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(54) Title: PHOTONIC SINTERING OF A SOLDERABLE POLYMER THICK FILM COPPER CONDUCTOR COMPOSITION

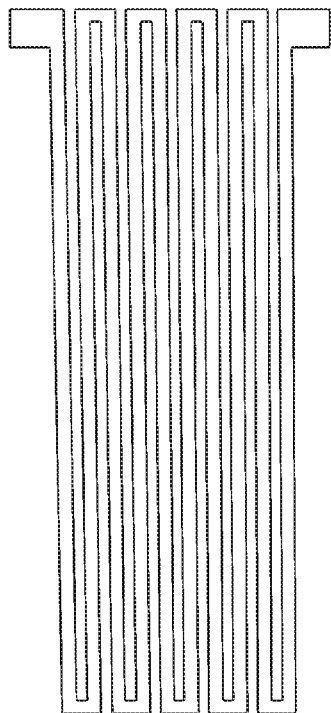


FIG. 1

(57) Abstract: This invention provides a polymer thick film copper conductor composition for forming a solderable and highly solder leach resistant electrical conductor and a method for using the polymer thick film copper conductor composition to form the electrical conductor in an electrical circuit. The method subjects the deposited thick film copper conductor composition to photonic sintering. The invention further provides electrical devices containing electrical conductors made from the polymer thick film copper conductor composition and also those formed by the method.

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**TITLE****PHOTONIC SINTERING OF A SOLDERABLE POLYMER THICK FILM  
COPPER CONDUCTOR COMPOSITION**

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**FIELD OF THE INVENTION**

The invention is directed to the photonic curing of a polymer thick film (PTF) copper conductor composition for use in many different applications. In one embodiment, the PTF copper conductor composition is used as a screen-printed conductor on a thin film substrate such as a polyimide. The PTF copper conductor functions as a grid electrode. This composition may further be used for any other application where conductivity (low resistivity) is required.

**BACKGROUND OF THE INVENTION**

This invention is directed to a polymer thick film copper conductor composition for use in electronic devices. PTF silver conductors are quite prevalent in electronic circuitry as the conductor of choice due to the low resistivity (<50 milliohms/sq) and the reliability of silver. The price of silver is high and it is therefore becoming expensive to use in circuitry. Alternatives to silver are being sought with little compromise in electrical properties but at reduced cost. It is the purpose of this invention to provide such an alternative.

**SUMMARY OF THE INVENTION**

This invention provides a polymer thick film copper conductor composition comprising:

- (a) 60 to 95 wt% copper powder possessing particles with an average particle size of 0.2 to 10  $\mu\text{m}$  and a surface area/mass ratio in the range of 0.2 to 3.0  $\text{m}^2/\text{g}$ ; dispersed in
- (b) 4 to 35 wt% organic medium comprising
  - (1) 2-7 wt% polyimide resin, dissolved in
  - (2) an organic solvent; and
- (c) 0.0 to 1 wt% viscosity stabilizing agent comprising a carboxylic acid containing compound;

in the absence of a reducing agent and wherein the ratio of the weight of the copper powder to the weight of the polyimide resin is at least 13 and wherein the wt% are based on the total weight of the polymer thick film copper conductor composition.

5           In one embodiment, the viscosity stabilizing agent comprising a carboxylic acid containing compound is a fatty acid. In an embodiment it is selected from the group consisting of oleic acid, stearic acid and mixtures thereof.

10           The polymer thick film copper conductor composition can be cured by photonic sintering.

This invention also provides a method for forming an electrical conductor in an electrical circuit, comprising:

- 15           a) providing a substrate;
- b) providing the polymer thick film copper conductor composition of the invention;
- c) applying said polymer thick film copper conductor composition onto said substrate; and
- 20           d) subjecting said polymer thick film copper conductor composition to photonic sintering to form said electrical conductor.

25           In an embodiment, the method further comprises a step of drying the thick film copper conductor composition, wherein this step is carried out following step (c) but before step (d). The composition is processed at a time and temperature necessary to remove all solvent. Photonic sintering after drying reduces the resistivity.

The invention also provides an electrical device comprising an electrical conductor formed using the polymer thick film copper conductor composition of the invention or formed by any of the embodiments of the above described method.

30           The conductor formed using the polymer thick film copper conductor composition of the invention is a solderable and highly solder leach resistant electrical conductor.

### **BRIEF DESCRIPTION OF THE FIGURE**

Figure 1 illustrates the serpentine screen printed paste pattern used in the Comparative Experiment and the Examples.

### **DETAILED DESCRIPTION OF INVENTION**

5           Generally, a thick film composition comprises a functional phase that imparts appropriate electrically functional properties to the composition. The functional phase comprises electrically functional powders dispersed in an organic medium that acts as a carrier for the functional phase. Generally, in thick film technology,  
10 the composition is fired to burn out the organics and to impart the electrically functional properties. However, in the case of polymer thick films, the organics, other than the solvent, remain as an integral part of the composition after drying. "Organics" as used herein comprise polymer, resin or binder components of the thick  
15 film composition. These terms may be used interchangeably and they all mean the same thing.

In one embodiment, the polymer thick film conductor copper composition is a polymer thick film copper conductor composition comprising a copper powder dispersed in an organic medium comprising a  
20 polymer resin and a solvent. This invention provides a polymer thick film conductor copper composition that does not require a reducing agent and it does not contain one. The components used in this embodiment of the polymer thick film conductor copper composition are discussed below.

As used herein, weight percent is written as wt%.

#### 25 **Polymer Thick Film Copper Conductor Composition**

##### **A. Copper Conductor Powder**

The electrically functional powder in the polymer thick film copper conductor composition is a copper conductor powder

30           The particle diameter and shape of the copper powder are particularly important and have to be appropriate to the application method. In one embodiment the particles are spherical in shape. In another embodiment the particles are in flake form. In still another embodiment the particles are irregular in shape. The particle size

distribution of the copper particles is also critical with respect to the effectiveness of the invention. As a practical matter, the particle size is in the range of 1 to 100  $\mu\text{m}$ . In an embodiment, the average particle size is 0.2 to 10  $\mu\text{m}$ . In addition, the surface area/mass ratio of the copper particles is in the range of 0.2 to 3.0  $\text{m}^2/\text{g}$ . In one embodiment, the copper particles have a flake form.

The polymer thick film copper conductor composition is comprised of 40 to 95 wt% copper powder, wherein the wt% is based on the total weight of the polymer thick film copper conductor composition.

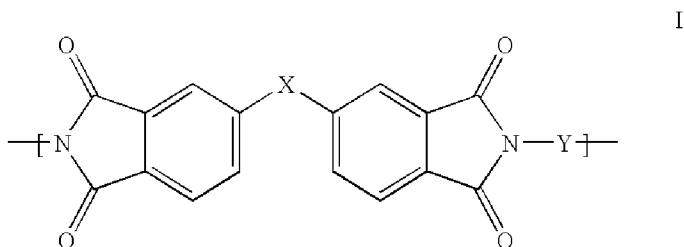
Furthermore, it is known that small amounts of one or more other metals may be added to the copper conductor compositions to modify the properties of the conductor. Some examples of such metals include: gold, silver, nickel, aluminum, platinum, palladium, molybdenum, tungsten, tantalum, tin, indium, lanthanum, gadolinium, boron, ruthenium, cobalt, titanium, yttrium, europium, gallium, sulfur, zinc, silicon, magnesium, barium, cerium, strontium, lead, antimony, conductive carbon, and combinations thereof and others common in the art of thick film compositions. The additional metal(s) may comprise up to about 1.0 percent by weight of the total composition.

## **B. Organic Medium**

The copper powder is typically mixed with an organic medium (vehicle) by mechanical mixing to form a paste-like composition, called "paste", having suitable consistency and rheology for printing. The organic medium must be one in which the solids are dispersible with an adequate degree of stability. The rheological properties of the organic medium must be such that they lend good application properties to the composition. Such properties include: dispersion of solids with an adequate degree of stability, good application of composition, appropriate viscosity, thixotropy, appropriate wettability of the substrate and the solids, a good drying rate, and dried film strength sufficient to withstand rough handling.

The organic medium comprises a solution of resin in organic solvent(s).

In an embodiment, the polyimide resin is represented by formula I:



wherein X is C(CH<sub>3</sub>)<sub>2</sub>, O, S(O)<sub>2</sub>, C(CF<sub>3</sub>)<sub>2</sub>, O-Ph-C(CH<sub>3</sub>)<sub>2</sub>-Ph-O, O-Ph-O- or a mixture of two or more of C(CH<sub>3</sub>)<sub>2</sub>, O, S(O)<sub>2</sub>, C(CF<sub>3</sub>)<sub>2</sub>, O-Ph-C(CH<sub>3</sub>)<sub>2</sub>-Ph-O, O-Ph-O-;

- 5 wherein Y is a diamine component or a mixture of diamine components selected from the group consisting of: m-phenylenediamine (MPD), 3,4'-diaminodiphenyl ether (3,4'-ODA), 4,4'-diamino-2,2'-bis(trifluoromethyl)biphenyl (TFMB), 3,3'-diaminodiphenyl sulfone (3,3'-DDS), 4,4'-(Hexafluoroisopropylidene)bis(2-aminophenol) (6F-AP), bis-(4-
- 10 (4-aminophenoxy)phenyl)sulfone (BAPS), 9,9-bis(4-aminophenyl)fluorene (FDA); 2,3,5,6-tetramethyl-1,4-phenylenediamine (DAM), 2,2-bis[4-(4-aminophenoxyphenyl)]propane (BAPP), 2,2-bis[4-(4-aminophenoxyphenyl)] hexafluoropropane (HFBAPP), 1,3-bis(3-
- 15 aminophenyl)hexafluoropropane, 2,2-bis(4-aminophenyl)hexafluoropropane (bis-A-AF), 4,4'-bis(4-amino-2-trifluoromethylphenoxy) biphenyl, 4,4'-[1,3-phenylenebis(1-methyl-ethylidene)], and bisaniline (bis-aniline-M) with the proviso that:
- 20 i. if X is O, then Y is not m-phenylenediamine (MPD), bis-(4-(4-aminophenoxy)phenyl)sulfone (BAPS) and 3,4'-diaminodiphenyl ether (3,4'-ODA); BAPP, APB-133, or bisaniline-M;
- ii. if X is S(O)<sub>2</sub>, then Y is not 3,3'-diaminodiphenyl sulfone (3,3'-DDS);
- 25 iii. if X is C(CF<sub>3</sub>)<sub>2</sub>, then Y is not m-phenylenediamine (MPD), bis-(4-(4-aminophenoxy)phenyl)sulfone (BAPS), 9,9-bis(4-aminophenyl)fluorene (FDA), or 3,3'-diaminodiphenyl sulfone (3,3'-DDS); and
- iv. if X is O-Ph-C(CH<sub>3</sub>)<sub>2</sub>-Ph-O or O-Ph-O-, then Y is not m-phenylene diamine (MPD), FDA, 3,4'-ODA, DAM, BAPP, APB-133, or bisaniline-M.

In one embodiment the polyimide can be prepared in the dry and powdered state by reacting monomers 2,2'-Bis(trifluoromethyl)-4,4'-diamino biphenyl (TFMB), 2,2Bis(3-amino-4-hydroxyphenyl)hexafluoropropane (6F-AP) and

5 Hexafluoroisopropylidenebis-phthalic dianhydride. (6-FDA). in a ratio of 33/10/57 (TFMB/6F-AP/6-FDA) through the well-known process of first making polyamic acid in N,N-Dimethylacetamide (DMAC) solvent, controlling the molecular weight of said polyamic acid with end-capping additives, then chemically imidizing and precipitating the polyimide

10 polymer using methanol neat additions to the DMAC solution. The precipitate was washed several times with methanol neat, filtered and then dried at approximately 200°C to form a dry and handleable powder and to reduce DMAC residuals to below 0.1% weight. The resulting powder can be dried and stored at room temperature or dissolved in a solvent in

15 preparation for forming the paste composition.

In another embodiment the polyimide can be prepared by reacting TFMB and 6-FDA in a ratio of 42/58 (TFMB/6-FDA).

The polymer thick film copper conductor composition is comprised of 4 to 35 wt% organic medium, wherein the wt% is based on the total

20 weight of the polymer thick film copper conductor composition. The organic medium is comprised of 2-7 wt% resin, wherein the wt% is based on the total weight of the polymer thick film copper conductor composition.

### **C. Viscosity Stabilizing agent**

The polymer thick film copper conductor composition is

25 comprised of 0.0 to 1 wt% viscosity stabilizing agent comprising a carboxylic acid containing compound. In one embodiment the viscosity stabilizing agent is a fatty acid. In an embodiment, the fatty acid is selected from the group consisting of oleic acid, stearic acid and mixtures thereof. In one such embodiment, the fatty acid is oleic acid.

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### **Application of Thick Films**

The polymer thick film paste composition is deposited on a substrate typical of those used in electric devices. In a typical

embodiment, the substrate is impermeable to gases and moisture. The substrate can be a sheet of flexible material. The flexible material can be an impermeable material such as a polyimide film, e.g. Kapton®. The material can also be a polyester, e.g. polyethylene terephthalate, or a  
5 composite material made up of a combination of plastic sheet with optional metallic or dielectric layers deposited thereupon. The substrate can be alumina, aluminum or any material that can withstand the process temperature.

The deposition of the polymer thick film conductive composition is  
10 performed preferably by screen printing, although other deposition techniques such as stencil printing, syringe dispensing or coating techniques can be utilized. In the case of screen-printing, the screen mesh size controls the thickness of deposited thick film.

The deposited thick film conductive composition may be dried, i.e.,  
15 the solvent is evaporated, by exposure to heat, e.g. at 130°C for minutes.

### **Photonic Sintering**

Photonic sintering uses light to provide high-temperature sintering. Typically, a flash lamp is used to provide the source of light and is  
20 operated with a short on time of high power and a duty cycle ranging from a few hertz to tens of hertz. The photonic sintering step is brief, typically less than 1 minute. Photonic sintering may also be referred to as photonic curing. Examples of commercial manufacturers of photonic sintering equipment include NovaCentrix Corp. (Austin, TX) and Xenon Corp  
25 (Wilmington, MA)

The photonic sintering of the deposited thick film conductor composition provides conductors with low resistivity.

In one embodiment, prior to the photonic sintering, the deposited thick film conductor composition is dried by exposure to heat at low  
30 temperatures, typically for 5-10 min at 80°C. In another embodiment, the deposited thick film conductor composition is not dried prior to photonic sintering.

The present invention will be discussed in further detail by giving practical examples. The scope of the present invention, however, is not limited in any way by these practical examples.

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### **EXAMPLES AND COMPARATIVE EXPERIMENTS**

The substrates Kapton® (500HPP-ST) and the unclad FR-4 substrates were obtained from DuPont® and used as received after cut into 2.5" x 3.5" sizes.

10 The low loss Itera substrates were obtained from Isola through Insulectro. and alumina (AD-96) substrates (obtained from CoorsTek, Golden, CO) were used with no further cleaning.

The polyimide resin polyimide #1 was prepared as described above by reacting TFMB, 6F-AP and 6-FDA. in a ratio of 33/10/57.

15 The polyimide resin polyimide #2 was prepared as described above by reacting TFMB and 6-FDA in a ratio of 42/58

Adhesion was measured by a Scotch® Tape test in which the tape was applied to the cured sample and then pulled off. The adhesion was judged on a scale of from poor (>10% peeling) to good (1% peeling).

20 The SAC alloy with a composition of Sn96.5%Ag3.0%Cu0.5% was used for the solder wetting test. Either Alpha 611 or Kester 952 flux was used. In the solder wetting test the cured samples were typically dipped for 3, 10, 30, or 60 seconds into the SAC alloy pot that was kept at 235 – 250°C.

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### **COMPARATIVE EXPERIMENT A**

A screen printable PTF Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #1 having a number average molecular weight of approximately 135,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 27 wt% resin, 31 wt% butylcarbitol acetate, 11 wt% dibasic esters (DBE-3) and 31 wt% diethyl adipate., wherein the wt%

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are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

5	73.5 wt%	copper powder
	17.3 wt%	organic medium
	1.7 wt%	glycerol
	3%	butylcarbitol acetate
	1.5 wt%	dibasic esters (DBE-3)
10	3 wt%	diethyl adipate

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 15.7.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 325 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the measured line resistance was 32.6  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 9.8  $\mu$ m using a profilometer. Therefore the resistivity was calculated to be 21.2 m $\Omega$ /□/mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, a sample with a resistance of 33  $\Omega$  dipped in the solder pot for 10 seconds showed no solder wetting and a resistance of 30.2  $\Omega$  after dipped in the SAC pot for 10 seconds. In contrast about 40% solder wetting was observed from the

sample dipped in the solder pot for 3 seconds, however, the sample dipped for 5 seconds showed no solder wetting. No defects such as voids or line delamination were detected from any of the samples.

The composition was also used to screen print a 600 square  
 5 serpentine pattern on 0.028 inch-thick FR-4 and 0.030 inch-thick Itera substrates. Using a 325 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic  
 10 sintering using the same profile used for curing the samples prepared on Kapton® substrates. After processing, the measured line resistance was 41.5 Ω on FR-4, and 59.6 Ω on Itera. The average conductor thickness over the 600 square pattern was determined to be 11.2 μm on FR-4 and 11.4 μm on Itera using a profilometer, which gave the calculated resistivity  
 15 of 31 and 45 mΩ/□/mil, respectively.

### **COMPARATIVE EXPERIMENT B**

A screen printable Cu composition was prepared using copper  
 flakes having an average particle size of 4 micron. A polyimide organic  
 20 medium was prepared by dissolving a polyimide #1 (27 wt%) having a number average molecular weight of approximately 135,000 in a mixture of the solvents, butylcarbitol acetate (31 wt%), dibasic esters (DBE-3, 11 wt%) and diethyl adipate (31 wt%). A phenoxy organic medium was prepared by dissolving a phenoxy resin (PKHH® resin from InChem Corp,  
 25 20 wt%) in Dowanol® DPM (80%), wherein the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition  
 were

30	73.5 wt%	copper powder
	13.8 wt%	polyimide organic medium
	3.5 wt%	phenoxy organic medium
	1.7 wt%	glycerol

2.4%	butylcarbitol acetate
1.2 wt%	dibasic esters (DBE-3)
2.4 wt%	diethyl adipate
1.5 wt%	Dowanol® DPM

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wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 19.4.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 325 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the measured line resistance was 44  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 10  $\mu$ m using a profilometer,. Therefore the resistivity was calculated to be 26.3 m $\Omega$ /□/ mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, a sample with 46.9  $\Omega$  showed over 90% solder wetting and a resistance of 25.8  $\Omega$  after dipped in the SAC pot for 3 seconds with no defects formed, and the samples dipped for 5 or 10 seconds showed 60 – 80% solder wetting but minor defects such as delamination or voids.

### COMPARATIVE EXPERIMENT C

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #2 having a number average molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

	66 wt%	copper powder
	26 wt%	organic medium
15	4 wt%	butylcarbitol acetate
	4 wt%	dibasic esters (DBE-3)

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 9.8.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500 μsec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 104.3 Ω. The average conductor thickness over the 600 square pattern was determined

to be 11.6  $\mu\text{m}$  using a profilometer. Therefore the resistivity was calculated to be 80.6  $\text{m}\Omega/\square/\text{mil}$ .

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples  
 5 dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of about 10, 50, 40 and 0%, respectively. The resistance of the samples was 94.4, 96.7, 95, or 91.3  $\Omega$ , which changed to 70, 82, 57 and 115  $\Omega$ , respectively, after the solder dipping. No defects such as voids or line delamination were detected from any of the samples.

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**COMPARATIVE EXPERIMENT D**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #2 having a number average  
 15 molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper  
 20 powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

	69.8 wt%	copper powder
	21.75 wt%	organic medium
25	4.23 wt%	butylcarbitol acetate
	4.23 wt%	dibasic esters (DBE-3)

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 12.3.

30 The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper

paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 53  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 7.6  $\mu$ m using a profilometer. Therefore the resistivity was calculated to be 28.2 m $\Omega$ /□/ mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of near 0, 50, 20, and 5%, respectively. No defects such as voids or line delamination were detected from any of the samples. The resistance decreased from 56.4, 56.5, 56.1, or 56.7  $\Omega$  to 51.5, 36.5, 43, and 67  $\Omega$ , respectively, after each of the solder dippings.

20

### **EXAMPLE 1**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #2 having a number average molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

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The components of the PTF copper conductor composition were

73.6 wt% copper powder

17.5 wt%	organic medium
4.45 wt%	butylcarbitol acetate
4.45 wt%	dibasic esters (DBE-3)

5 wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 16.2.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400  
10 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix  
15 (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500 µsec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 34.2 Ω. The  
20 average conductor thickness over the 600 square pattern was determined to be 11.6 µm using a profilometer. Therefore the resistivity was calculated to be 26.4 mΩ/□/mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples  
25 dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of over 90%. No defects such as voids or line delamination were detected for any of the samples. The resistance of the samples was 32.7, 34.5, 32.8, or 33 Ω, which changed to 17.1, 21.1, 18.8, 17.4 Ω, respectively, after the solder dippings

30 Adhesion was good.

**EXAMPLE 2**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #2 having a number average molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

	77.57 wt%	copper powder
	8.97 wt%	organic medium
15	6.6 wt%	butylcarbitol acetate
	6.86 wt%	dibasic esters (DBE-3)

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 33.3.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 56  $\Omega$ . The average conductor thickness over the 600 square pattern was determined

to be 10.9  $\mu\text{m}$  using a profilometer. Therefore the resistivity was calculated to be 41.3  $\text{m}\Omega/\square/\text{mil}$ .

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples  
 5 dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of over 90%. No defects such as voids or line delamination were detected for any of the samples. The resistance decreased from 62.5, 65.8, 57, or 59  $\Omega$  to 34, 43, 24, and 27  $\Omega$ , respectively, after the solder dippings.

Adhesion was good.

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### **EXAMPLE 3**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #1 having a number average  
 15 molecular weight of approximately 32,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 37.8 wt% resin, 26.4 wt% butylcarbitol acetate, 9.4 wt% dibasic esters (DBE-3) and 26.4 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper  
 20 powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

	75.34 wt%	copper powder
	12.26 wt%	organic medium
25	6.2 wt%	butylcarbitol acetate
	6.2 wt%	dibasic esters (DBE-3)

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 16.3.

30 The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper

paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 58  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 9.7  $\mu$ m using a profilometer. Therefore the resistivity was calculated to be 37.2 m $\Omega$ /□/ mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of near 90, 90, 90, and 90%, respectively. No defects such as voids or line delamination were detected from any of the samples. The resistance decreased from 51.5, 56.4, 53, or 55.2  $\Omega$  to 29, 35, 34, and 30.9  $\Omega$ , respectively, after each of the solder dippings.

Adhesion was good.

#### **EXAMPLE 4**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #1 having a number average molecular weight of approximately 135,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 27 wt% resin, 31 wt% butylcarbitol acetate, 11 wt% dibasic esters (DBE-3) and 31 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

71.78 wt%	copper powder
16.5 wt%	organic medium
5.86 wt%	butylcarbitol acetate
5.86 wt%	dibasic esters (DBE-3)

5

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 16.1.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600  
10 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic  
15 sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM.  
20 After processing, the average measured line resistance was 38.6  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 8.6  $\mu$ m using a profilometer. Therefore the resistivity was calculated to be 21.8 m $\Omega$ /□/ mil.

Solder wettability and solder leach resistance was tested in the  
25 manner described above using the samples. As examples, the samples dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of near 30, 70, 80, and 90%, respectively. No defects such as voids or line delamination were detected for any of the samples. The resistance decreased from 37.5, 36.9, 36.3, or 38.2  $\Omega$  to 24.4, 23.2, 17.7, and 17.3  $\Omega$ ,  
30 respectively, after each of the solder dippings.

Adhesion was good.

**EXAMPLE 5**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium was prepared by dissolving a polyimide #2 having a number average  
 5 molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein the wt% are based on the total weight of the organic medium. The copper  
 10 powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

	73.5 wt%	copper powder
	17.5 wt%	organic medium
15	4.4 wt%	butylcarbitol acetate
	4.4 wt%	dibasic esters (DBE-3)
	0.2 wt%	oleic acid

wherein the wt% are based on the total weight of the composition. The ratio of the weight of the copper to the weight of the polyimide is 16.2.

20 The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400 mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable  
 25 resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse  
 30 composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 45  $\Omega$ . The average conductor thickness over the 600 square pattern was determined

to be 9.5  $\mu\text{m}$  using a profilometer. Therefore the resistivity was calculated to be 28  $\text{m}\Omega/\square/\text{mil}$ .

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples  
 5 dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of over 90%. No defects such as voids or line delamination were detected for any of the samples. The resistance measured from the samples was 39.9, 42.2, 40.2, or 40.8  $\Omega$ , which changed to 20.5, 24.9, 23.5, and 25.2  $\Omega$ , respectively, after each of the solder dippings  
 10 Adhesion was good.

### **EXAMPLE 6**

A screen printable Cu composition was prepared using copper flakes having an average particle size of 4 micron. An organic medium  
 15 was prepared by dissolving a polyimide #2 having a number average molecular weight of approximately 40,000 in a mixture of the solvents, butylcarbitol acetate, dibasic esters (DBE-3) and diethyl adipate. The organic medium contained 26 wt% resin, 31.3 wt% butylcarbitol acetate, 11.4 wt% dibasic esters (DBE-3) and 31.3 wt% diethyl adipate., wherein  
 20 the wt% are based on the total weight of the organic medium. The copper powder was then dispersed in the organic medium.

The components of the PTF copper conductor composition were

25	73.1 wt%	copper powder
	17.4 wt%	organic medium
	4.4 wt%	butylcarbitol acetate
	4.4 wt%	dibasic esters (DBE-3)
	0.7 wt%	oleic acid

wherein the wt% are based on the total weight of the composition. The  
 30 ratio of the weight of the copper to the weight of the polyimide is 16.2.

The components were combined and mixed for 60 seconds in a Thinky-type mixer. The composition was used to screen print a 600 square serpentine pattern (shown in Fig. 1) on Kapton® film. Using a 400

mesh stainless steel screen, several patterns were printed, and the copper paste was dried at 80°C for 10 min. The samples yielded no measurable resistance.

The dried serpentine patterns were then subjected to photonic sintering. A PulseForge 3200 sintering unit manufactured by NovaCentrix (Austin, TX) was employed. The unit was operated in an arbitrary mode. The process settings were as follows: pulse voltage: 230 V, A pulse composing of five micro pluses: 200, 100, 1500, 1500, and 1500  $\mu$ sec to give energy equal to 3.3 J/cm<sup>2</sup>, overlap factor: 2.2, web speed: 25 FPM. After processing, the average measured line resistance was 48.2  $\Omega$ . The average conductor thickness over the 600 square pattern was determined to be 7.9  $\mu$ m using a profilometer. Therefore the resistivity was calculated to be 25.4 m $\Omega$ /□/ mil.

Solder wettability and solder leach resistance was tested in the manner described above using the samples. As examples, the samples dipped in the solder pot for 3, 10, 30, or 60 seconds showed solder wetting of over 90%. The resistance measured from the samples was 43.4, 42, 50.4, or 53.5  $\Omega$ , which changed to 33.2, 21.8, 33.9, and 28.4  $\Omega$ , respectively, after each of the solder dippings.

Adhesion was good.

**CLAIMS**

What is claimed is:

1. A polymer thick film copper conductor composition comprising:
  - 5 (a) 60 to 95 wt% copper powder possessing particles with an average particle size of 0.2 to 10  $\mu\text{m}$  and a surface area/mass ratio in the range of 0.2 to 3.0  $\text{m}^2/\text{g}$ ; dispersed in
  - (b) 4 to 35 wt% organic medium comprising
    - 10 (1) 2-7 wt% polyimide resin, dissolved in
    - (2) an organic solvent; and
  - (c) 0.0 to 1 wt% viscosity stabilizing agent comprising a carboxylic acid containing compound;

in the absence of a reducing agent and wherein the ratio of the weight of the copper powder to the weight of the polyimide resin is at least 13 and

15 wherein the wt% are based on the total weight of the polymer thick film copper conductor composition.
2. The polymer thick film copper conductor composition of claim 1, wherein said viscosity stabilizing agent is a fatty acid.

20
3. The polymer thick film copper conductor composition of claim 2, wherein said viscosity stabilizing agent is selected from the group consisting of oleic acid, stearic acid and mixtures thereof.
- 25 4. The polymer thick film copper conductor composition of claim 3, wherein said viscosity stabilizing agent is oleic acid.
5. A method for forming an electrical conductor in an electrical circuit, comprising:
  - 30 a) providing a substrate;
  - b) providing the polymer thick film copper conductor composition of claim 1
  - c) applying said polymer thick film copper conductor composition onto said substrate; and

d) subjecting said polymer thick film copper conductor composition to photonic sintering to form said electrical conductor.

5 6. The method of claim 5, said method further comprising a step of drying said polymer thick film conductor composition, wherein said step of drying is carried out following step (c) but before step (d).

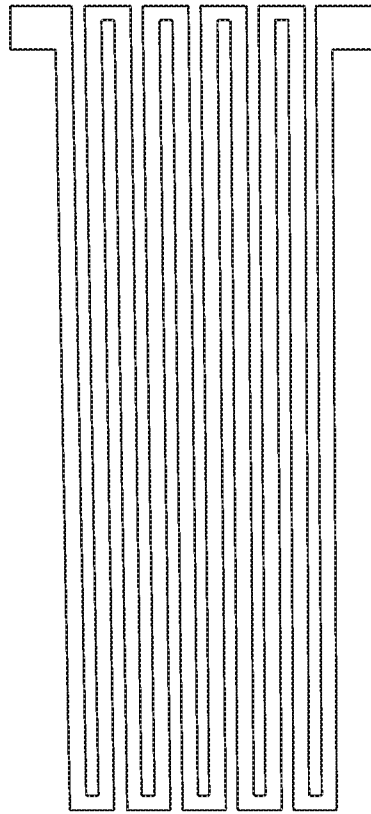
7. The method of claim 5, wherein said viscosity stabilizing agent is a  
10 fatty acid.

8. The method of claim 7, wherein said viscosity stabilizing agent is selected from the group consisting of oleic acid, stearic acid and mixtures thereof.  
15

9. An electrical device comprising an electrical conductor formed from the polymer thick film copper conductor composition of claim 1.

10. An electrical device comprising an electrical conductor formed by the  
20 method of claim 5.

*1/1*



*FIG. 1*