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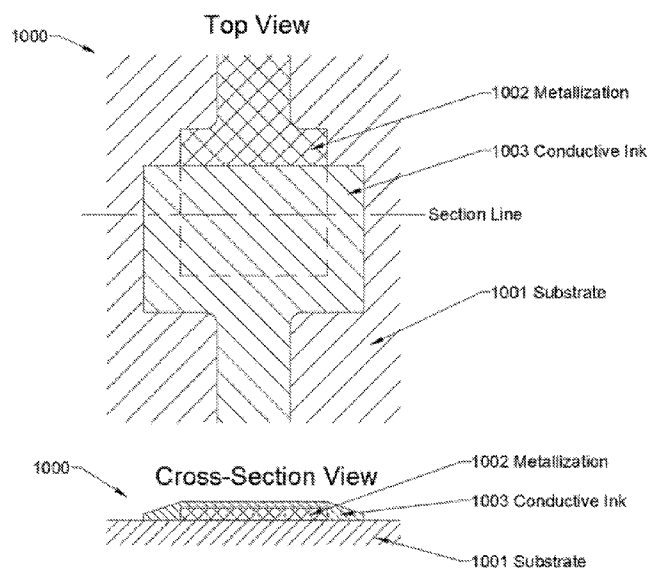
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(54) Title: METHOD AND APPARATUS FOR FORMING AN ELECTRICAL CIRCUIT INCLUDING ALUMINUM AND ONE OR MORE DISSIMILAR METALS

FIG. 1



(57) Abstract: An electrical circuit includes a substrate, at least one first metal formed on the substrate, and at least one second metal. The second metal is different from the first metal and is formed on the substrate such that at least a portion of the second covers at least a portion of the first metal. The second metal forms an electrical connection with the first metal where the second metal covers the first metal.

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METHOD AND APPARATUS FOR FORMING AN ELECTRICAL CIRCUIT INCLUDING ALUMINUM AND ONE OR MORE DISSIMILAR METALS

RELATED APPLICATIONS

[0001] This application claims priority to US Provisional Application number 62/543,731, filed August 10, 2017, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure relates to the field of electrical circuits, more specifically to methods and apparatus for forming an electrical circuit including aluminum and one or more dissimilar metals.

DESCRIPTION OF RELATED ART

[0003] It is common for high electrical resistance to negatively impact performance of electronic circuit designs. For example, high resistance in RF waveguides that are passing signals will cause higher attenuation coefficients, resulting in signal power losses. As another example, high resistance in NFC antenna coils will limit the maximum current that can flow as part of the RLC resonant circuit, resulting in reduced resonator quality (Q) values and lower ranges for data readout.

[0004] The resistance in an electronic circuit arises from a variety of sources, including the resistance of metallic traces and interconnections between components (e.g., resistors, capacitors, integrated circuits, and the like) and the metallic traces.

[0005] It is a major technical challenge to form mechanically robust and low-resistance (i.e., high-conductivity) electrical connections to aluminum metallizations on flexible substrates. Past efforts to form this type of electrical connection have required exposure to high temperatures (e.g., metal ultrasonic spot welding), custom tooling (e.g. thermodes for anisotropic conductive adhesives), or substrate puncturing (e.g. crimping). The inability to form mechanically robust and low-resistance electrical connections to aluminum prevents solder from being used to attach electrical components (e.g., resistors, capacitors, packaged IC's, and the like) to circuits formed from aluminum.

[0006] Forming mechanically robust and low-resistance electrical connections to aluminum is challenging because (1) the fast oxidation rate of aluminum in atmospheric ambients and chemical stability of the resulting aluminum oxide and (2) the large difference in galvanic index between aluminum and most other metals, resulting in galvanic corrosion of aluminum over time. Because of these challenges, additional process steps are required for cleaning and surface preparation of the aluminum. These process steps include cleaning and/or degreasing with solvents, abrading the aluminum surface mechanically, etching the aluminum using strong acid solutions to remove the aluminum oxide layer, and rinsing with deionized water.

[0007] As a result, certain individuals would appreciate further improvements in this area.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present application is illustrated by way of example and not limited in the accompanying figures in which like reference numerals indicate similar elements and in which:

[0009] FIG. 1 illustrates both a top view and a cross-sectional view of a typical interface construction of electrical circuit 1000.

DETAILED DESCRIPTION

[0010] The detailed description that follows describes exemplary embodiments and the features disclosed are not intended to be limited to the expressly disclosed combination(s). Therefore, unless otherwise noted, features disclosed herein may be combined together to form additional combinations that were not otherwise shown for purposes of brevity.

[0011] In some embodiments, the present disclosure provides an apparatus including a metal that readily forms a native oxide and one or more dissimilar metals forming an electrical circuit and methods for fabricating the electrical circuit by forming an electrical connection between the metal that readily forms a native oxide and the one or more dissimilar conductive materials.

[0012] In some embodiments, the present disclosure provides an apparatus including aluminum and one or more dissimilar metals forming an electrical circuit and methods for fabricating the electrical circuit by forming an electrical connection between aluminum and the one or more dissimilar conductive materials.

[0013] In some embodiments, the present disclosure includes an electrical circuit comprising one or more aluminum traces formed on a substrate and at least one silver trace formed on the substrate such that at least a portion of the silver trace covers at least a portion of the aluminum trace, wherein the silver trace forms a mechanically robust and electrically low-resistance connection with the aluminum trace at the location(s) where the silver trace covers the aluminum trace. In some embodiments, the aluminum trace forms a low-resistance antenna structure and the silver trace forms a circuit with pads that are solderable. In yet another embodiment the pads of the silver trace include one more electrical components attached thereto.

[0014] In some embodiments, the substrate includes one or more of any of a number of flexible materials, such as polymeric materials including but not limited to, polyethylene terephthalate film (PET), polyethylene naphthalate (PEN), polyimide foil (PI), polypropylene, polyethylene, polystyrene, polycarbonate, polyether ether ketone (PEEK), or any of a variety of polymer films or combinations thereof. In an alternative embodiment, the substrate is rigid and comprises glass, wood, metal, PVC, silicon, epoxy resin, polycarbonate, or any of a variety of rigid materials or combinations thereof. In yet another embodiment, the substrate includes a combination of one or more flexible materials described herein and one or more rigid materials described herein.

[0015] In some embodiments, the aluminum trace can be formed from chemical etching, stamping, milling, printing or by other means. In some other embodiments, the aluminum trace is formed from an aluminum wire that has been drawn and or wound to create a shape or pattern.

[0016] In some embodiments, the one or more dissimilar metals can comprise a printable or otherwise selectively deposited conductive material containing metallic particles such as, for example, but not limited to, silver, platinum, palladium, copper, nickel, gold, or aluminum or carbon or conductive polymer, or some combination thereof. The conductive metals or composites can be flakes, fine particulates, or nano-particulates, or combinations thereof, in some embodiments. The conductive material can be in the form of a printable conductive ink, toner, or other coating. In some embodiments, electrically functional electronic inks are available from Henkel Corporation or DuPont Inc., for example. The one or more dissimilar metals can also be formed by other means known to those having skill in the art. In some embodiments, the functional electronic inks further include non-conductive particles or particulates that are included to mechanically pierce or penetrate a native oxide formed on the

aluminum surface and thereby create a low-resistance electrical contact between the aluminum and the dissimilar metal. In some such embodiments, the non-conductive particles have a surface that includes features useful for piercing the oxidized aluminum surface. In other embodiments, the conductive particles have a surface that includes features useful for piercing the oxidized aluminum surface. In some embodiments, the functional ink includes solvents and/or binders to assist with removing or penetrating the native oxide layer to expose a non-oxidized aluminum surface.

[0017] In some embodiments, intricate patterns can be selectively printed or otherwise deposited to form the circuit traces by any of a variety of printing or additive deposition methodologies, including, for example, any form of gravure, flatbed screen, flexography, lithography, screen, rotary screen, digital printing, inkjet printing, aerosol jet printing, 3-D printing, and like print methods, or combinations thereof.

[0018] In some embodiments, the present disclosure provides a method for forming mechanically robust and low resistance electrical connections between aluminum and one or more dissimilar metals and an apparatus that includes an electrical circuit comprised of layer structure formed from aluminum and the one or more dissimilar metals, the apparatus formation being compatible with print-based formation of printed electrical circuits and flexible hybrid electronics (FHE).

[0019] In some embodiments, the present disclosure provides a fabrication process that includes printing silver ink directly onto an aluminum surface to form a mechanically strong and electrically low-resistance interconnect to form an electrical circuit. In some embodiments, the silver ink is thermally cured, such that electrical testing after completion of the cure process provides a mechanically and low electrical resistance between the silver ink and aluminum. In some other embodiments, the present disclosure provides a fabrication process that includes printing silver ink directly onto an aluminum wire to form a mechanically strong and electrically low-resistance interconnect to form an electrical circuit.

[0020] In some embodiments, the present disclosure provides an electrical circuit 1000 that includes, at least, the following materials, as shown in FIG. 1.

[0021] An electrically-conductive ink 1003 which is applied using a contact printing method or similar means in order to create an electrical interface with a metallization layer 1002. In some embodiments, the ink is comprised of silver particles in a matrix of one or more polymer binders, which is screen printed in a desired pattern, and then thermally cured to produce a film with isotropic electrical conductivity.

[0022] A metallization layer 1002 to which an electrical interface is desired. In some embodiments, the metallization layer is comprised of an aluminum foil which has been laminated to the substrate 1001, and then chemically etched to form the desired pattern.

[0023] A polymer substrate 1001 which provides mechanical support for the electrical conductors created by metallization layer 1002 and conductive ink 1003, and further provides dielectric/isolative properties between these conductors and other components of the device. In some embodiments, the substrate is comprised of a polyethylene terephthalate film.

[0024] FIG. 1 provides a graphical representation of the present disclosure showing a top view of the interconnection between the aluminum metallization 1002 and the conductive ink 1003 and a cross-section view of the same interconnection as shown by the Section Line in the top figure.

[0025] In this construction, the conductive ink 1003 is applied to the substrate 1001 in the desired pattern, which includes some regions of overlap with the metallization layer 1002, with a thick enough deposit such that a continuous layer of ink is formed on the surface of the substrate, across the edge of the metallization, and up on the surface of the metallization.

[0026] In some such embodiments, this construction provides a conductive ink 1003 that forms a continuous film with adequate thickness to provide electrical continuity and bridges the elevation change between the surface of the substrate 1001 and the surface of the metallization layer 1002. In some embodiments, the ink 1003 is applied in to form a continuous coating over the surface of the metallization layer 1002, which becomes electrically continuous with the metallization 1002.

[0027] In such an embodiment, an electrically-continuous path is formed by the conductive ink 1003 trace onto the metallization 1002, where the primary location and means of electrical interface between the conductive ink 1003 and the metallization 1002 is the surface area where

the two materials are overlapped and in intimate mechanical and electrical contact with each other.

[0028] The present disclosure provides a method and apparatus that addresses the difference in galvanic index by encapsulating at least a portion bond interface area formed between the overlap of the printed silver and aluminum. In some embodiments, the galvanic index remains unaffected, however the printed silver encapsulate prevents or minimizes ingress of ambient oxygen into the bond area to eliminate or decrease the rate of galvanic corrosion between the aluminum and silver.

[0029] In some embodiments, the metallic particulates in the conductive ink mechanically pierce the native oxide formed on the aluminum in order to form a low-resistance electrical contact between the aluminum and the conductive ink. In some other embodiments, solvents and binders present in the printable conductive ink act to partially or completely remove or penetrate the surface oxide such that the conductive particles can intimately contact the non-oxidized aluminum metal. Thereby, the present disclosure provides a method and apparatus that addresses the rapid oxidation of aluminum by penetrating the oxidized aluminum to expose non-oxidized aluminum in the interface area, thereby enabling the aluminum to bond to silver and results in a low-resistance connection between the silver and aluminum.

[0030] The disclosure provided herein describes features in terms of preferred and exemplary embodiments thereof. Numerous other embodiments, modifications and variations within the scope and spirit of the appended claims will occur to persons of ordinary skill in the art from a review of this disclosure.

We claim:

1. An electrical circuit comprising:
a substrate;
at least one first metal formed on the substrate; and
at least one second metal, different from the first metal, formed on the substrate such that at least a portion of the second covers at least a portion of the first metal, wherein the second metal forms an electrical connection with the first metal where the second metal covers the first metal.
2. The electrical circuit of claim 1, wherein the substrate is rigid and comprises glass, wood, metal, PVC, silicon, epoxy resin, polycarbonate, or any of a variety of rigid materials or combinations thereof.
3. The electrical circuit of claim 1, wherein the first metal comprises an aluminum trace and the second metal comprises a silver trace.
4. The electrical circuit of claim 3, wherein the aluminum trace forms a low-resistance antenna structure and the silver trace forms a circuit with pads that are solderable.
5. The electrical circuit of claim 3, wherein the pads of the silver trace include one more electrical components attached thereto.
6. The electrical circuit of claim 3, wherein the substrate includes one or more of any of a number of flexible materials, such as polymeric materials including polyethylene terephthalate film (PET), polyethylene naphthalate (PEN), polyimide foil (PI), polypropylene, polyethylene, polystyrene, polycarbonate, polyether ether ketone (PEEK), or any of a variety of polymer films or combinations thereof.
7. The electrical circuit of claim 3, wherein the aluminum trace is formed by chemical etching, stamping, milling, or printing.
8. The electrical circuit of claim 3, wherein the aluminum trace is formed from an aluminum wire that has been drawn and or wound to create a shape or pattern.
9. The electrical circuit of claim 1, wherein the second metal comprises a printable or otherwise selectively deposited conductive material containing particles of at least one of

silver, platinum, palladium, copper, nickel, gold, aluminum polymer, carbon polymer, or conductive polymer.

10. The electrical circuit of claim 9, wherein the conductive material is at least one of flakes, fine particulates, or nano-particulates.

11. The electrical circuit of claim 9, wherein the conductive material can be in the form of a printable conductive ink, toner, or other coating.

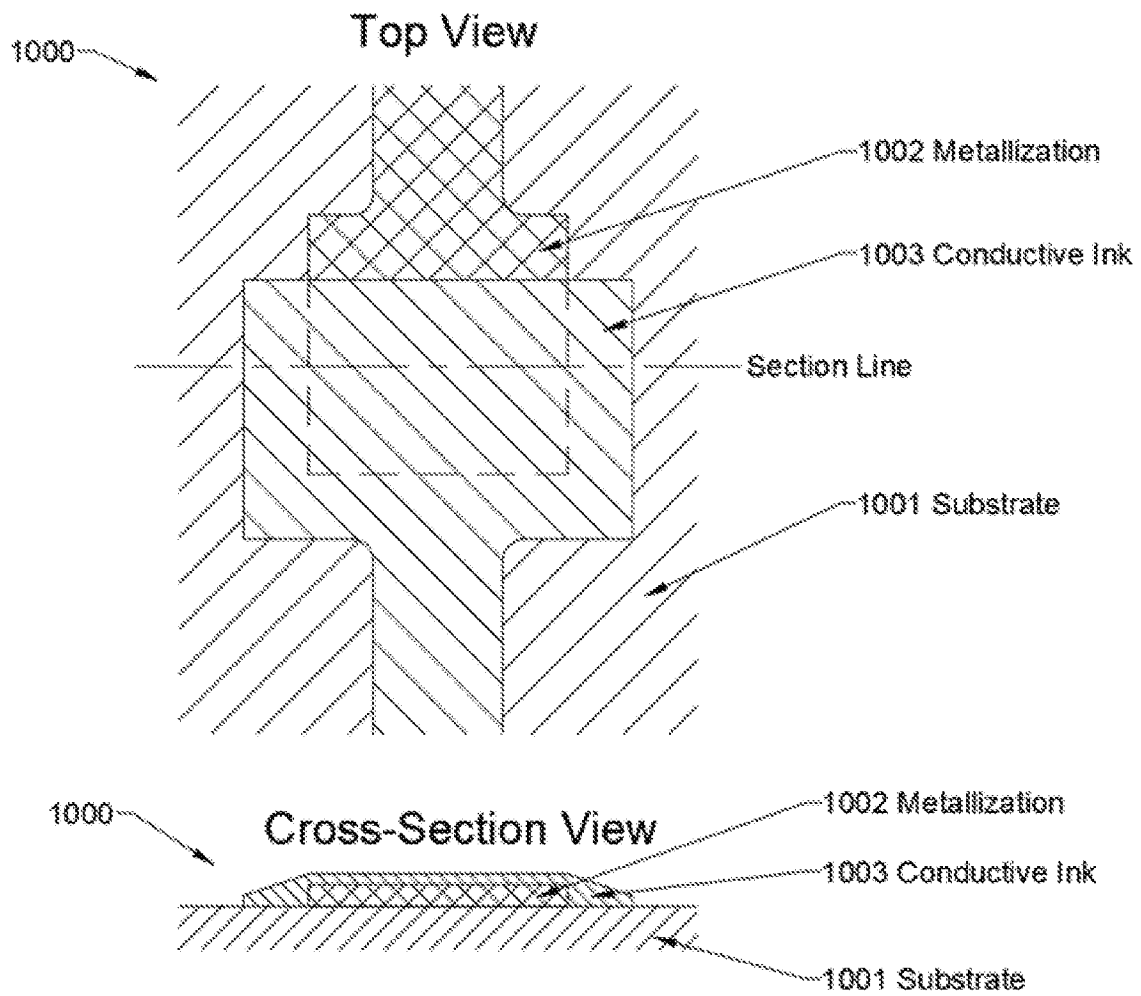
12. The electrical circuit of claim 11, wherein the printable conductive ink further comprises non-conductive particles or particulates configured to mechanically pierce or penetrate a native oxide formed on a surface of the first metal and thereby create a low-resistance electrical contact between the first metal and the second metal.

13. The electrical circuit of claim 11, wherein the printable conductive ink comprises solvents and/or binders to assist with removing or penetrating the native oxide layer to expose a non-oxidized aluminum surface.

14. A method for fabricating an electrical circuit comprising:
printing silver ink directly onto an aluminum surface to form an electrical interconnect;
and
thermally curing the silver ink.

15. A method of claim 14, wherein the aluminum surface is an aluminum wire.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/046040**A. CLASSIFICATION OF SUBJECT MATTER****H05K 1/02(2006.01)i, H05K 1/03(2006.01)i, H05K 1/09(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H05K 1/02; B41J 2/045; G06F 3/047; H01L 21/768; H05K 1/03; H05K 1/09; H05K 3/06; H05K 3/28; H05K 5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: electrical circuit, metal, covering, electrical connection, aluminum, silver, low-resistance, solderable, printable conductive ink, particle

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0248230 A1 (HONGCHUN PARK et al.) 26 September 2013 See paragraphs [0046]–[0073] and figures 1–5.	1–2, 9–11
Y		3–8, 12–15
Y	US 2013-0224513 A1 (KINSUS INTERCONNECT TECHNOLOGY CORP.) 29 August 2013 See paragraph [0021] and figure 2A.	3–8, 14–15
Y	US 2012-0314384 A1 (CHARLES G. WOYCHIK et al.) 13 December 2012 See paragraph [0057] and figure 1E.	12–13
A	US 2016-0143153 A1 (3M INNOVATIVE PROPERTIES COMPANY) 19 May 2016 See paragraphs [0018]–[0070] and figures 1–5.	1–15
A	US 2013-0215200 A1 (ROHM CO., LTD.) 22 August 2013 See paragraphs [0074]–[0085] and figures 1–6.	1–15

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

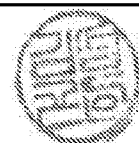


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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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