solder paste and placing of a component when assembly based on the reflow soldering is used. Then the adhesive is cured according to the curing schedule recommended by the manufacturer.

If adhesive with anisotropic electrical conductivity is used for adhesive mounting a mechanical pressing of contact or terminal of a mounted component to a printed circuit board must also be used when the cure.

BASIC APPLICATIONS OF ELECTRICALLY CONDUCTIVE ADHESIVES

Some electronic components, e.g. such as LCDs, cannot be mounted using soldering due to the too high temperature used for soldering. Such a temperature would destroy the liquid crystals. Therefore, electrically conductive adhesives must be used for mounting such devices.

The conductive adhesives are also used in flexible electronics. The flexibility of soldered joints is very low. On the other hand, flexible electronics is under development intending to manufacture flexible types of electronic equipment. Therefore, the soldered joints are in the flexible electronics substituted with the adhesive ones, which have higher flexibility than the soldered ones.

The development in the area of packages of integrated circuits as well as other electronic devices is constantly evolving. The density of packaging increases and the width of terminals and gaps between them is decreasing. Into practical use entering the housing, which leads have a width of 0.3 mm and a gap between them also 0.3 mm. Assembly of these components using soldering is connected with a higher frequency of occurrence of bridges between neighboring leads. Because electrically conductive adhesives can have isotropic as well as anisotropic electrical conductivity, adhesives or foils from adhesives with anisotropic electrical conductivity are used for mounting packages of these types.

PROPERTIES OF ELECTRICALLY CONDUCTIVE ADHESIVES

Properties of electrically conductive adhesives can be divided into 3 main groups:

- Electrical properties.
- Mechanical properties.
- Other properties, such as climatic ones, influence of current or current pulses on the electrical properties of the adhesive, the influence of shape and dimensions on adhesive properties, and others.

Electrical properties

For electrical properties of conductive adhesives, their resistivity or the resistance of adhesive joints is often monitored. This parameter is higher in comparison with lead-free solders. Therefore great effort is paid to improve this parameter. Different methods of increase of adhesives conductivity have been tested.
The addition of the conductive nano-particles such as nano-spheres, nanowires, nanotubes has been tested to improve the conductivity of adhesives. It has been found that the addition of the nano-spheres will not improve the conductivity, but the mechanical properties such as shear strength and tensile strength of adhesive joints. The addition of nanowires improves both the electrical and mechanical properties of adhesive joints. A conductivity level of adhesives, however, does not increase to a level comparable with the conductivity of lead-free solders.
Another method of how to improve the conductivity of adhesives could be the additional curing of adhesive joints at a temperature near to 200 ºC for some minutes. This curing will cause an additional decrease of the adhesive matrix in the volume, whereas the volume of the filler particles will not change. This change can improve the contacts between the filler particles and increase the conductivity of the conductive net inside the adhesive joint. We have tested such the method but our results did not confirm this assumption.
The best method for improvement of the conductivity of adhesive joints seems to be curing the adhesive joints that will cause the sintering of filler particles. In this case, the conductivity of adhesive and soldered joints can be comparable. To achieve sintering at a temperature near the temperature recommended by the manufacturer for curing of the adhesive is not a simple process. It requires a special surface treatment of the filler particles or the use of filler particles an appropriate type of appropriate material [12-14].
As for other electrical properties of adhesive joints, such as noise and nonlinearity of the current-voltage characteristic, these values are higher for adhesive in comparison with the soldered joints. The reason is clear: the conductivity net in an adhesive joint is formed from the resistances of individual filler

particles and contacts between them. Because the filler particles are from highly conductive material, contact resistances between the filler particles form the dominant resistance of the conductive net.
Two types of contact resistances occur in the conductive net:

- Tunnel resistance.
- Constriction resistance.

Tunnel resistance occurs because the filler particles are covered with a very thin film of oxide or another chemical compound that causes tunneling of electrons between the filler particles when a voltage is connected. Constriction resistance occurs in the case of anisotropic adhesives where the filler particles are spheres. The anisotropic conductivity is achieved with these adhesives so that there is a very small concentration of the filler particles here. These particles are microspheres. When mounting the contact or the terminal of an SMT component, first the contact or the terminal is placed on a pad with the bump from adhesive, then pressed toward the PCB, and then the adhesive is cured. Thus, filler particles are clamped between a contact (terminal) and a pad on the PCB, and thus conductivity is ensured in the axial direction perpendicular to the surface of the PCB. The filler particles do not touch each other, therefore the conductivity in the plane of the PCB is very low because it is the conductivity of the adhesive matrix only. Therefore, these adhesives are also called z-adhesives.

Mechanical properties

As for the mechanical properties, especially retractile force (the force required to peel a component) and shear force are monitored with the adhesive joints. In modifications of adhesives held to increase their electrical conductivity has been found that the addition of nanospheres in the adhesive at a suitable concentration improves mechanical characteristics. It has been also found that a significant role plays also the material and the surface finish of the contact (terminal) of a component and the pad. These forces are usually slightly smaller than the forces detected by the solder joints.

Other properties

It has been found that the epoxy resin, which is mostly used for the formation of electrically conductive adhesives, is hygroscopic. Molecules of water can penetrate the resin and form hydrides and oxides on the particles of the filler. These chemicals increase the thickness of the tunnel barrier between the filler particles. The tunnel resistance increases and the conductivity of adhesive bond decreases.
It has been also found the dependence of the adhesive joint conductivity on the current flowing through the joint. The long-time loading of the joint with the DC current, AC current, or current pulses, causes a slow increase of the joint resistance. The reason is, that the current density in the contacts between the filler particles is very high and causes the formation of „hot points“ inside the adhesive. The temperature at these points is very high and causes degradation of the matrix in the surroundings of these contacts. The products of this chemical degradation react with the filler particles, increasing the thickness of the tunnel barriers between them, and consequently the resistance of the adhesive bonds.
The low difference of the adhesive resistivity has been also observed depending on the dimensions of the area of the adhesive contact in the case of adhesives with isotropic conductivity. It can be caused by the alignment of the filler particles under the body of contact or the terminal. It has been observed that the flakes in the adhesive are normally oriented randomly. However, after mounting the SMT component, they are oriented in parallel with the plane of the contact or terminal. The level of this alignment can depend on the dimensions of the area covered with the adhesive and the area of the contact. The research in this field is continuing.

EXPERIMENTS AND RESULTS

Adhesive joints have been formed by adhesive assembly of SMT resistors 1206. Six types of adhesives, all with the isotropic electrical conductivity have been used for experiments. All have been with epoxy matrix and silver filler. Four types have been one-component, two types two-component. The filler concentration in adhesives has been from 65 to 75 wt%.
Fourteen joints from every adhesive has been used for every type of the load.
Mechanical load has been carried out with the force 14 Nm, humidity aging has been carried out at 98 % RH and 24 ºC, heat aging at 120 ºC and 64 % RH, combined Humidity/Heat aging at 98 % RH and 80 ºC. All types of the load have been applied for 300 hours.
The results are presented in Fig. 1 – Fig. 6.

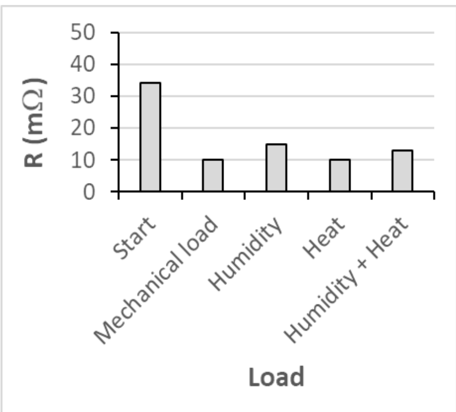

Fig. 1: Average resistance of adhesive joints formed from one-component adhesive type I before and after different types of aging.

DISCUSSION

With exception of the adhesive number one, the highest average resistance of the joints has been found after aging at the high humidity and temperature.

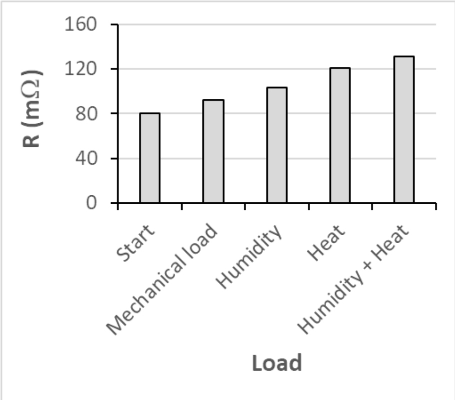

Fig. 2: Average resistance of adhesive joints formed from one-component adhesive type II before and after different types of aging.

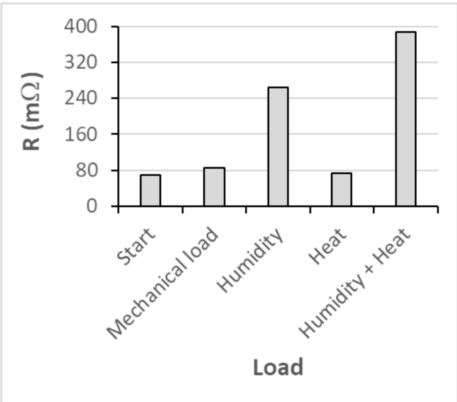

Fig. 3: Average resistance of adhesive joints formed from one-component adhesive type III before and after different types of aging.

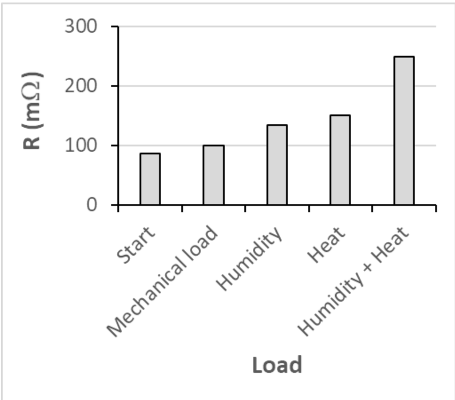

Fig. 4: Average resistance of adhesive joints formed from one-component adhesive type IV before and after different types of aging.

The reason is that the temperature supports the diffusion of the water molecules into the resin as well as chemical reactions between the water molecules and filler particles. The result of these reactions is growing of the thickness of insulating films between the filler particles, which reduces the possibility of tunneling electrons and thereby causes the growth of the joint resistance.

The increase of the joint resistance after the mechanical load can be associated with the formation of microcracks in the volume of the adhesive.

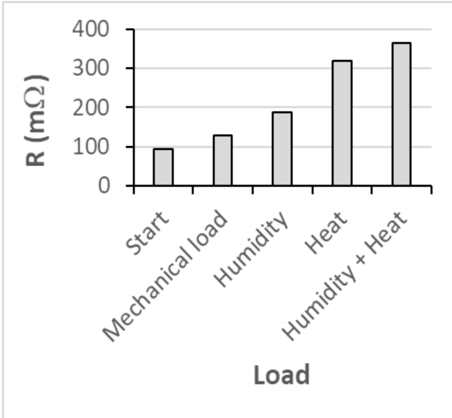

Fig. 5: Average resistance of adhesive joints formed from two-component adhesive type II before and after different types of aging.

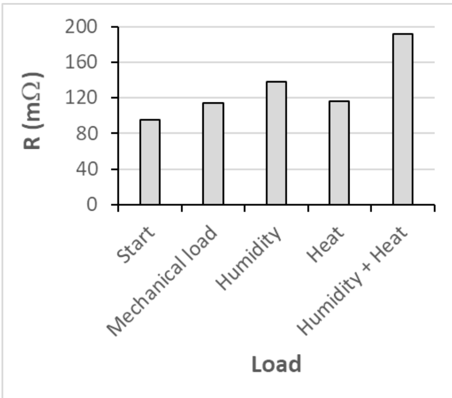

Fig. 6: Average resistance of adhesive joints formed from two-component adhesive type II before and after different types of aging.

CONCLUSIONS

Basic types, properties, and applications of conductive adhesives have been described. The results of experiments focused on examination of the changes of the joints resistance at different types of loading have been presented for joints formed from one-component as well as two-component adhesives. It has been found that the maximum changes are caused by combination of the moisture and heat.

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