PALLADIUM SURFACE COATINGS SUITABLE FOR WIREBONDING AND PROCESS FOR FORMING PALLADIUM SURFACE COATINGS

1. Field of the Invention

The present invention relates to palladium surface coatings, and more particularly, to palladium surface coatings useful in packaging integrated circuit devices.

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2. Description of the Related Art

Integrated circuit (IC) packages are protective enclosures within which are typically sealed an integrated circuit (IC) unit and a leadframe. The IC unit is attached to the leadframe. The leadframe electrically interconnects the IC unit to circuitry located outside of the IC package.

A leadframe **10** useful for integrated circuit packages is shown in FIG. 1. The leadframe **10** includes a mounting area **15** and a plurality of lead members **20**. The lead members **20** extend away from locations **25** adjacent to the mounting area **15**. An IC unit **30** is attached on the mounting area **15** of leadframe **10**. Examples of IC units include integrated circuit chips and hybrid integrated circuit modules. Hybrid integrated circuit modules typically include one or more IC chips as well as other electronic components mounted on a plastic or ceramic carrier.

After the IC unit **30** is attached on the mounting area **15** of the leadframe **10**, wire bonds **35** are formed between the IC unit **30** and the lead members **20**. The wire bonds **35** electrically connect the IC unit **30** with the lead members **20**. Wire bonds are typically made of gold and aluminum wires.

Some wire bonds are formed using thermosonic techniques. In thermosonic techniques, a wire **50** is threaded through a capillary **55**, so an end of the wire protrudes therefrom, as shown in FIG. 2A. The end of the wire that protrudes from the capillary **55** is then melted by an electrical spark, forming a ball **60** just below the tip of the capillary **55**, as depicted in FIG. 2B. After the ball **60** is formed, it is bonded to an IC unit **70** mounted on a portion of a leadframe **75**, as shown in FIG. 2C. The ball **60** is bonded to

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☑ Description : paged ...1... to paged ...10...
☑ Claim(s) : paged ...11... to paged ...13...
☑ Drawing(s) : paged ...1/4... to paged ...4/4...
☑ Abstract : paged ...14... to paged ...14...

the IC unit **70** by applying a vertical load on the ball **60**, pressing it against the surface of the IC unit **70** while ultrasonically exciting the wire. As the ball **60** is pressed against the IC unit **70** the IC unit is heated. After the ball **60** is attached to the IC unit **70**, the wire **50** is looped and a wedge bond **80** (crescent bond) is formed to the leadframe **75**, as depicted in FIG. 2D. The wedge bond **80** is also formed by applying a vertical load to the portion of the wire **50** in contact with the lead frame **75**, pressing it against the surface of the leadframe **75** while ultrasonically exciting the wire. As the wedge bond is formed the leadframe **75** is heated. After the wedge bond **80** is formed, the capillary **55** breaks the wire **50** so the wedge bond **80** covers a crescent-shaped area on the surface of the leadframe **75**, as depicted in FIG. 2E.

Oxides on the leadframe surface interfere with the adhesion of wire bonds formed thereto. For example, wire bonds do not stick to oxides on the surface of a leadframe. Consequently, the surface finish of the leadframe plays an important role for packaging integrated circuits and should be oxide free.

Leadframes are made of a variety of materials. Suitable leadframe materials are selected for their mechanical strength, conductivity, machinability, formability, corrosion resistance, thermal expansion as well as their solderability and wirebondability. Although suitable leadframe materials include gold and palladium, the cost of these materials makes their use prohibitive for most applications.

To reduce manufacturing costs, many leadframes are made of materials such as copper and copper alloys. Examples of suitable copper alloys include alloy 151 (99.9 weight % copper, 0.1 weight % zirconium); alloy 194 (97.5 weight % copper, 2.35 weight % iron, 0.03 weight % phosphorous, 0.12 weight % zinc); and alloy 7025 (96.2 weight % copper, 3.0 weight % nickel, 0.65 weight % silicon, 0.15 weight % magnesium). However, the formation of reactive copper products (e. g., copper oxides) reduces the solderablity and wirebondability of leadframes made from such materials.

Typically, leadframes made of copper and copper alloys are coated with a layer of nickel. The nickel layer serves as a barrier to the formation of copper oxides on the surface of the leadframe. However, nickel also oxidizes in air, and such oxides are

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undesirable. Thus, a thin layer of a metal that does not oxidize is formed over the nickel layer to prevent oxide formation. Examples of these materials, typically referred to as "noble metals" include gold and palladium.

Nickel coatings formed on the leadframes using conventional electrodeposition techniques have a tendency to crack when the lead members of the leadframe are bent at angles of about 82 degrees to about 90 degrees with a radius of about 250 μm for connection to larger assemblies. When the nickel coatings crack, the layer of noble metal thereon also cracks exposing the underlying copper leadframe to oxygen, and potentially forming oxides thereon.

Summary of the Invention

The present invention is directed to a surface finish which provides improved wirebonding performance for integrated circuit packages. The surface finish which is formed on a substrate includes a palladium layer and one or more material layers. The one or more material layers are interposed between the substrate and the palladium layer. The palladium layer has a hardness that is less than about 500 (KHN_{50}) while at least one material layer has a hardness that is less than about 250 (KHN_{50}). The term hardness as used in this disclosure describes the indentability of a material under a specified load. The term KHN_{50} as used in this disclosure identifies the Knoop hardness number of a material under a 50 gram load.

Surface finishes including palladium layers with hardnesses less than about 500 (KHN_{50}) formed over a material layer or layers with hardnesses less than about 250 (KHN_{50}) are ductile. Such ductile layers typically do not crack during IC package assembly, preventing oxides from forming thereon. Oxide formation is undesirable because it prevents wirebonds from adhering to the surface finish.

The substrate is made of a material useful for an integrated circuit package. Examples of suitable substrate materials include copper or copper alloys, and nickel or nickel alloys.

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The material layer or layers interposed between the substrate and the palladium layer are formed using any suitable method such as electroplating. An example of a suitable material layer includes nickel.

The palladium layer is formed over the material layer or layers by electroplating the substrate in a palladium bath that contains about 5 gm/l to about 20 gm/l of palladium. The palladium bath is maintained at a pH of about 7.0 to about 8.0. Palladium is plated over the material layer using a current density of about 5 Amps/ft^2 to about 150 Amps/ft^2, at a bath temperature of about 25 °C to about 65 °C. The palladium bath is agitated at a speed of about 10 cm/sec to about 100 cm/sec.

The palladium bath optionally includes an additive which is useful for controlling the hardness of palladium layers plated therefrom. Additives useful for controlling palladium layer hardness include many sulfur-containing organic compounds. Examples of additives useful for controlling palladium layer hardness include benzenesulfonic acid and allyl phenyl sulfone.

The palladium layer preferably has a thickness greater than about 0.075 μm. Palladium layer thicknesses greater than about 0.075 μm prevent oxides from forming on the underlying material layers.

Other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and do not serve to limit the invention, for which reference should be made to the appended claims.

Brief Description of the Drawings

FIG. 1 shows a leadframe typically used for packaging integrated circuit devices;

FIG. 2A depicts a portion of a thermosonic wirebonder wherein an end of a wire protrudes from a capillary;

FIG. 2B illustrates how the protruding end of the wire is transformed into a ball;

FIG. 2C shows the formation of a ball bond on an IC unit;

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FIG. 2D shows the formation of a wedge bond on a leadframe;

FIG. 2E illustrates a top view of the ball bond and the wedge bond;

FIG. 3 shows a cross-sectional view of a substrate having a palladium layer of the present invention formed thereon;

FIG. 4 shows a plot of the hardness of electroplated palladium layers as a function of the concentration of an additive (allyl phenyl sulfone) in the palladium plating bath; and

FIG. 5 shows a cross-sectional view of a wirebond undergoing a pull-test.

Detailed Description

The present invention is directed to a surface finish which provides improved wirebonding performance for integrated circuit packages. The surface finish which is formed on a substrate includes a palladium layer and one or more material layers. The one or more material layers are interposed between the substrate and the palladium layer. The palladium layer has a hardness that is less than about 500 (KHN_{50}) while at least one material layer has a hardness that is less than about 250 (KHN_{50}).

Surface finishes including palladium layers with hardnesses less than about 500 (KHN_{50}) formed over a material layer or layers with hardnesses less than about 250 (KHN_{50}) are ductile. Such ductile layers typically do not crack during IC package assembly, preventing oxides from forming thereon. Oxides on the surface finish are undesirable because they prevent wirebonds from adhering to the palladium layer.

FIG. 3 shows a cross-sectional view of a substrate **100** useful in integrated circuit packages. Substrate **100** has an IC mounting area **110** with a plurality of separate lead members **120** extending away from locations adjacent to the mounting area **110**. An IC unit **125** is attached to mounting area **110**. Wire bonds **135** formed between the IC unit **125** and the lead members **120** electrically connect the IC unit **125** with leadframe **100**.

Substrate **100** is made of a material useful for an integrated circuit package. Examples of suitable substrate materials include copper or copper alloys, and nickel or nickel alloys.

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As shown in FIG. 3, the material layer **155** or layers interposed between with the substrate **100** and the palladium layer **150** are formed using any suitable method such as electroplating.

For example, a nickel layer with a hardness less than about 250 (KHN_{50}) is electroplated on the substrate from a NikelTech MLS nickel bath containing about 100 gm/l to about 130 gm/l nickel. The nickel bath is maintained at a pH of about 2.0 to about 2.5. Nickel is plated on the substrate using a current density of about 50 Amps/ft^2 to about 300 Amps/ft^2 at a bath temperature of about 50 °C to about 65 °C. It is advantageous if the bath is agitated at a speed of about 10 cm/sec to about 100 cm/sec. NikelTech MLS nickel baths are commercially available from Lucent Technologies Inc., Murray Hill, N.J.

A palladium layer **150** with a hardness less than about 500 (KHN_{50}) is formed on the at least one material layer **155**. The palladium layer is formed on the material layer or layers by electroplating the substrate in a palladium bath that contains about 5 gm/l to about 20 gm/l of palladium. The palladium bath is maintained at a pH of about 7.0 to about 8.0. Palladium is plated on the at least one material layer using a current density of about 5 Amps/ft^2 to about 150 Amps/ft^2, at a bath temperature of about 25 °C to about 65 °C. It is advantageous if the plating bath is agitated at a speed of about 10 cm/sec to about 100 cm/sec.

Palladium in the aqueous bath is a soluble species suitable for use in an electroplating process. Particularly useful are palladium complex ion compounds including palladium tetra-amine salts such as $Pd(NH_3)_4Cl_2$ and the corresponding bromides and iodides as well as other stable anions such as sulfates, and various palladium complexes in which the complexing agent is an organic compound such as an amine (see for example U.S. Pat. No. 4,911,799 which is hereby incorporated by reference). Also useful as a source of palladium are palladium complex hydroxides such as palladium hydroxide complexed with various organic compounds such as organic amines and polyamines (e.g. di-μ-hydroxo-bis-[cis-diamine palladium (II)]).

Other compounds useful as a source of palladium for the aqueous bath include $PdCl_2$ and the corresponding bromide and iodide, as well as $PdSO_4$, and $Pd(NO_3)_2$. Halide

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palladium salts, including palladium halide complex salts (particularly chlorides) are preferred as are sulfate palladium salts because of stability and high solubility. Also, ammonia is preferred as the complexing agent (palladium amine salts) because of cost, availability, solubility and ease of removing the ammonia from the bath.

The palladium bath optionally includes an additive which controls the hardness of palladium layers plated therefrom. Additives which control the hardness of palladium layers plated from palladium baths include sulfur-containing organic compounds. Suitable examples are o-benzaldehydesulfonic acid, 1-naphthalene sulfonic acid, 2-naphthalenesulfonic acid, benzenesulfinic acid, oxy-4,4-bis(benzene)sulfinic acid, p-toluene sulfinic acid, and 3-trifluoromethyl benzene sulfinic acid. Additional additives include allyl phenyl sulfone, o-benzoic sulfamide, benzylsulfonyl propionamide, phenylsulfonyl acetamide, 3-(phenylsulfonyl) propionamide, benzene sulfonamide, bis (phenylsulfonyl) methane, guanidine carbonate, sulfaguanidine and nicotinic acid.

The graph of FIG. 4 plots the hardness of electroplated palladium layers as a function of the concentration of an additive (allyl phenyl sulfone) in the palladium plating bath. The graph of FIG. 4 illustrates that electroplated palladium layers formed from palladium plating baths containing less than about 0.1 gm/l allyl phenyl sulfone have hardnesses ranging from about 180 (KHN_{50}) to about 460 (KHN_{50}).

The palladium layer preferably has a thickness greater then 0.075 μm. Additionally, a gold flash layer is optionally plated over the palladium layer. The gold flash layer preferably has a thickness of about 0.005 μm to about 0.075 μm.

The wirebondability of the palladium surface finish is evaluated by performing pull-tests on wirebonds formed thereto, as shown in FIG. 5. Each wirebond includes both a ball bond **220** and a wedge bond **210** which are formed to a palladium layer **200**. Interposed between the palladium layer **200** and a substrate **250** is a nickel layer **255**. During the pull-test a force is applied to the wirebond, by pulling on the wire **240** with a steel hook **230**. The force is increased until the wire **240** breaks or either of the ball **220** and wedge bond **210** lifts away from the palladium surface **200**. Ideally, the wirebond should break along the length of the wire **240** instead of lifting away from the palladium surface **200** under either the ball bond **220** or the wedge bond **210**.

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A wirebondable surface is typically determined based on the number of bond failures resulting from nonadhesion of either the ball bonds or the wedge bonds on the palladium surface. For some applications, one bond failure identifies a palladium surface finish as a poor wirebonding surface.

Additionally, some industry standards require that the wirebond withstand a minimum pull force. For example, some industry standards require that wirebonds made using 25 μm diameter gold wire, with between about 3 % to about 6 % elongation and breaking load of about 8 grams to about 10 grams, withstand pull forces of at least about 5.00 grams. The term breaking load as used in this disclosure identifies the force above which a wire is expected to break when it is pulled laterally along its length.

The following examples are provided to illustrate specific embodiments of the present invention.

Example 1

A 194 copper alloy leadframe was plated with a nickel layer. The 194 copper alloy leadframe was obtained from Olin Corporation, Norwalk, Conn.

The nickel was plated from a NikelTech MLS nickel bath containing about 120 g/l nickel. The nickel layer was plated with a current density of about 100 Amps/ft^2 at a temperature of about 60 ^{0}C and pH of about 2.2. A nickel layer about 2.5 μm thick was plated on the copper alloy leadframe. The nickel had a hardness of about 200 KHN_{50}. The NikelTech MLS nickel bath was obtained from Lucent Technologies, Murray Hill, N. J.

A palladium coating was formed over the nickel layer. The palladium was plated from a PallaTech PdLF palladium bath containing 5 gm/l palladium and about 0.5 gm/l of allyl phenyl sulfone. The palladium coating was plated with a current density of 10 Amps/ft^2 at a temperature of 22 ^{0}C and pH of 7.0. A palladium layer about 0.175 μm was plated over the nickel layer. The palladium coating had a hardness of about 516 KHN_{50}. The PallaTech PdLF palladium bath was obtained from Lucent Technologies, Murray Hill, N. J.

100 gold wire bonds were formed on the nickel/palladium coated leadframe. The gold wire had a diameter of 25 μm, with between 3 % to 6 % elongation, and a breaking load of about 8 grams to about 10 grams. The gold wire was obtained from Kulicke &

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Soffa Industries, Inc. (American Fine Wire, Packaging Materials Group), Selma, Alabama. Pull tests were performed to test the strength of each wire bond. One wire bond did not adhere to the palladium surface. Pull-forces as low as 2.00 grams were found to remove wire bonds formed on the palladium coated leadframe.

Example 2

A leadframe was plated with a conformable nickel layer. The nickel was plated according to the conditions described in Example 1.

A palladium coating was formed over the nickel layer. The palladium was plated from a PallaTech PdLF palladium bath containing 10 gm/l palladium and about 0.05 gm/l of allyl phenyl sulfone. The palladium coating was plated with a current density of 6 Amps/ft^2 at a temperature of 35 ^{0}C and pH of 7.5. A palladium layer about 0.175 μm thick was plated on the nickel layer. The palladium coating had a hardness of about 425 KHN_{50}.

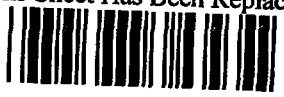
100 gold wire bonds were formed on the nickel/palladium coated leadframe as described in Example 1. Pull tests were performed to test the strength of each wire bond. All wire bonds were adherent to the palladium surface. Pull-forces greater than about 5.90 grams were required to break the wire bonds formed on the nickel/palladium coated leadframe. The average pull force for the 100 pull-tests was about 7.72 grams. For each wire bond, the gold wire broke along the length of the wire rather than under either the ball bond or the wedge bond.

Example 3

A leadframe was plated with a conformable nickel layer. The nickel was plated according to the conditions described in Example 1.

A palladium coating was formed over the nickel layer. The palladium was plated from a PallaTech PdLF palladium bath containing 25 gm/l palladium. The palladium coating was plated with a current density of 10 Amps/ft^2 at a temperature of 65 ^{0}C and pH of 8.0. A palladium layer about 0.175 μm thick was plated on the nickel layer. The palladium coating had a hardness of about 145 KHN_{50}.

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100 gold wire bonds were formed on the nickel/palladium coated leadframe as described in Example 1. Pull tests were performed to test the strength of each wire bond. All wire bonds were adherent to the palladium surface. Pull-forces greater than about 6.16 grams were required to break the wire bonds formed on the nickel/palladium coated leadframe. The average pull force for the 100 pull-tests was about 7.80 grams. For each wire bond, the gold wire broke along the length of the wire rather than under either the ball bond or the wedge bond.

Example 4

A leadframe was plated with nickel/palladium layers. The nickel and palladium layers were plated according to the conditions described in Example 2.

A gold flash was plated over the nickel/palladium layers. The gold flash was plated from a AuRoTech P gold bath containing 8 gm/l gold. The gold flash was plated with a current density of 1 Amps/ft^2 at a temperature of 55 ^{0}C and pH of 5.5. A gold flash about 0.025 μm thick was plated over the nickel/palladium layers. The AuRoTech P gold bath was obtained from Lucent Technologies, Murray Hill, N. J.

100 gold wire bonds were formed on the nickel/palladium/gold coated leadframe as described in Example 1. Pull tests were performed to test the strength of each wire bond. All wire bonds were adherent to the surface. Pull-forces greater than about 5.92 grams were required to break the wire bonds formed on the nickel/palladium coated leadframe. The average pull force for the 100 pull-tests was about 8.08 grams. For each wire bond, the gold wire broke along the length of the wire rather than under either the ball bond or the wedge bond.

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The Invention Claimed is:

1. An article of manufacture, comprising:

a substrate having at least one material layer formed thereon, wherein at least one material layer has a hardness less than about 250 (KHN_{50}); and

a palladium layer formed on the at least one material layer, wherein the palladium layer has a hardness less than about 500 (KHN_{50}).

2. The article of claim 1 wherein the at least one material layer is a nickel layer having a thickness within the range of about 0.5 μm to about 5.0 μm.

3. The article of claim 1 wherein the substrate is made of a material selected from the group consisting of copper, copper alloys, nickel, and nickel alloys.

4. The article of claim 1 wherein the palladium layer is formed by electroplating the substrate in a palladium bath comprising about 5 gm/l to about 20 gm/l of palladium and maintaining the pH of the palladium bath in the range of about 7.0 to about 8.0 while applying a current density of about 5 Amps/ft^2 to about 150 Amps/ft^2 for a period of time sufficient to plate the layer of palladium of the desired thickness onto the substrate.

5. The article of claim 4 wherein the palladium bath further comprises an additive which controls the hardness of palladium layers plated therefrom.

6. The article of claim 5 wherein the additive is a sulfur containing organic compound.

7. The article of claim 6 wherein the sulfur containing compound is allyl phenyl sulfone.

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8. The article of claim 7 wherein the palladium bath includes less than about 0.1 gm/l allyl phenyl sulfone.

9. The article of claim 4 wherein the palladium bath is maintained at a temperature of about 25 °C to about 65 °C while the substrate is electroplated.

10. The article of claim 4 wherein the palladium bath is agitated at a speed of about 10 cm/sec to about 100 cm/sec while the layer of palladium is electroplated on the substrate.

11. The article of claim 1 wherein the palladium layer has a thickness greater than about 0.075 μm.

12. The article of claim 1 wherein the substrate is a leadframe.

13. A method for electroplating a layer of palladium on a substrate comprising the steps of:

providing a substrate with at least one material layer formed thereon, wherein at least one material layer has a hardness less than about 250 (KHN_{50}); and

electroplating a layer of palladium on the at least one material layer, wherein the electroplated palladium layer has a hardness less than about 500 (KHN_{50}) and wherein the electroplated palladium layer is formed from a palladium bath comprising about 5 gm/l to about 20 gm/l of palladium and maintaining the pH of the palladium bath in the range of about 7.0 to about 8.0 while applying a current density of about 5 Amps/ft^2 to about 150 Amps/ft^2 for a period of time sufficient to plate the layer of palladium of the desired thickness onto the substrate.

14. The method of claim 13 wherein the palladium bath further comprises an additive which controls the hardness of palladium layers plated therefrom.

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15. The method of claim 14 wherein the additive is a sulfur containing organic compound.

16. The method of claim 15 wherein the sulfur containing organic compound is allyl phenyl sulfone.

17. The method of claim 16 wherein the palladium bath includes less than about 0.1 gm/l allyl phenyl sulfone.

18. The method of claim 13 wherein the substrate is made of a material selected from the group consisting of copper, copper alloys, nickel, and nickel alloys.

19. The method of claim 13 wherein the palladium bath is maintained at a temperature of about 25 °C to about 65 °C while the substrate is electroplated.

20. The method of claim 13 wherein the palladium bath is agitated at a speed of about 10 cm/sec to about 100 cm/sec while the substrate is electroplated.

21. The method of claim 13 wherein the palladium layer has a thickness greater then about 0.075 μm.

22. The method of claim 13 wherein the at least one material layer is nickel having a thickness within the range of about 0.5 μm to about 5.0 μm.

23. The method of claim 13 wherein the substrate is a leadframe.

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