Pressure Electrical Contact Improved by Carbon Black Paste

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Pressure and pressureless electrical contacts were evaluated by measuring the contact electrical resistivity between copper mating surfaces. Pressure electrical contacts with a contact resistivity of 2×10^{-5} Ω·cm^2 have been attained using a carbon black paste of a thickness of less than 25 μm as the interface material. In contrast, a pressureless contact with silver paint as the interface material exhibits a higher resistivity of 3×10^{-5} Ω·cm^2 or above. A pressureless contact with colloidal graphite as the interface material exhibits the same high contact resistivity (1×10^{-4} Ω·cm^2) as a pressure contact without any interface material. On the other hand, pressureless contacts involving solder and silver epoxy exhibit lower contact resistivity than carbon black pressure contacts.

Key words: Electrical contact, pressure contact, carbon black, silver, graphite, solder

INTRODUCTION

Electrical contacts are needed for electrical interconnections in electronics. They can be in the form of pressure contacts (i.e., contacts made by the use of pressure to hold the mating surfaces together) and pressureless contacts, which are made without pressure by the use of an electrically conductive joining medium, such as solder, silver epoxy, and silver paint. A particularly common form of pressure contact involves the use of clips to provide the pressure. The advantage of a pressure contact lies in the ease of disconnection and reconnection, as needed during the use of the electronics. In fact, a pressure contact is referred to as a separable interconnect.[1] In contrast, disconnection is not convenient for nonpressure contacts, as it may require heating or the application of a considerable mechanical force.

Pressure contacts are widely used for computer interconnects.[1,2] They can take the form of a personal computer edge-board connector,[2] a contact to a bipolar transistor,[3] hand-twisted conductor slices in communication cables,[4] and clips.

Previous research in electrical contacts has emphasized pressureless contacts, particularly soldered joints. The limited research on pressure contacts has addressed the effect of repeated pressure application (mating) and pressure removal (unmating)[5,6] and the effect of temperature cycling.[6]

(Received September 26, 2003; accepted November 3, 2003)

This paper is focused on the improvement of pressure contacts by using an interface paste. The paste functions like a grease. It does not dry up and does not harden. In contrast, silver epoxy and silver paint dry up and harden. In the dry state, pressure application would damage the contact because of the brittleness of the dried material. Therefore, electrically conductive colloids and adhesives cannot be used as interface materials in pressure contacts although they are commonly used in pressureless contacts.

The interface pastes used in this work to improve pressure contacts are organic-based carbon black dispersions, which have been previously used for improving thermal contacts in the form of pressure contacts.[7] Carbon black is attractive because of the compressibility of its agglomerates[8] and the consequent conformability of the paste to the topography of the mating surfaces. Each agglomerate has a porous morphology resembling a bunch of grapes. Because of the insulating character of air, the displacement of air from the interface by the conforming paste helps to improve the contact. The carbon black pastes are superior to diamond particle paste, carbon nanotube paste, and solder (applied in the liquid state) for improving thermal contacts.[7]

For the sake of comparison, this paper investigates both pressure and pressureless contacts. The pressureless contacts in this study include those involving silver paint, colloidal graphite, silver epoxy, and solder. Such a comparative study has not been previously reported. It is valuable for advancing the art of making electrical contacts.

EXPERIMENTAL METHODS

The carbon black pastes used in this study were of two types. Type A involved polyethylene glycol, 3 vol.% ethyl cellulose, and 1.25 vol.% carbon black. Type B involved di(ethylene glycol) butyl ether, 40 vol.% ethyl cellulose, and 0.20 vol.% carbon black. The carbon black was Vulcan XC72R GP-3820 from Cabot Corp. (Billerica, MA). This carbon black was chosen because of its electrical conductivity and easy dispersion. It was a powder with an average particle size of 30 nm, a nitrogen-specific surface area of 254 m^2/g, a maximum ash content of 0.2%, and a density of 1.7–1.9 g/cm^3. The materials and the carbon black paste fabrication method are described in Ref. 7.

Two types of silver paint were used, labeled A and B. Silver paint A was obtained as Product No. 6103 Silver Conductor from Metech, Inc. (Elverson, PA). It consisted of 72 wt.% of silver particles of size 5 μm and 28 wt.% of a vehicle comprising glycol ethers and isophorone. After application, curing of the paint was conducted either at room temperature and a pressure of 0.14 MPa for 24 h or by heating at 150°C and a pressure of 0.14 MPa for 20 min. Silver paint B was obtained as Electrodag 416 from Acheson Colloids Company (Port Huron, MI). It comprised silver particles (50 wt.%) in ethanol and was cured at room temperature and a pressure of 0.14 MPa for 24 h.

The colloidal graphite used was a dispersion of 22 wt.% graphite particles of average size 0.7–0.8 μm in water, containing a starch-type binder (Grafo Hydrograf A M2 from Fuchs Lubricant Co., Emlenton, PA). After application, curing of the colloid was conducted at room temperature and a pressure of 0.14 MPa for 24 h.

Three types of silver epoxy were used, labeled A, B, and C. Silver epoxy A was Product No. 3888 from Loctite (Rocky Hill, CT). It was comprised of 75 wt.% of silver flake of size less than 40 μm. After application, curing was conducted at 150°C and a pressure of 3.3 MPa for 30 min. The cured material exhibited volume electrical resistivity $\leq$0.0005 Ω·cm, according to the manufacturer data sheet. Silver epoxy B was Product No. 3882 from Loctite. It comprised 70–80 wt.% silver. Curing was conducted at 110°C and a pressure of 3.3 MPa for 1 h. The cured material exhibited volume resistivity $\leq$0.005 Ω·cm, according to the manufacturer data sheet. Silver epoxy C was Product No. LCA-24 from Bacon Industries, Inc. (Watertown, MA). Curing was conducted at 95°C and a pressure of 3.3 MPa for 2 h. The cured material exhibited a volume resistivity of 0.002 Ω·cm, according to the manufacturer data sheet.

The solder was tin-lead-antimony (63 Sn-36.65 Pb-0.35 Sb), with an activated rosin flux core and was supplied as Solder Type 361A-20R by Measurements Group, Inc. (Raleigh, NC). Molten solder at a temperature of 187°C, as measured using a Type-T thermocouple, was sandwiched between copper blocks that had been preheated to this temperature also. This temperature was above the liquidus temperature of 183°C. The heat was provided by a hot plate. The copper-solder-copper sandwich was allowed to cool on the hot plate with the power off under a slight pressure of 62 kPa.

Various conductive dispersions were sandwiched between the 10 mm × 10 mm surfaces of the two copper blocks (these surfaces having been mechanically polished using 0.05-μm alumina particles) that had a height of 20 mm, except that the height was 65 mm when solder was used in place of conductive paint. The difference between solder and conductive paint cases was due to the low contact resistivity in the solder case. The thickness of the interface material, as listed in Table I, was obtained by subtraction of the thickness of the two copper blocks from the thickness of the sandwich, as measured using a micrometer.

Two electrical contacts were applied to each copper block, as shown in Fig. 1. The outer two contacts (A and D in Fig. 1) were for passing current. The inner two contacts (B and C in Fig. 1) were for voltage measurement. Each contact was made by using silver paint in conjunction with copper wire. The wire was wound around a copper block. The four-probe method was used to measure the resistance between B and C. This resistance consists of the contact resistance of the interface between the two copper mating surfaces and the volume resistance of the parts of the two copper blocks between B and C. The volume resistance contribution was subtracted from the measured resistance in order to obtain the contact resistance. The product of the contact resistance and the contact area is the contact resistivity. The volume resistance was calculated from a separately measured value of the volume resistivity (1.7×10^{-6} Ω·cm) of the copper in the form of a single block (130 mm × 10 mm × 10 mm), again using the four-probe method (100 mm between the voltage contacts and 10 mm between a voltage contact and its adjacent current contact).

Because of the low contact resistance of the joints made with solder and silver epoxy, the contact resistivity of these joints was measured using the preceding method mentioned and shown in Fig. 1, as well as a method mentioned later. The method mentioned later serves to provide an upper bound for the contact resistivity. It involved a modified configuration, in which distances between the voltage contacts (B and C) was just 4 mm. The measured resistance between B and C, without subtraction of the calculated volume resistance between B and C, was used as the upper bound of the contact resistance.

Table I. Contact Electrical Resistivity ($\Omega \cdot cm^2$) of the Interface Between Copper Blocks*

Interface Material	Resistivity	Upper Bound of Resistivity	Thickness[a] (μm)
None[b]	$(1.1 \pm 0.2) \times 10^{-4}$	—	—
Carbon black + PEG[b]	$(1.7 \pm 0.3) \times 10^{-5}$	—	<25
Carbon black + BE[b]	$(1.6 \pm 0.4) \times 10^{-5}$	—	<25
Silver paint A (room temperature cured)[c]	$(1.6 \pm 0.2) \times 10^{-4}$	—	<25
Silver paint A (heat cured)[c]	$(4.4 \pm 0.5) \times 10^{-5}$	—	<25
Silver paint B[c]	$(3.3 \pm 0.6) \times 10^{-5}$	—	<25
Silver epoxy A[c]	$(1.5 \pm 0.3) \times 10^{-6}$	$(2.4 \pm 0.4) \times 10^{-6}$	<25
Silver epoxy B[c]	$(1.8 \pm 0.4) \times 10^{-6}$	$(2.2 \pm 0.4) \times 10^{-6}$	<25
Silver epoxy C[c]	$(3.4 \pm 1.8) \times 10^{-6}$	—	<25
Colloidal graphite[c]	$(1.3 \pm 0.2) \times 10^{-4}$	—	<25
Solder[c]	$(5.0 \pm 0.5) \times 10^{-7}$	$(8.3 \pm 3.1) \times 10^{-7}$	~25

*PEG = polyethylene glycol and BE = butyl ether
[a]Thickness of the interface material
[b]Pressure contact
[c]Pressureless contact

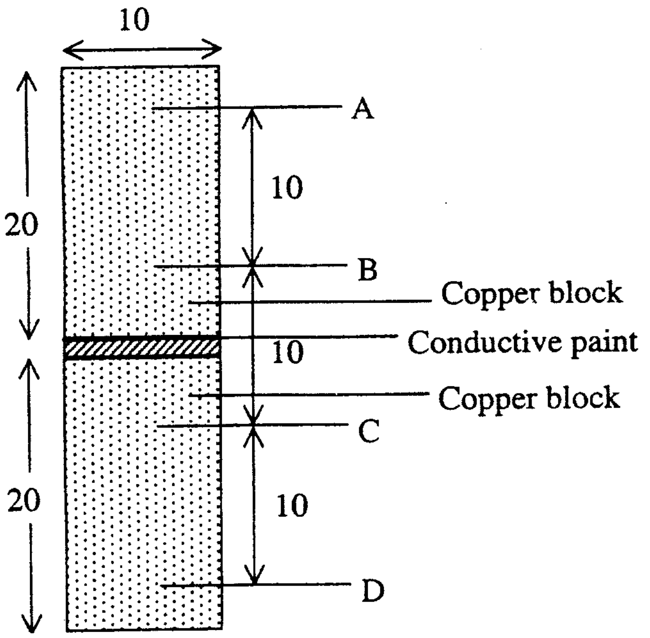

Fig. 1. Specimen configuration for measuring the contact electrical resistivity. All dimensions are in mm. Conductive paint was sandwiched by two copper blocks. In the case of the solder in place of conductive paint, each copper block was of height 65 mm instead of 20 mm, the distance between B and C was 100 mm instead of 10 mm, and the distance between A and D was 120 mm instead of 30 mm. The larger distances used in the case of the solder are because of the low contact resistance involved.

At least four specimens of each composition were tested, except that one specimen was tested for each of silver epoxy A and B. The consistency among the results of silver epoxy A, B, and C, among the results of multiple specimens of the same composition and between the resistivity and the upper bound of the resistivity substantiate the reliability of the results reported here.

During measurement of the contact resistivity using the configuration of Fig. 1, pressure (0.92 MPa) was optionally applied on the sandwich in the direction perpendicular to the plane of the interface. The application of pressure resulted in a pressure contact.

RESULTS AND DISCUSSION

Table I lists the contact resistivity as well as the upper bound of the contact resistivity. The upper bound values are slightly higher than the corresponding resistivity values, thereby providing support for the correctness of the lowest few resistivity values (Table I), which are harder to measure than the higher values.

The contact resistivity is lower for both carbon black dispersions (whether based on polyethylene glycol or butyl ether) than silver paint (whether A or B; whether heat cured or not), that is, in turn, superior to colloidal graphite. However, the carbon black dispersions are inferior to silver epoxy A, B, and C that are, in turn, inferior to the solder. Having no interface material at all gives essentially the same high resistivity as colloidal graphite. The origin of the superiority of silver epoxy (A, B, and C) compared to silver paint (A and B) is presently unclear, as it may relate to the difference in size and shape of the silver particles and to the difference in silver particle content; such information is mostly proprietary for these commercial products. On the other hand, the usefulness of heat curing in improving the performance of silver paint A is reasonable, as the heat curing is expected to promote the electrical connectivity of adjacent silver particles.

Figure 2 shows that repeated compressive loading and unloading does not affect the contact resistivity in the loaded state for the pressure contact involving the carbon black dispersion based on polyethylene glycol. Figure 2 also shows the degree of noise of the contact resistivity in the loaded state. Similar behavior was observed for the carbon black dispersion based on butyl ether.

It is technologically significant that the carbon dispersions (pressure contacts) are superior to silver

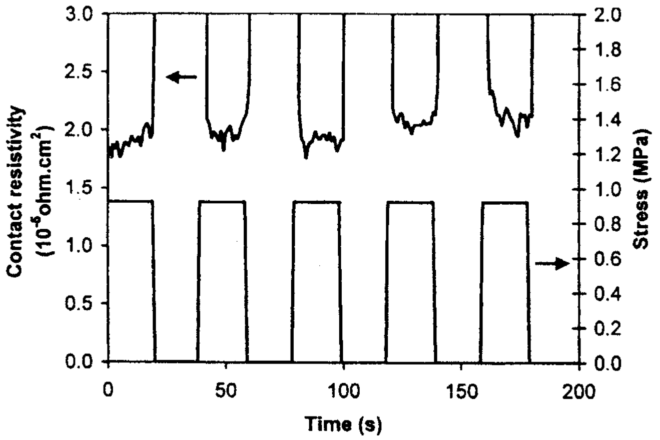

Fig. 2. Contact electrical resistivity versus time and compressive stress versus time during repeated loading for the case of carbon black dispersion based on polyethylene glycol as the interface material. In the unloaded state, the resistivity is so high that it is off the scale.

paint (pressureless contacts) for providing a low contact resistivity, as carbon black is much less expensive than silver paint. The poor performance of colloidal graphite (comparable to a pressure contact that has no interface material) compared to silver paint is due to the low conductivity of graphite compared to silver. The good performance of the carbon black dispersions compared to silver paint and colloidal graphite is due to the conformability of carbon black, as mentioned in explaining the high effectiveness of the carbon black dispersions as thermal pastes.[7] On the other hand, the carbon black dispersions are inferior to silver epoxy A, B, and C. This is probably due to the flake geometry and high conductivity of the silver in the silver epoxy.

In spite of the possible interfacial reaction between solder and copper,[9–11] solder gives the lowest contact resistivity among all the interface materials tested. This is due to the bulk metallic form of the solder and the ability of molten solder to conform to the topography of the mating copper surfaces during joint formation.

The carbon black dispersions are highly effective for pressure contacts. However, they are not suitable for pressureless contacts (because of the need to compress the carbon black agglomerates for the purpose of conforming to the topography of the mating surfaces), unless the pressureless contacts are formed under pressure.

CONCLUSIONS

The use of a carbon black dispersion as an interface material between copper surfaces under a pressure of 0.92 MPa is effective for decreasing the contact electrical resistivity from 1×10^{-4} $\Omega\cdot cm^2$ to 2×10^{-5} $\Omega\cdot cm^2$. Carbon black dispersions based on polyethylene glycol and with butyl ether are equally effective. In contrast, a pressureless contact with colloidal graphite as the interface material and a pressure contact with no interface material give similarly high contact resistivity of 1×10^{-4} $\Omega\cdot cm^2$.

Carbon black pressure contacts exhibit lower contact electrical resistivity than silver paint or colloidal graphite pressureless contacts, but exhibit higher contact resistivity than silver epoxy or solder pressureless contacts. Silver epoxy is more effective than silver paint for providing pressureless contacts of low resistivity. A pressureless contact involving solder exhibits lower contact resistivity (5×10^{-7} $\Omega\cdot cm^2$) than any of the pressureless or pressure contacts investigated.

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