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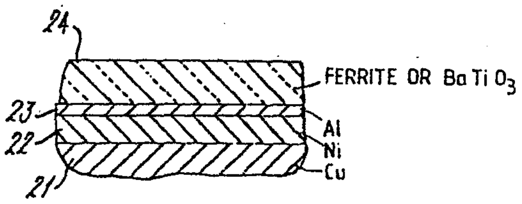
(54) **Electrical component.**

(57) An electrical component comprises a metallic conductor and an inorganic conductive layer thereon. The conductive layer has preferably been formed by a vacuum deposition method, and is bonded to the electrical conductor by an intermediate layer.

The inorganic conductive layer may, for example, be a non-linear material, a ferromagnetic, or ferro-magnetic material, or a material exhibiting PTC or NTC behaviour.

Fig. 5.



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ELECTRICAL COMPONENT

This invention relates to electrical components, and in particular to components that include a conductive layer formed from an electrically conductive metal compound or alloy.

The present invention provides an electrical component which comprises a metallic electrical conductor and a conductive layer formed from an electrically conductive inorganic metal compound, the conductive layer being bonded to the electrical conductor by an intermediate metallic or refractory layer.

The invention is applicable to many forms of electrical component in which an electrically conductive layer is provided in order to exhibit an electrical effect. The electrically conductive layer may be a semi-conductor or it may have a higher electrical conductivity, and may be either linear or non-linear in its electrical characteristics. For example in one form of device, the conductive layer may be formed from a material for example a doped ceramic such as an alkaline earth metal titanate, that exhibits a positive temperature coefficient of resistance (referred to hereinafter as a P.T.C. material) or it may exhibit a negative temperature coefficient of resistance (referred to hereinafter as an N.T.C. material). Such materials may have resistivities that vary through several orders of magnitude as the temperature of the material is raised through an interval of 10 to 50°C. Devices that utilise such P.T.C. materials may be used for instance as self limiting resistance heaters, circuit protection devices, electric motor start windings, contactless electrical switches and the like. In some applications the conductive layer may be formed from a ferroelectric material or from a ferromagnetic material or from other curie point materials. Electrical conductors that are coated with ferromagnetic materials may be used as high frequency attenuation lines in which unwanted high frequencies are attenuated, while components having ferroelectric coatings may be used for example as skin effect heaters. Examples of ferroelectric materials include those ceramics of the general formula AMO_3 wherein A represents lead or an alkaline earth metal, preferably barium or strontium, and M represents titanium, tin zirconium or hafnium; lithium niobate, lithium tantalate, lead titanate zirconate or lead metaniobate; and examples of ferromagnetic materials include ferrites, e.g. compounds of the general formula MFe_2O_4 wherein M represents for example iron (Fe_3O_4), nickel, cobalt or zinc; magnesium manganese ferrites and ferrochromates; magnetic iron oxides such as gamma Fe_2O_3 or certain oxides of chromium or nickel. In yet other applications, the conductive layer may have a voltage dependent resistivity, for example in the case of zinc oxide varistors and vanadium oxide devices. Other forms of voltage dependent device that may be made according to this invention include threshold and memory switching devices that use chalcogenide glass layers e.g. germanium-arsenic-tellurium-silicon glasses as described for example in U.S. Patent Specification No. 3,271,591, the disclosure of which is incorporated herein by reference.

As will be appreciated the above examples represent only a sample of the range of conductive layers that may be used for one reason or another in an electrical component.

Although such components are very useful in many circumstances, they often suffer from the disadvantage that it is difficult for the conductive coating to adhere well to the underlying metallic conductor with the result that the component is unable to withstand severe mechanical abuse. In other cases, even if the conductive coating does adhere satisfactorily to the metallic conductor, the ability of the component to withstand high temperatures e.g. above 200°C or temperature cycling is severely limited. According to the present invention, however, the ability of the component to withstand mechanical abuse and/or temperature excursions may be significantly improved by the provision of an intermediate metallic or refractory layer. The preferred forms of intermediate layers used according to the present invention are as described in European Patent Specification No. 132343, the disclosure of which is incorporated herein by reference, and in our copending British Patent Applications Nos. 8500816 and 8500817 corresponding to European Patent Applications Nos. 85304871.8 and 85304872.6, the disclosures of which are also incorporated herein by reference. The conductive layer employed in the present invention may be present in place of the refractory coating or layer described in those applications or it may, if desired, be present in addition to a semiconducting or conducting refractory layer, e.g. a substoichiometric oxide, in which case the layer acts as a keying layer to improve the adhesion of the conductive layer.

Preferably the metal from which the electrical conductor is formed has a melting point of at least 800°C more preferably at least 900°C, and especially at least 1000°C. The present invention is particularly applicable to articles in which the metal is copper or an alloy thereof for example wire and cable that may need to be capable of functioning when subjected to temp erature excursions, or even when subjected to temperatures of 200°C or above, for lengths of time.

In certain forms of component according to the invention e.g. electrical wire, and especially one or more additional conducting layers may be provided on top of the conductive layer. The further layer or layers may be formed by the methods that give faster deposition rates such as those mentioned in our British Patent Application No. 8500818.

In the case where the article comprises an electrical wire or cable, so that the underlying copper forms the conductor of the cable, the conductor may be a single, solid conductor or it may be a stranded conductor in which individual strands are laid together to form a bundle which preferably contains 7, 19 or 37 strands. Where the conductor is stranded it is preferred for the bundle to be coated rather than the individual strands, that is to say, the conductive coating extends around the circumference of the bundle but not around the individual strands so that substantially only the outwardly lying surfaces of the outermost layer of strands are coated. The intermediate layer may also extend around the bundle or, for example in the case of a nickel intermediate layer, may extend around the individual strands.

This form of conductor has the advantage that the inter strand electrical contact is retained and the dimensions of the bundle are kept to a minimum (since the thickness of the coating may constitute a significant proportion of the strand dimensions for fine gauge conductors) and also it aids the formation of good electrical connections, e.g. crimp connections, to the conductor because a large proportion of the surface of the strands, and the entire surface of the strands in the central region of the conductor, will be uncoated by the layer. If a cable is formed according to the invention from a stranded conductor, it has the advantage that is it very flexible as compared with solid conductor wires and yet has sufficient electrical insulation provided by the outermost insulating refractory layer, as described in the above European Patent Specification.

The thickness of the conductive and keying layers will depend on the application to which the component is put and the nature of the conductive layer.

The properties of intermediate coatings are known to depend significantly on the method by which they are formed or deposited onto a substrate, and in general, the techniques that exhibit relatively low deposition rates will form layers having relatively high density, i.e. not being porous, and having higher adhesion to metallic substrates. Preferably the intermediate layer has been formed by a vacuum deposition process, e.g. a sputtering, evaporation, ion plating, or chemical vapour deposition process. Such methods are also appropriate and are preferred for forming the conductive layer although it may, if desired, be formed by other methods, e.g. plasma ashing methods, solution coating methods or flame spraying methods.

In order to optimise the adhesion between the intermediate or keying layer and the conductive layer, it may be beneficial for the intermediate or keying layer to comprise the or one of the metals that is present in the conductive layer. Alternatively or in addition keying layers that are capable of supporting epitaxial growth of the conductive layer, e.g. spinels, may be used.

As stated above, the intermediate layer may be formed from a metal or refractory. It is possible for the component to include more than one such layer and for the layers to be both metallic, both refractory or for a metallic and a refractory layer to be present. In order to improve further the high temperature properties of the component, and especially in the case where the underlying metal is copper or an alloy thereof, it is preferred for a metallic intermediate layer (hereinafter called the "additional layer") to be present between the intermediate layer and the metallic conductor. The metal is preferably one which forms a good bond between the underlying metal and the refractory keying layer and also, as described in our copending Application No. 8500816 one which acts as a barrier to diffusion of oxygen or copper or both or which acts to reduce stress in the refractory layers imposed by substrate strain resulting from mechanical or thermal stress. Preferred metallic intermediate or additional layers include those formed from aluminium, and alloys for example with magnesium, titanium, tantalum chromium, manganese, silicon or nickel although other metals may be used. In the case of wires having stranded conductors, it is preferably for the wire to have the structure as described in our Patent Application No. 8500817, i.e. one in which the additional layer may extend around the individual strands while the conductive layer extends around the conductor but not around the individual strands.

In the case of wires according to the invention, polymeric insulation may be provided in order to provide additional insulation to the conductor during normal service conditions and also to enable the wire to have the desired dielectric properties and other properties e.g. mechanical properties, scuff resistance, colour coding ability etc. Such polymeric insulation is described in our patent applications referred to above.

In some cases it may be desirable for the wire to be provided with a polymeric layer that contains conducting, semi-conducting or ferromagnetic particles (especially ferrites) or the like.

As stated above, the preferred methods of forming the intermediate or keying layer include evaporation, plasma assisted chemical vapour deposition and sputtering methods.

An advantage of using a relatively slow deposition method such as a sputtering method, for forming the intermediate or keying layer is that it allows greater control over the chemical composition and mechanical properties of the keying layer to be exercised. For example, it is often advantageous for the keying layer to be non-stoichiometric since this may increase the adhesion between the keying layer and any underlying layer, and especially if the stoichiometry of the keying layer varies through at least part of its thickness so that stresses that may be induced in the coating, for example due to differential thermal expansion, are not localised to a boundary of the layer and so that different parts of the layer will exhibit different properties. For example, a relatively metal-rich part of the keying layer may exhibit good adhesion to the conductor or additional intermediate layer while part of the coating having least metal or semi-metal may exhibit better adhesion to the conductive layer.

If desired, the stoichiometry of the keying layer may vary continuously throughout the thickness of the layer or it may contain one or more layers or strata of relatively uniform stoichiometry. Thus the keying layer may have an outer region of relatively uniform stoichiometry in order to exhibit the optimum electrical properties or adhesion to the further refractory layer. The relative thicknesses of the non-uniform and uniform layers may vary widely. For example the major part of the keying may have a non-uniform stoichiometry or the major part of the layer's thickness may be of uniform stoichiometry, in which latter case the non-uniform part of the layer could even be considered as an intermediate layer that improves adhesion of the rest of the layer especially at high temperatures. If the underlying metal- or semi-metal-rich part of the keying layer is intended to improve the adhesion of the conducting coating, its particular composition will depend on the composition of any additional layer, and in some cases it may be desirable for the metal or semi-metal rich part to consist substantially entirely of the metal or semi-metal so that there is a gradual change from the metal or semi-metal to the composition of the conductive layer. This is particularly preferred if the system includes an underlying layer of the same metal or semi-metal.

The precise stoichiometry of the uniform top layer can be determined experimentally using wavelength dispersive electron microprobe analysis or by using x-ray photoelectron spectroscopy (XPS). The composition of the coating as it changes from metal to refractory throughout its depth can be assessed using Auger electron spectroscopy (AES) in which the film is continuously sputtered away to expose fresh surface for composition analysis.

The variation in stoichiometry is not limited to a variation in the metal or semi-metal/oxygen proportions. In addition or alternatively the relative proportions of two different metals or semi-metals may be varied so that, for example, there is a gradual change from one metal, which may constitute an intermediate layer, to the oxide of a different metal.

In the sputtering method, predominantly neutral atomic or molecular species are ejected from a target, which may be formed from the material to be deposited, under the bombardment of inert gas positive ions e.g. argon ions. The high energy species ejected will travel considerable distances to be deposited on the wire conductor substrate held in a medium vacuum, e.g. 10^{-4} to 10^{-2} mbar. The positive ions required for bombardment may be generated in a glow discharge where the sputtering target serves as the cathode electrode to the glow discharge system. The negative potential (with respect to ground and the glow discharge) is maintained in the case of insulating target materials by the use of radio frequency power applied to the cathode, which maintains the target surface at a negative potential throughout the process. DC power may be applied when the target is an electrically conducting material. The advantage of such techniques is that control over the coating material is greatly enhanced, and the energy of the species ejected is very much higher than with evaporation methods e.g. typically 1 to 10 eV for sputtering as compared with 0.1 to 0.5 eV for evaporation methods. Considerable improvements in interfacial bonding are achieved but the deposition rate in the sputtering process described will be lower than that for electron beam evaporation.

In magnetron sputtering processes the plasma is concentrated immediately in front of the cathode (target) by means of a magnetic field. The effect of the magnetic field on the gas discharge is dramatic. In that area of discharge where permanent magnets, usually installed behind the cathode, create a sufficiently strong magnetic field vertically to the electric field, secondary electrons resulting from the sputter bombardment process will be deflected by means of the Lorentz force into circular or helical paths. Thus the density of electrons immediately in front of the cathode as well as the number of ionised argon atoms bombarding the cathode are substantially increased. There is an increase in plasma density and a considerable increase in deposition rate. Bias sputtering (or sputter ion plating) may be employed as a variation of this technique. In this case the wire conductor is held at a negative potential relative to the chamber and plasma. The bombardment of the wire conductor by Argon ions results in highly cleaned surfaces. Sputtering of the target material onto the wire conductor thoughout this process results in a simultaneous deposition/cleaning mechanism. This has the advantage that the interfacial bonding is considerably improved. In sputter ion plating systems both target and the wire conductor are held at a negative potential. In this case the relative potentials are balanced to promote preferential sputtering of the target material. The target voltage will be typically less than 1kV, dependent on system design and target material. The wire substrate, may be immersed in its own localised plasma dependent upon its bias potential, which will be lower than that of the target. The exact voltage/power relationship achieved at either target or substrate is dependant upon many variables and will differ in detail from system to system. Typical power densities on the target are 10-20W/cm^2. The load to the substrate may be substantially lower, often as little as 5% of the target load.

One preferred technique that is used to apply the conductive coating is a reactive bias sputtering method in which reactive gas is introduced into the vacuum chamber in addition to argon so that a compound of the target material, which in this case is a metal or semi metal rather than the compound itself, will be deposited. Experimental results have shown that the level of reactive gas and its admission rate have a significant effect on deposition rates. The precision control of partial pressure of the reactive gas and the analysis of the sputtering atmosphere in a closed loop control system is considered highly desirable. Apart from the simultaneous deposition/cleaning advantages mentioned above, the ion bombardment of the substrate enhances surface reaction between the reactive gas and depositing species, resulting in more efficient formation of the coating with the required stoichiometry.

Partial pressure of reactive gas is determined experimentally but will normally be between 2 and 25% but sometimes up to 30%, the exact level depending on the required stoichiometry of the coating and depostion rate. Reactive sputtering is also a preferred technique because it facilitates alterations to the stoichiometry of the coating. For example, an intermediate "layer" of the pure metal used for the conductive coating may be deposited in such a way that there is no defined boundary between the conductor metal, keying layer and conducting layer.

The vacuum chambers and ancillary equipment, including micro-processor gas control units and a variety of targets used in these methods may be purchased commercially. Many variations in design are possible but most employ the use of "box" shaped chambers which can be pumped down to high vacuum for use in any of the vacuum deposition processes mentioned. Systems are normally, but not exclusively, dedicated to one deposition process. One system which may be employed to coat wire uses air to air transfer tech niques for passage of the wire conductor through the deposition chambers and employs one or more ancillary vacuum chambers either side of the main deposition chamber.

These ancillary chambers are held at progressively higher pressures as they extend from deposition chamber to air. This reduces the load on individual vacuum seals. The system described has the advantage of continuous feed of the wire conductor over batch process arrangements. In the vacuum deposition chamber the pressure is held constant at a pressure normally between 10^{-4} and 10^{-2} Torr.

The targets employed are commercially available Planar Magnetron Sputtering sources. Their size may vary widely, and targets in excess of 2 metres in length may be employed. Between two and four such sources may be arranged opposite one another so as to surround the wire conductor passing through the chamber or to sputter from at least two sides. The arrangement may be employed in series to increase wire throughput rates. As described above a negative bias is applied to the magnetron to initiate the sputtering process. The wire may be held at a lower negative bias as described earlier.

Refinements to the system can, if desired, be employed. For example, the use of an intermediate vacuum station between the air (input side) and the deposition chamber may be employed to generate an Argon ion glow discharge which cleans the wire conductor suface by ion bombardment prior to its entry into the vacuum deposition chamber and also heats the wire conductor.

Further intermediate chambers can be employed between the cleaning and deposition chamber to deposit intermediate layers.

Conditions may be controlled to produce any of the conductor coatings described above in which no defined boundries occur between the layers. For example an additional, underlying "layer" of the pure metal used for the conducting coating may be deposited in such a way that there is no defined boundary between the conductor additional layer and the conducting coating. In a similar fashion additional chambers can be employed between the deposition chamber and air (output side) to deposit the conductive coating onto the intermediate layer and also any subsequent layers, e.g. for lubrication, wear resistance or the provision of additional electrodes.

Evaporation and the related processes of activated evaporation and ion plating offer alternative techniques for deposition of the coating.

Evaporation of the coating material is achieved by heating the material such that its vapour pressure exceeds 10^{-2}mbar. Evaporation temperatures vary according to coating material, e.g. 1300-3500°C for refractory metal oxides, the chamber pressure being usually 10^{-4} to 10^{-6}mbar. Similar wire transport systems to those described may be used to hold the substrate about 30-40 cm above the source. Several heating methods exist e.g. resistive, inductive, electron beam impingement etc. although the preferred method is an electron beam source where a beam of high energy electrons e.g. 10,000eV impinge onto the coating material contained in a water-cooled crucible. The use of multi-pot crucibles or twin source guns, enable multiple layers and graded stoichiometry layers to be deposited with the aid of electronic monitoring and control equipment.

Compound coatings can be made either by direct evaporation from that compound e.g. TiN or by reactive evaporation, e.g. titanium evaporated into a partial pressure of nitrogen to give titanium nitride. Variations in the process exist either to promote reactions or adhesion, e.g. Activated reactive evaporation (ARE) can be used to increase the reaction probably between the evaporant and the reactive gas.

In ion-plating, negative bias applied to the substrate in an inert gas promotes simultaneous cleaning/deposition mechanisms for optimising adhesion as described in the sputtering process. Bias levels of -2kV are typically used but these can be reduced to suit wire substrates. Alternatively, high bias can be applied to a plate positioned behind the traverse wire to achieve a similar effect. As operating pressures are higher in the ion plating technique, e.g. 10^{-3} to 10^{-2}mbar, gas scattering results in a more even coating distribution. To protect the filament the electron beam gun in the ion plating technique is differentially pumped to maintain vacuum higher than 10^{-4}mbar.

In the Plasma assisted chemical vapour deposition (PACVD) method the substrate to be coated is immersed in a low pressure (0.1 to 10 Torr) plasma of the appropriate gases/volatile compounds. This pressure is maintained by balancing the total gas flow-rate against the throughput of the pumping system. The plasma is electrically activated and sustained by coupling the energy from a power generator through a matching network into the gas medium. Thin films have been successfully deposited from direct current and higher frequency plasmas well into the microwave range. At high frequencies the energy may be capacitatively or inductively coupled depending on chamber.design and electrode configuration. Typically a 13.56 MHz radio-frequency generator would be used having a rating which would allow a power density of between 0.1 - 10W/cm^2 in a capacitatively-coupled parallel-plate type reactor. The substrate, which could be set at a temperature of up to 400°C, may be grounded, floating or subjected to a dc voltage bias as required. Typically deposition rates for this technique can be favourably compared with those obtained by sputtering.

After the keying layer has been formed, the conductive layer is applied. As stated above, many of the methods for forming the intermediate or keying layer may be used for forming the conductive layer, or other methods may be used instead. Reactive sputtering, evaporation and chemical vapour deposition are preferred methods although faster deposition methods may be used.

After the keying layer and conductive refractory layer have been deposited on the wire conductor it may be desirable to coat the layer with a thin coating of a polymeric resin or lacquer in order to provide mechanical protection and a barrier against water or electrolytes during service. Further conductive particle loaded polymer and/or polymeric insulation may then be extruded onto the coated conductor by methods well known in the art.

In order to form a cable, the appropriate wires according to the invention may simply be laid together and be enclosed in a jacket. If desired the wires may be provided with a screen or electromagnetic interference shield before the cable jacket is applied. Thus a cable may be formed in a continuous process by means well known in the art by braiding the wire bundle and extruding a cable jacket thereon. Any of the materials described above for the wire polymeric insulation may be used although halogen-free compositions e.g. compositions as described in the U.K. Patent Specifications Nos. 1,603,205 and 2,068,347A mentioned above are preferred. It is of course possible to employ additional means for providing integrity of the cable such as mica tape wraps, but these are not necessary nor are they desirable in view of the increased size and weight of the cable.

Several embodiments of the invention and a method of production thereof will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a cross-section through one form of wire according to the present invention;

Figure 2 is a cross-section through a cable employing the wires of figure 1;

Figure 3 is a cross-section through part of a flat conductor flat cable;

Figure 4 is a schematic view of part of the sputtering apparatus showing its wire handling mechanism; and

Figure 5 is a schematic section through part of the thickness of component in accordance with the invention.

Referring to figure 1 of the drawings, a 26 AWG stranded copper conductor formed from 19 copper strands is coated with a 3 micrometre thick intermediate or keying layer of aluminium by the sputter ion plating method described above, followed by a ferrite conductive layer for attenuation of unwanted high frequency signals, both layers being indicated by reference numeral 2. A coating 3 based on a polyetherimide or a polyether ether ketone or polyether ketone or an ETFE copolymer is then extruded on the oxide coated conductor to form a polymeric insulating layer of mean wall thickness 0.2 mm.

Figure 2 shows a cable formed by laying together seven wires shown in figure 1, forming an electromagnetic interference screen 4 about the bundle by braiding and then extruding thereon a jacket 5 based on a halogen-free composition as described in British Patent Specification No. 2,068,347 Example 1A.

Figure 3 shows a flat conductor flat cable comprising an array of flat copper conductors 1 with a 100 mil (2.54 mm) spacing. Each copper conductor 1 is provided with a 3 micrometre thick aluminium intermediate layer (not shown) and a ferrite layer thereon as described above, both the aluminium and ferrite layers shown by reference numberal 2, and the coated conductors are embedded in a single polymeric insulating layer 3 formed for example from one of the polymers described with reference to figure 1.

Apparatus for use in a batch process for providing the keying layer on a wire conductor substrate by the sputtering method is illustrated in Fig. 4. The apparatus comprises a vacuum chamber into which a complete wire transport mechanism which includes wire pay-off reel 2 and take-up reel 3, wire support rolls 10 and tensioning rolls 11 is loaded. The mechanism engages motor drives which control the passage of wire 4 so that the wire traverses a vertically mounted target 5 a number of times. Deposition occurs by the processes previously described. As before, variations in set-up are possible. An additional target (not shown) may be employed on the other side of the wire to increase coating rates and additional targets, e.g. target 6 can be employed to deposit intermediate layers before and/or after deposition of the primary coating. Suitable design of the gas inlet system to suit the specific geometries employed can facilitate deposition of layers which have no defined boundaries as described previously. Batch length will depend on chamber dimensions and transport system design.

In the operation of such a batch process wire 4 is transferred from one reel 2 to the other 3 within the chamber. The route taken by the wire may cause it to pass before the smaller ancillary target 6 to deposit an intermediate layer of any desired material. Power to this target, combined with wire speed and the number of passes in front of the target will control the thickness of the intermediate layer deposit. The wire 4 may then pass in front of the larger primary target 5 to deposit the main coating. Again thickness will be dictated by a combination of power, wire speed and a number of passes. The ratio of thicknesses between the intermediate and the primary coating is controlled in the same way. Multi-layers can be built up by reversing the mechanism as desired such that the wire 4 passes back past the targets 5,6 in reverse order. Thickness and composition may be altered in the reverse pass as required, e.g. the process employed at the smaller magnetron may be reactive on the reverse pass to deposit a compound of the metal on the intermediate layer, e.g. Ti and TiO_x. Deposition of layers with no defined boundary between the metal intermediate layers (or substrates) and the oxide coatings may be achieved by setting up gradients of reactive gas in front of the primary target, such that wire at the top edge of the target 5 is subjected to deposition in an Argon rich atmosphere which gradually increases in reactive gas content as the wire progresses down the face of the target. A gradient can be achieved by a baffle system (not shown) which progressively leaks oxygen introduced at the bottom end of the target towards the upper end. Alternatively, a graded metal flux to the substrate could be employed by interposing suitable shields between the target and the substrate.

A simpler technique for producing the layer with no defined boundary involves use of a multipass process in which wire 4 is passed back and forth through the system, and with each pass the level of reactive gas is increased to a final level required to obtain the correct stoichiometry. Thus the stoichiometry of the intermediate layer increases in a series of small incremental steps from metal to required stoichiometry. Composite targets may also be used to produce intermediate layers with stoichiometry gradients. In the case of discrete articles, the articles may instead be held in front of the target by means of a rotating sample holder.

Figure 5 is a schematic section through parts of an article according to the invention showing a typical arrangement of layers that may be formed on the copper substrate, the thickness of the layers being exaggerated for the sake of clarity.

A copper substrate 21 is provided with a thick (e.g. 1 to 3 micrometres) layer 22 of nickel followed by a layer 23 of aluminium metal, the layer 23 having been formed e.g. by a sputtering method. An additional, layer 24 of ferrite or doped barium titanate (e.g. of about 5 to 15 micrometres thickness) has been deposited on the layer 23 by an appropriate method.

Although the layers are clearly demarcated in the drawing by means of lines, it will be appreciated that such boundaries may not, and preferably will not, be formed in practice, especially between the copper/-aluminium layers.

If desired, further layers may be formed on the article as appropriate. For example an aluminium layer or an aluminium/nickel/copper composite layer may be formed on the barium titanate layer 24 to act as a second electrode.

The following Examples illustrate the invention:

EXAMPLES 1 AND 2

19 strand, 22 AWG copper wire conductors were provided with a 4 micrometres thick titanium intermediate layer by use of the sputtering apparatus shown

schematically in figure 4 of the drawings. The sputtering conditions were as follows: the wire 4 was precleaned by vapour degreasing in 1,1,1-trichloroethane prior to deposition. The cleaning was achieved by passing the wire through a vapour degreasing bath such that a residence time of 3 minutes was achieved. The wire 4 was then loaded into the vacuum chamber. The chamber was then evacuated to a pressure of $1x10^{-6}$ mbar prior to starting the process. At this stage argon was admitted to attain a pressure of 1.5×10^{-2} mbar whereupon a high frequency (80 kHz) bias potential was applied to the wire handling system which was isolated from ground. A bias potential of -850V was achieved, and the wire was transferred from reel 3 to reel 2 such that a residence time of 10 minutes was achieved. On completion of the cleaning cycle the pressure was reduced to 8.10^{-3} mbar and the deposition process started.

4kW of DC power was applied to the titanium target 5. The wire passed from reel 2 to reel 3 being coated as it passed the target 5. Residence time in this region was controlled by wire speed and adjusted to give the required thickness. The roller mechanism alternated the wire face exposed to the target as it progressed down the target length.

The titanium-coated wire was then coated with a substoichiometric oxide of titanium, TiO_x, by reversing the wire handling mechanism and sputtering from the titanium target in an argon/oxygen atmosphere. By way of comparison, bare copper wire (with no Ti intermediate layer) was also coated with TiO_x. Both Ti and TiO_x layers surrounded the bundles of copper strands, but not each individual strand. The samples were assessed for the adhesion of the TiO_x layer, and the results are given in Table 1.

TABLE 1

Example	Ti layer thickness (μm)	TiO_x layer thickness (μm)	Adhesion
1	0	4	Very poor; coating spalled with minimal handling.
2	4	4	Excellent; survived severe mechanical abuse without detectably spalling (tight knotting of wire).

The ability of Examples 1 and 2 to withstand thermal cycling was also tested. Square wave current pulses (30A, 60 seconds on, 30 seconds off) were repeatedly passed down the wire samples, which heated them from 25°C to 350°C and back again. The TiO_x coating of example 1 was seen to spall away from the conductor after 1 cycle, whereas Example 2 remained completely intact even after 10 cycles.

The results show that the Ti intermediate layer significantly improves the adhesion of the TiO_x to the copper wire.

The electrical properties of the sputtered TiO_x were investigated by coating a flat copper strip with 4µm Ti plus 4µm TiO_x. The current/voltage relationship of the TiO_x was measured using a variable voltage DC power supply and an ammeter, making contact to the TiO_x film via an electrode made of silver-loaded conductive paint. A non-linear relationship between current and voltage was found, and the TiO_x had a negative temperature coefficient of resistance (i.e. the TiO_x was an NTC material). The resistivity of the TiO_x film was found to be 7.10^7 ohm cm with an applied potential of 1V (lower with higher potential).

EXAMPLES 3 AND 4

19 strand, 22 AWG copper wire conductors were coated with layers of Ni and NiO as shown in Table 2. The sputtering method described above was used to manufacture these samples. NiO is an antiferromagnetic material at room temperature.

The samples were then tested to determine the adhesion of the top coat as follows. A fixed length of wire was subjected to a tensile stress whilst the strain was continuously recorded. During testing the wire sample was viewed through an optical microscope. When the coating was seen to spall significantly the strain was recorded. The strain value recorded at this point gave a measure of the adhesion at the coating. The results of this adhesion testing are also given in Table 2.

TABLE 2

Example	Ni layer thickness (µm)	NiO layer thickness (µm)	Adhesion (arbitary units)
3	0	4	600
4	0.5	4	*

* no failure observed, even when the wires were stretched beyond their breaking strain.

Examples 3 and 4 were also subjected to the thermal cycling test described above. Again, Example 3 (no Ni intermediate layer) was seen to spall after 1 cycle, but Example 4 (0.5µm Ni intermediate layer) was intact after 10 cycles.

EXAMPLES 5 AND 6

Flat copper conductors were sputter coated with a 4um titanium intermediate layer, and subsequently coated with Si-doped barium titanate by thermal evaporation. The evaporation process used was as follows: pieces of Si-doped barium titanate were loaded into a molybdenum crucible, and the vacuum chamber pumped down to about 10^{-4} mbar. The power supply to the crucible was then switched on, heating the evaporant. When the heating current reached about 280A, the charge started to evaporate. Heating was continued for about 12 minutes, during which time Si-doped $BaTiO_3$ was deposited onto the Ti-coated copper substrates (which were held about 20cm above the crucible). Using this method, films about 0.3μm thick were deposited. To form a comparison, bare copper substrates (with no Ti intermediate layer) were also coated.

The adhesion of the Si-doped $BaTiO_3$ films was tested by heating the coated flat conductors to about 500°C for 1 minute. On cooling, the titanate film had spalled away from the bare copper substrates, exposing copper that had oxidised in places. In contrast, those samples provided with the 4μm Ti intermediate layer remained undamaged.

Examples 1-6 clearly demonstrate that the adhesion of inorganic metal compounds to metallic substrates can be significantly improved by the use of intermediate layers.

EXAMPLE 7

NiO- coated copper wire conductors, identical to those of Example 3, were subsequently coated with substoichiometric titanium oxide, TiO_x, as described in Example 1. In this instance, the NiO was used as an intermediate layer, and not for its antiferromagnetic properties. These Cu-NiO-TiO_x samples were found to be very robust compared with the wires of Example 1 (no NiO intermediate layer), and could be handled easily. They also survived 10 thermal cycles from room temperature to 250°C, while those of Example 1 spalled badly after only 1 cycle.

CLAIMS:-

1. An electrical component which comprises a metallic electrical conductor and a conductive layer comprising an electrically conductive inorganic metal compound, the conductive layer being bonded to the electrical conductor by a metallic or electrically non-insulating refractory intermediate layer.

2. A component as claimed in claim 1, wherein the conductive layer has been formed by a vacuum deposition method and preferably by a sputtering or a chemical vapour deposition method.

3. A component as claimed in claim 1 or claim 2, wherein the conductive layer comprises a curie-point, non-linear, ferromagnetic, ferroelectric, P.T.C. or N.T.C. material.

4. A component as claimed in any one of claims 1 to 3, wherein the conductive layer comprises a ferrite, chromite, ferrochromite, a metal titanate or zirconate, a nickel oxide, chromium oxide, or zinc oxide or a titanium oxide.

5. A component as claimed in any one of claims 1 to 4, wherein the intermediate layer comprises the or one of the metals that is present in the conductive layer.

6. A component as claimed in any one of claims 1 to 5, wherein the intermediate layer has been formed by a vacuum deposition process and preferably by a sputtering method or a chemical vapour deposition method.

7. A component as claimed in any one of claims 1 to 6, wherein the intermediate layer comprises a metal compound in which the metal is present in a stoichiometric excess.

8. A component as claimed in any one of claims 1 to 7, wherein the intermediate layer is capable of supporting epitaxial growth of the conductive layer.

9. A component as claimed in any one of claims 1 to 8, which contains one or more additional metallic or conductive refractory layers.

10. A component as claimed in claim 9, wherein the intermediate layer is a refractory layer and an additional layer formed from a metal is present between the refractory layer and the conductor.

11. A component as claimed in claim 1, wherein the metallic electrical conductor has a melting point of at least 800°C and is preferably copper.

12. A component as claimed in any one of claims 1 to 11, which is an electrical wire.

13. A component as claimed in claim 12, wherein the electrical conductor is a stranded conductor and the conductive layer extends around the conductor but not around the individual strands.

14. A component as claimed in claim 12 or claim 13, which is provided with an additional outer insulating polymeric layer.

15. A component as claimed in any one of claims 1 to 11, which is a flat cable and has a plurality of the metallic electrical conductors that are laid side-by-side relationship and are enclosed in a continuous polymeric insulation.

* * * * * *

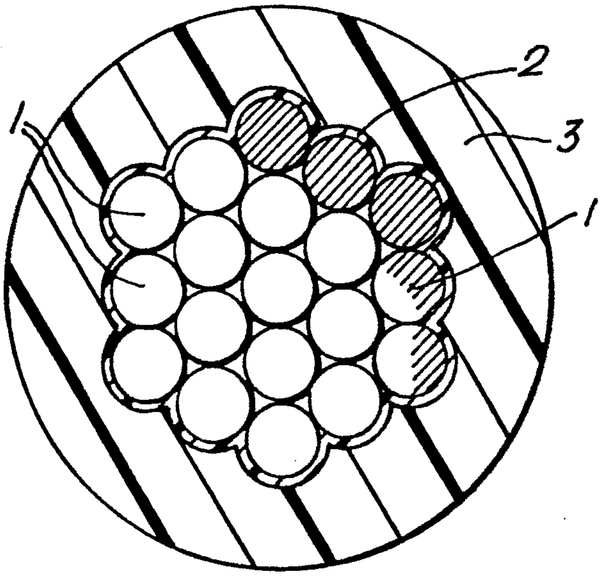

Fig. 1.

Fig. 2.

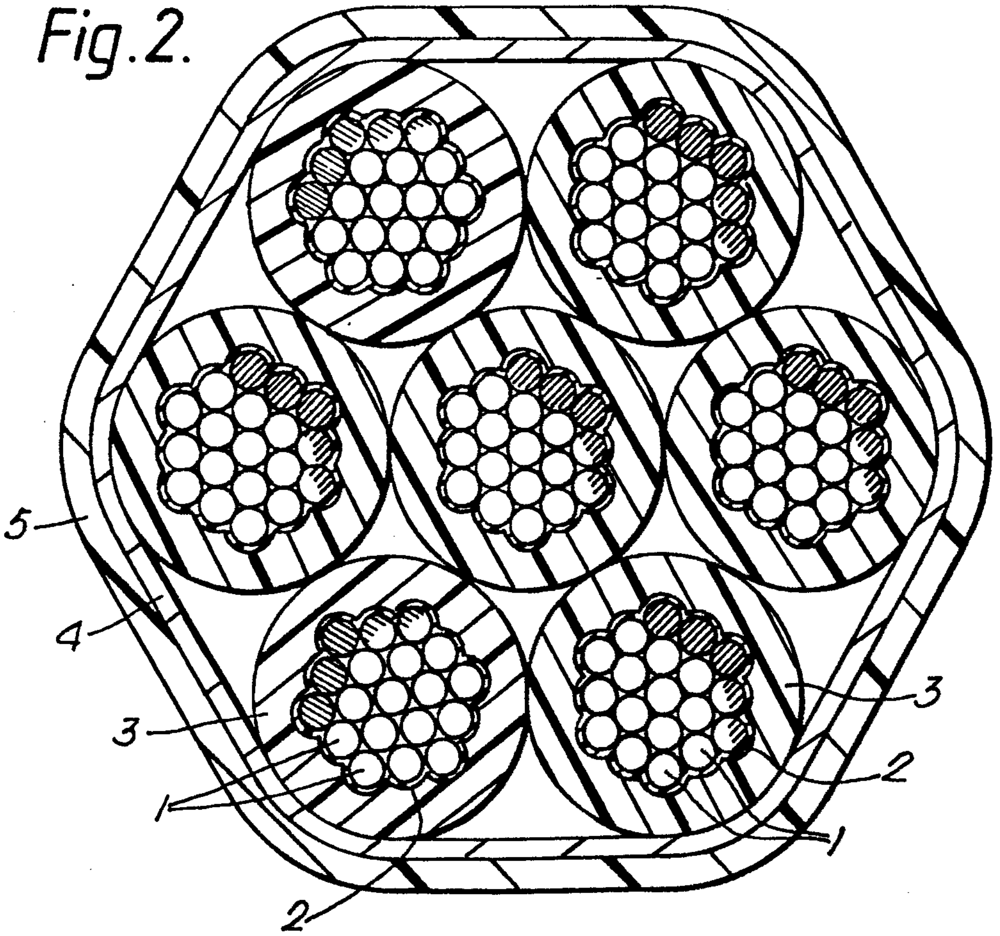

Fig. 3.

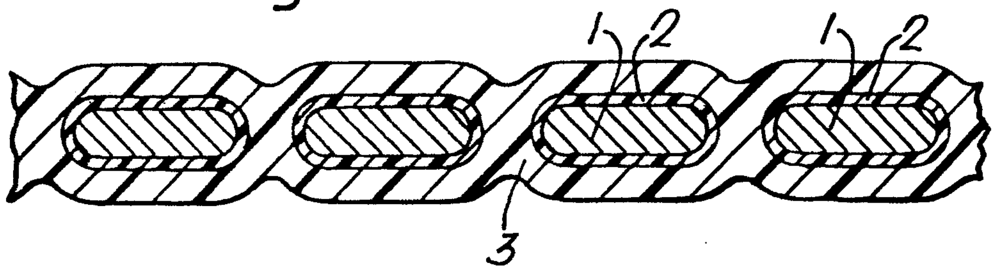

Fig. 4.

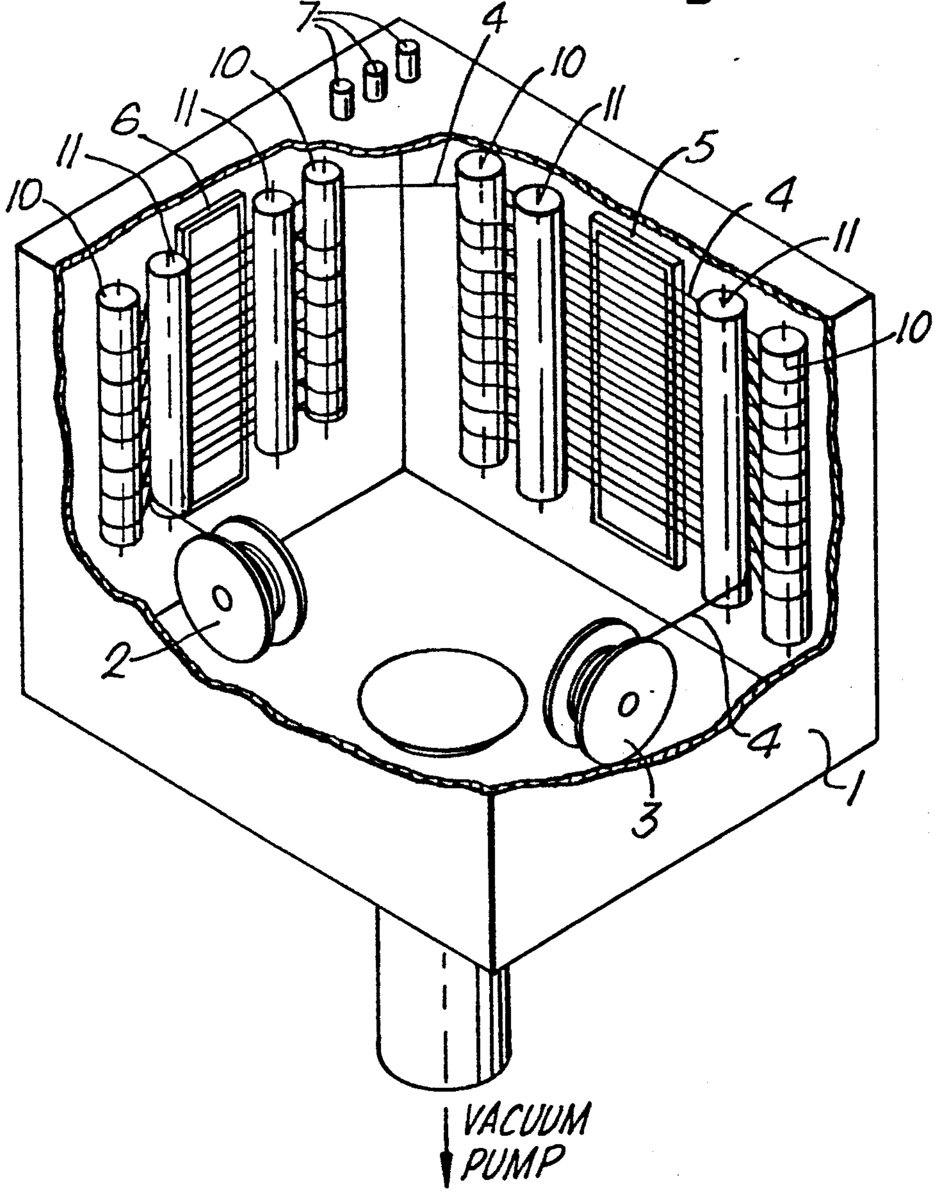

Fig. 5.