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(54) **Electric power connectors.**

(57) Electric power connectors made with at least one contacting component having a gold contacting surface wherein the gold contacting surface is metallurgically bonded to an underlying layer of nickel or nickel-rich alloy . At the contact surface the gold contains a total of about 1-10% by weight nickel with the amount of nickel generally increasing in the direction from the surface to the underlying metal the increase starting at a point inward of and remote from the contacting surface.

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ELECTRIC POWER CONNECTORS

The present invention is concerned with electrical connectors or contacts and, more particularly, with electrical connectors useful in carrying substantial currents at voltages in excess of, perhaps, 10 volts.

It is known in electronic, particularly computer technology, to use electronic contacts of pure gold in order to reduce to the irreducible minimum value the contact resistance of faying, usually spring-loaded contact surfaces. Such contact surfaces having contact resistances of less than one milliohm when tested against a lightly weighted, polished gold probe are generally not designed for frequent make and break service. Thus, thin, pure gold contact surfaces on circuit boards and their mating components are the standard means for providing electrical circuits in electronic and computer devices which often operate at voltages up to only 100 mV and with extremely low amperages. Such contacts are very resistant to corroding media and oxidation. However, if gold is used on certain metal bases, e.g. copper or silver, without an intermediate layer of nickel, the electronic contacts tend to degrade if exposed to temperatures elevated above 25°C even as low as 100°C. Gradually atoms of copper and silver migrate to the gold surface. Migrated copper makes the contact surface subject to sulfidation and oxidation while migrated silver is particularly detrimental when the contact surface is used in sulfidizing atmospheres as mild as ordinary room air. Accordingly, it is generally standard practice to employ a layer of nickel (or perhaps cobalt or a nickel- or cobalt-rich alloy) between a base of copper or silver or copper- or silver-base alloy and the gold in order to prevent copper or silver migration and also to provide an exposed layer of relatively tarnish-resistant metal anywhere there may be breaks in the overlying layer of gold. A good description of electronic-type contact materials is contained in the article "Properties of Inlay Clad Wrought Gold Alloys", Robert J. Russell, Solid State Technology, 10 pages (8/76).

There is a need for electrical contact materials which have a low contact resistance, but not necessarily the extremely low contact resistances required by the electronics industry, and which have sufficient abrasion resistance in order to survive multiple makes and breaks.

It is an object of the present invention to provide such electrical contacts adapted to carry reasonably high amperages at voltages in excess of perhaps 10 volts.

It is a further object of the invention to provide an electrical contact material which can be employed in the electrical contacts of the present invention.

The present invention contemplates an electric power connector adapted to provide an interruptible conductive path for electrical current (for example, current of at least about 0.1 ampere) comprising at least two components adapted to be placed in surface contact one with another. At least one of the components has a fayable surface of contact made of an alloy of gold and nickel. At the fayable contact surface the alloy contains about 1 to about 10% by weight of nickel. The amount of nickel in the gold generally increases with distance from the fayable contact surface to an underlying metallurgically bonded layer preferably of essentially pure nickel. However, the alloy which is made by diffusing nickel from an underlayer into a gold overlayer usually exhibits a particular structure when examined by sputtering and Auger analysis. The immediate surface, perhaps 150 Angstrom units thick, exhibits a relatively high nickel content. Immediately below this surface layer, the nickel content falls somewhat and remains relatively constant for perhaps up to two-thirds of the thickness of the gold layer which ranges from 0.3 to 2 micrometers. Over the remaining thickness of the gold-containing layer, the nickel content rises rapidly to the nickel content of the underlying metal. Those skilled in the art will appreciate that this type of Auger analysis sometimes produces results at the surface of an object being examined which may be surface artifacts and may not represent or be significant with respect to properties of the bulk material. Accordingly, it appears safe to say that in the gold layer of the contact structure of the present invention, the nickel content near the outer surface is at a relatively low level. It remains at that low level until, at some point remote from the surface the nickel content of the gold rapidly increases.

The electrical power connector can be in any conventional contact form such as male and female plug components, pins, threaded structures or the like. Advantageously, the connectors are of such configuration that they can be made from composite, electrical contact material in strip form. Such contact material which is also within the contemplation of the present invention comprises a strip-form structural base of electrically conductive material, e.g. metal having at least one major surface comprised of nickel or nickel-rich alloy underlying a layer of gold about 0.1 to 2 micrometers thick metallurgically bonded to the nickel or nickel-rich alloy. This diffusion is such as to provide about 1 to about 10% by weight of nickel at the outer major surface. In this connection, "nickel-rich alloy" means an alloy containing at least about 90% nickel advantageously at least 95% or 99% nickel and includes commercially pure nickel and nickel-cobalt alloys.

Specific examples of contact materials of the present invention include copper, copper-base alloys such as brass, cupro-nickel, beryllium copper, copper-nickel-tin alloy and copper-nickel-aluminium alloy, nickel, cobalt or nickel-cobalt alloy particularly in strip form. In the cases of copper, copper-base alloys and cobalt the basic metal has an electrodeposited layer of nickel about 3 to 10 micrometers thick on at least one major surface. The outer portion of that at least one major surface comprises a layer of electroplated gold or a gold alloy containing up to about 1% total nickel and/or cobalt about 0.1 to about 2 micrometers thick which layer of electroplated gold or gold alloy is heat bonded to the nickel so as to provide diffusion of nickel to the gold surface in an amount at or near the surface of about 1% to about 10% total nickel. The strip can be faced on all surfaces with gold or, on the two major surfaces, i.e. the top and bottom or on one major surface.

Nickel and nickel-rich alloy strip can be made by conventional metallurgical melt technology wherein a charge of metal is melted, then cast and then hot- and/or cold-worked to strip form. A particularly advantageous method of making nickel, cobalt or nickel-rich alloy strip is to roll compact metal powder, sinter bond and interdiffuse the roll-compacted metal powder and thereafter or simultaneously roll the bonded powder product to strip form and thickness.

Strip of metal other than nickel or nickel-rich alloy which can form the principal structural element of the connectors of the present invention is generally made in a conventional manner and is commercially available from many sources. The present invention contemplates use of commercially available strip of copper, brass, aluminium bronze, cupro-nickel, beryllium copper, copper-nickel-tin alloy and any other metal or other electrically conductive material useful in the electrical contact art. This strip is thoroughly cleaned by conventional means such as alkaline cleaning baths, solvent and vapor degreasing, etc. and then electroplated to provide a layer of nickel about 5 to about 10 micrometers thick. One of the electroplating baths set forth in Electroplating Engineering Handbook, 3rd Ed., A. Kenneth Graham, Van Nostrand Reinhold Company, Copyright, 1971 at page 247 can be used to electroplate nickel.

Gold is electrodeposited over either the nickel strip or plated nickel from a cyanide-type, citrate-type or other type of bath adapted to produce a pure soft gold electro-deposit. The strip is then heat treated at about 350°C to 600°C for times ranging from 2 hours to 10 seconds so as to diffuse nickel into the gold to reach a level of from 1 to 10% nickel at the gold outer surface.

The electrical connector materials and electrical contacts made therefrom as contemplated in the present invention are advantageous with respect to contacts made of base metals in that they are and remain through their useful lives essentially free of corrosion products and thus give reliable, stable contact service. Compared to pure gold contact surfaces, when high currents (e.g. greater than 0.1 ampere) are passed through an electrical circuit, the contacts and contact materials of the present invention are advantageous when the contact must be broken periodically. In these situations, a pure gold surface becomes galled or roughened, gold-on-gold contacting surfaces tend to sinter or fuse together and the contact cannot readily be separated. Conversely, the present invention is based upon the discovery that when gold contacting surfaces contain 1 to 10% nickel such modified gold-on-modified gold contacts do not exhibit the fusing or sintering character of pure gold and thus the contacts can always be easily broken, provided of course, that the circuit including the contact has not been overloaded beyond design capacity.

In making the contact materials of the present invention, those of normal skill in the metallurgical art will appreciate that heat treatment time will normally vary with temperatures such that longer times will be used at lower temperatures and vice versa with a given thickness of gold. Lower temperatures and shorter times at a given temperature will be employed with thinner gold layers than with thicker gold layers. As disclosed in GB-A-2 203 450 diffusion of nickel into gold can be carried out simultaneously with age-hardening of an age-hardenable substrate. Normally, this age-hardening of, for example, copper-base-alloys such as beryllium copper or a copper-nickel-tin alloy or a copper-nickel aluminium alloy will be carried out after the contact material is in final form as an electrical contact. For example, strip form of beryllium copper is blanked and shaped to contact configuration. The thus shaped contacts are then electroplated sequentially with nickel and gold and then heat treated at a temperature and time combination selected in consideration of the thickness of electroplated gold so as to achieve both age-hardening of the substrate and proper gold-nickel interdiffusion at the same time. Alternatively, contacts may be blanked out of composite gold-nickel-copper beryllium strip, formed and then heat treated.

The annealing heat treatment which produces diffusion of nickel and gold can be carried out simultaneously with hot rerolling of plated strip material. For example, nickel strip made by roll compacting and then sintering and rolling nickel powder can be electroplated with gold and then rerolled at a temperature in the range of 350°C to 500°C to enhance the metallurgical bond between the nickel and gold and effectuate the diffusion of the nickel. Alternatively, the metallurgical bond and diffusion can be accomplished by the annealing heat treatment as described hereinbefore and the composite can be cold rolled either before or after annealing so as to enhance mechanical characteristics.

In order to give those skilled in the art a greater appreciation of the advantages of the invention the following example is given:

A nickel strip made from roll compacted and sintered nickel powder about 0.5 mm thick, about 30 mm wide and about 70 meters long is thoroughly cleaned, mildly etched and electroplated with gold from a citrate-base electroplating bath to provide a uniform, pure gold deposit about 0.5 micrometer thick. The plated strip is thoroughly rinsed to remove any trace of electrolyte, dried and then heat treated by being passed through a furnace. The furnace is held at 480°C and contains an atmosphere of 10 volume percent hydrogen, balance nitrogen. Cool strip is fed to the furnace and passes through with a residence time of six minutes. As the strip exits the furnace it is cooled under the same reducing conditions and then coiled.

The composite nickel-gold contact material made in this way gives excellent results in electric contact service composite material to composite material. The contacts exhibit essentially no detrimental behavior over time when exposed to normal service. The contacts do not corrode, gall or pit in service and can be disconnected hundreds of times without difficulty even when exposed in use to temperatures up to about 200°C.

While specific embodiments of the invention are illustrated and described herein, those skilled in the art will understand that changes may be made in the form of the invention covered by the claims and that certain features of the invention may sometimes be used to advantage without a corresponding use of the other features.

Claims

1. An electric power connector adapted to provide an interruptible conductive path for electric current comprising at least two components adapted to be placed in surface contact, one with another, at least one of said components having a fayable surface of contact made of an alloy of gold and nickel, said alloy containing about 1 to about 10% by weight of nickel near said fayable surface of contact, said amount of said nickel remaining essentially constant through some distance from the surface and then starting at a point interior of said fayable surface to increase with distance from said fayable surface of contact toward the interface of gold-containing metal with an underlying, metallurgically bonded layer of metal from the group of nickel and alloys rich in nickel.

2. An electric power connector as claimed in claim 1 wherein said underlying metallurgically bonded layer is a layer of essentially pure nickel.

3. An electric power connector as claimed in claim 2 wherein said layer of essentially pure nickel is the principal structural element of said connector.

4. An electric power connector as claimed in claim 1 wherein said underlying metallurgically bonded layer is an electrodeposit of nickel about 3 to about 10 micrometers thick on an electroconductive substrate.

5. An electric power connector as claimed in claim 4 wherein said electroconductive substrate is selected from the group of copper, brass, aluminium bronze, copper-nickel-aluminium alloy, cupronickel, beryllium copper and copper-nickel-tin alloy.

6. An electric power connector as claimed in claim 5 wherein said electroconductive substrate is selected from the group of age-hardened copper-base alloys.

7. An electric power connector as claimed in any preceding claim wherein two or more components of said connector have fayable surfaces of said alloy of gold and nickel.

8. An electric power connector as claimed in any preceding claim having mateable male and female components.

9. An electric power connector material comprising an electroconductive base having at least one surface made of a metal from the group of nickel and nickel-rich alloys and having overlying and metallurgically bonded thereto a layer of gold about 0.1 to about 2 micrometers thick, said layer of gold containing near its outer surface about 1 to 10% by weight of nickel, the content of nickel remaining essentially constant over some distance interior of said outer surface and starting to increase at a point remote from said outer surface and continuing to increase as the distance from said outer surface increases.

10. An electric power connector material as claimed in claim 9 wherein the underlying metal is nickel.

11. An electric power connector material as claimed in claim 10 wherein said nickel is an electrodeposit on an electroconductive base.

12 An electric power connector material as claimed in any of claims 9 to 11 wherein said electroconductive base is a metal from the group of copper, brass, aluminium bronze, copper-nickel-aluminium, cupro-nickel, beryllium copper and copper-nickel-tin alloy.

13. An electric power connector material as claimed in claim 12 wherein said electroconductive substrate is an age-hardened and copper-base alloy.

14. An electric power connector material as claimed in any of claims 9 to 13 in strip form.