26th International Spring Seminar on Electronics Technology
May 8 – 11, 2003, Stará Lesná, Slovak Republic

Degradation of Adhesive Bonds with Short Current Pulses

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Abstract

Degradation of adhesive bonds powered by rectangular very short current pulses of the width of 1 μs and frequency of 1 kHz of high amplitude has been examined. The amplitudes of the pulses have been 5 and 10 A. Power supported by these pulses into the adhesive bonds has been chosen very low to cause very low increase of the temperature of the bond only. Therefore changes of examined electrical parameters have been dominantly caused with effects different from effects caused by thermal aging. The specimens have been prepared by mounting of resistors with "zero" value on a test board with Cu layout which has made 4-point measurement of the bonds possible. Seven resistors have been mounted on one board. Two types of isotropic electrically conductive adhesives with Bisphenol A resin binder and Ag filler have been used. Resistance of the bonds has been measured. The pulses have been applied at the normal temperature and at the temperature of 90 °C, the time of application of the pulses has been 90 minutes. It has been found that the current pulses influence resistances of the bonds, amplitude of the pulses has not influenced changes of the resistances substantially. Unlike the examination of current-induced degradation with DC current of higher density on properties of the joints published elsewhere [1], the increase of normalized resistance with the time of application of the current pulses has not been found so explicit. It has also been found that changes of resistances depend on the number of applied pulses.

1. Introduction

Examination of electrically conductive adhesives is mostly focused on their testing in different types of climates or at increased temperature [2, 4-6]. However, investigation of their properties after application of very short current pulses could also be interesting, because of their influence on microcontacts among conductive particles of a filler. Properties of these microcontacts influence total electrical parameters of adhesive joints.

The aim of this experiment has been to investigate non-thermal influence of current pulses on the adhesive joints. Therefore it has been necessary to avoid substantial increase of temperature of the joints caused by the pulses. Therefore energy, which has been fed by these pulses to the joints, has been chosen very low.

The pulses of oblong form have been chosen for this test. It is possible that the shape of the pulses can also influence types or magnitude of changes, which can be induced in the joint, but the results of our experiment have shown that the influence of the pulses is not as significant as, e.g., influence of increased temperature. Maybe that by repetition our of experiments with another shape of the current pulses a small differences in results would be found, but it is no reason to assume that the differences would be significant.

Influence of the current pulses in combination with increased temperature has also been examined. The joints have been powered by the pulses at the increased temperature and results of these experiments have been compared with the results obtained from the experiments, when the joints have been powered by the pulses at the normal temperature.

This investigation could be very interesting for producers, which use electrically conductive adhesives in for montage of components of power electronics. The processes, induced by short current pulses of high power, can influence the properties of the joints and their reliability.

 0-7803-8002-9/03/$10.00 ©2003 IEEE

2. EXPERIMENTAL

2.1. Specimens

Adhesive joints have been realized by assembly of SMT resistors with "zero" resistance on test PCB. The test board has been fabricated of FR4 insulator plated with 40 μm copper foil. Seven resistors have been mounted on one board. The test board makes measurement of resistance of single joints, single resistors as well as groups of mounted resistors joined in series, possible.

Electrically conductive adhesives have been of an isotropic type; formulations have been based on Bisphenol-A resin binder and Ag filler. The resin has been filled with 80 % Ag flakes. Adhesives have been applied by dispensing.

Two types of isotropically conductive adhesives have been investigated. The basic parameters of these materials are presented in Tab.1.

Electrically conductive adhesives				
Type	**Company**	**Number of components**	**Curing temperature (°C)**	**Curing time (min)**
Eco Solder AX 65 MN	Amepox Microelectronics Ltd.	1	120	30
Elpox SCE 515	Amepox Microelectronics Ltd.	1	180	40

Tab. 1 Types of electrically conductive adhesives used in the test

Curing of adhesives has been carried out at the normal atmosphere according to the recommendation of a producer. Before the start of the test the resistances of the joints and resistors have been measured to obtain initial values.

2.2. Generator of the current pulses

Calculation of amplitude and width of the pulses has been carried out with respect to the maximum accepted increase of temperature of the adhesive joints caused by the pulses. For calculation of heat generated inside adhesive it is assumed that adhesive has similar physical parameters like silver. Specific heat capacity *c* of silver is 232 J/kgK, density 10500 kg/m^3. If it is estimated that the volume of the adhesive used for fabrication of 1 bond as 0.2 mm^3, the mass of adhesive for 1 joint will be 2 mg (it is meaned mass of adhesive, which creates an electrical contact between component and pad and is under the contact area of the component, because this area has a dominant influence on the properties of the bond). Energy necessary for increase of temperature of this volume of adhesive by 1 K will be 0.5 mJ. When amplitude of the pulse would be 1A, its width 10 μs, and the frequency of pulses 100 Hz, then energy, which will cause increase of temperature of adhesive by 1 K, will be supported after 500 s. However, real increase of the temperature will be lower, because adhesive is located between a pad and a contact of the component. Therefore heat is leaded away and adhesive joint is cooled.

For detail investigation of temperature conditions in adhesive bond would by necessary a deeper analysis based on simulation, e.g. by the finite elements method. On the other hand rough estimation of temperature conditions makes estimation of frequency and amplitude of the pulses for pulse loading of the bonds also possible. On the basis of this estimation a generator has been designed and realized.

The generator consists of a control and a power part. The control part is based on the circuit 555 and its frequency is 100 kHz. This generator is used for control of width of the pulses. This circuit is followed by binary counter 4020 and by sliding register 4013 joined with a coincidence circuit 4011. Power switch MOSFET IRF 640 is controlled with the circuit 4049.

For calculation of amplitude of a current pulse has been derived a formula:

$$I = \frac{U_1 - 1}{0.5 + R_{cab}} \qquad (1)$$

Where: U_1 ... voltage used for powering of power switch, R_{cab} ... resistance of cables.

Schematic diagram of the generator is shown in Fig. 1. The output terminals for connection of the specimen are marked OUT. The shape of a current pulse is shown in Fig. 2. Arrangement of measurement is shown in Fig. 3.

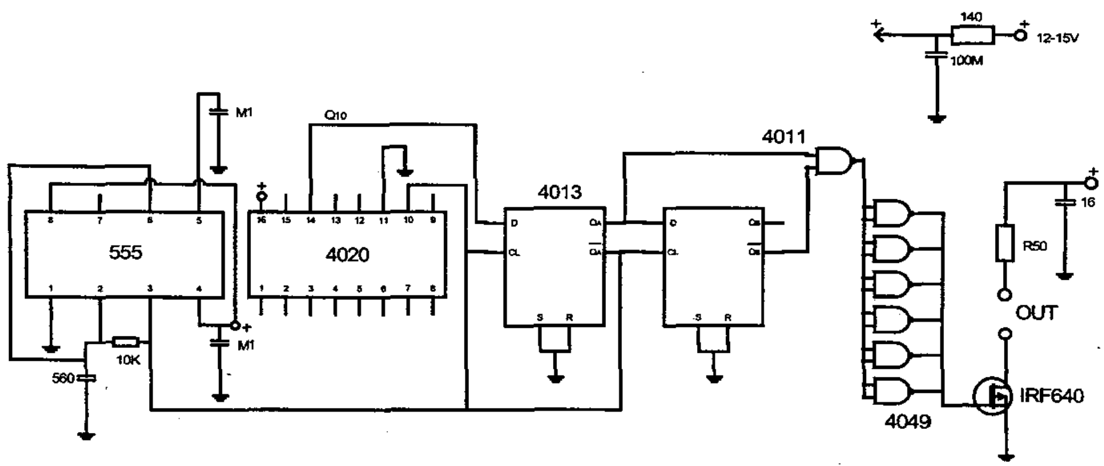

Fig. 1 Schematic diagram of the generator of current pulses

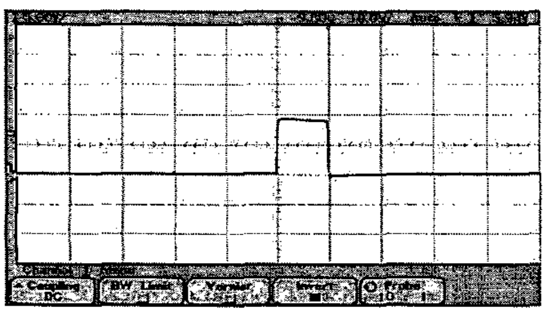

Fig. 2 Shape of a current pulse with the width of 10 μs.

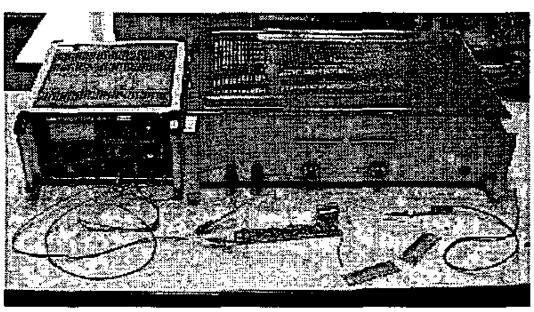

Fig. 3 Arrangement for powering of adhesive joints with current pulses. The DC sources are at the back, in front of the big source is the generator of the current pulses and two test boards with mounted resistors

The amplitudes of the pulses have been 5 A and 10 A. The time of their application has been 90 minutes. With respect to the frequency of the pulses the number of pulses for the shorter time has been 270 . 10^3, for the longer time 540 . 10^3. The joints have been loaded at the normal temperature and at the temperature of 90 °C.

A slight increase of temperature in the interior of the adhesive due to Joule-heating cannot be avoided while applying the current. However, this increase should be too small to cause a significant change of the joint resistance.

3. Measurement of the resistance, Measured Values

LCR meter HP 4284A in four-point connection has been used for measurement of the resitance (Fig. 4).

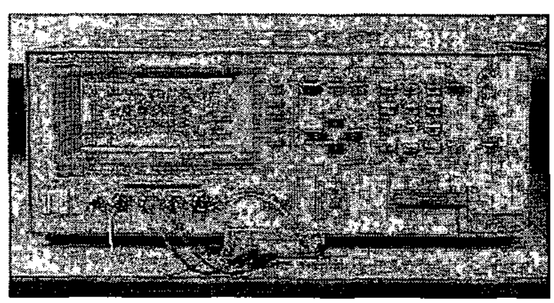

Fig. 4 Measurement of the resistances of the joints

Values of the joint resistances have been in the range of mOhms. Changes of measured values are expressed in Fig. 5 – Fig. 8. The value S is calculated according to the formula:

$$S = (R_M/R_S)*100 \quad (2)$$

Where

S (%) ... a relative change of the resistance of the joint regarding to its initial value,
R_M ... measured value of the resistance of the adhesive joint,
R_S ... initial value of the resistance of the adhesive joint.

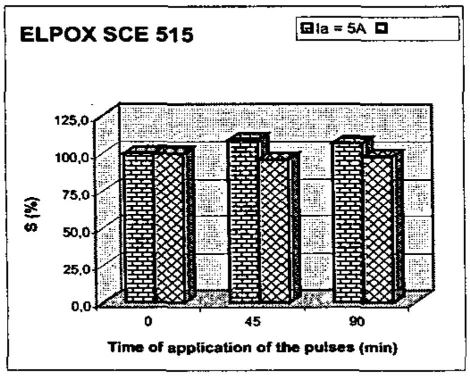

Fig. 5 Changes of the resistance of the joints of adhesive ELPOX SCE 515 after application of the current pulses with amplitude of 5A and 10A at the normal temperature

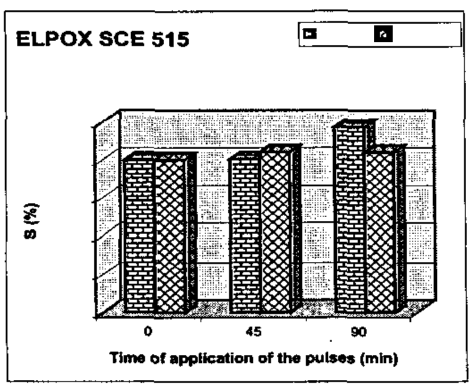

Fig. 6 Changes of the resistance of the joints of adhesive ELPOX SCE 515 after application of the current pulses with amplitude of 5A and 10A at the temperature of 90 °C

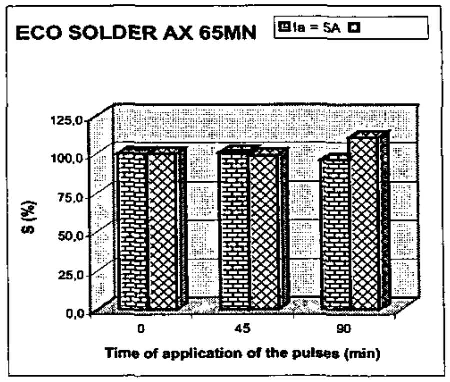

Fig. 7 Changes of the resistance of the joints of adhesive ECO SOLDER AX 65MN after application of the current pulses with amplitude of 5A and 10A at the temperature of 90 °C

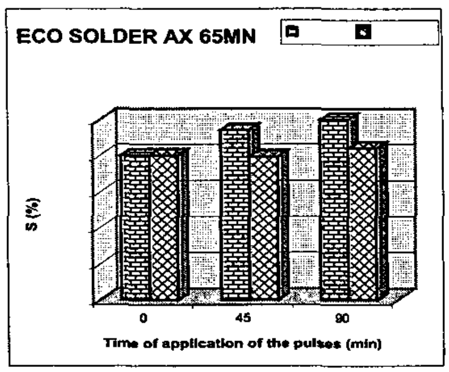

Fig. 8 Changes of the resistance of the joints of adhesive ECO SOLDER AX 65MN after application of the current pulses with amplitude of 5A and 10A at the temperature of 90 °C.

4. CONCLUSIONS

With respect to the very small contact areas among flakes of a filer, it is very difficult to estimate current density, which will occur here during application of the pulses. It is usually assumed that particle-particle-contact current density is ten thousand times higher than the mean current density flowing through the joint.

It is presumed that an effective force F_{eff} acts on the metal ion resulting in a drift velocity v of that particle:

$$v = \mu F_{eff} = \mu e Z^* \rho (j - j_C) \quad (3)$$

Where μ ... mobility, e ... charge of an electron, ρ ... specific resistivity, j ... applied current, j_C ... a critical current density, Z^* ... effective valence of the iont.

Due to the backward force, which is caused by mechanical stress, the atoms are prevented from moving and therefore they do not move at the low current densities [3].

The mobility of the ions μ can be described by the formula:

$$\mu = D_0.exp(-Q/k_BT)/k_BT \qquad (4)$$

Where D_0 ... frequency factor, Q ... activation energy, k_B ... Boltzman factor, T ... absolute temperature. The value of Q for silver is 0.83 – 0.93 eV.

Because resistance of the adhesive is a macroscopic quantity, it is necessary to describe a resistance change by an equation:

$$(1/R_0).(\Delta R/\Delta t) = C.(j^n - j_{Eq}^n) \,.\, exp(-E_a/k_BT) \qquad (5)$$

Where R_0 ... the initial resistance, ΔR ... the resistance change within the time interval Δt, E_a ... the overall activation energy, C ... constant, n ... exponent with the value 2 – 5, j_{Eq} ... equilibrium current density.

It has been found (instead one case) that application of the current pulses has led to increase of the resistance. This conclusion is in accordance with the conclusions presented in [1], where influence of high DC current has been investigated. The pulses have been applied 90 min, what is a region, where maximum changes can be found. Unlike measurements carried out by the DC current of higher current density has not caused application of pulses of higher amplitude higher change of the resistance. The reason of this difference could be following: the loading using DC current of high intensity has caused increase of temperature of specimens and degradation of resin, which is always joined with increase of resistance caused by creation of a thin insulating (mostly oxide) layer on surface of conductive particles. Application of the pulses of such the total power, which will not cause heating global increasing of temperature of the adhesive, or will cause very low increase of the temperature only, will influence the properties only by diffusion of ions. However, the situation is not so simple, because also these pulses will cause high increase of temperature of microcontacts and can this way induce changes of resin in near surrounding of the microcontact and influence its conductivity.

It has been also presented that after application of DC current on electrically conductive adhesive immobile clusters of nano particles inside the resin has been found. These clusters are created of atoms coming from the surfaces of flakes, it is assumed that the surface is 0.9 $m^2.g^{-1}$. Mobility of these atoms is expressed by the equation (2). The atoms have to diffuse throughout the resin and are catched on inhomogenities. Unfortunately no diffusivity data are known for the epoxy resin as for polyimide [7], but it is assumed that the time of substantial changes will be in a time scale of 100 hours. Therefore loading of the specimens for 90 minutes could probably start forming of clusters but the clusters will not be formed after this short time.

The experiments, which have been carried out are the starting experiments in the field. Therefore it will be necessary to extend the number of types of adhesives under-test as well as number of methods for their analysis, including such as TEM and EDAX. This way better understanding of processes caused in electrically conductive adhesives by current pulses will be possible.

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