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METHOD AND APPARATUS FOR MAKING CYLINDRICAL PRINTED CIRCUITS

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FIG. 1

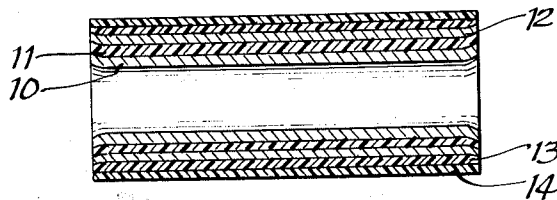


FIG. 2

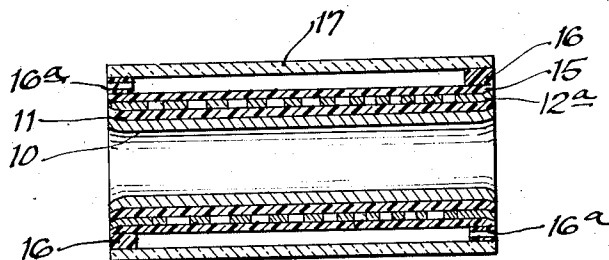
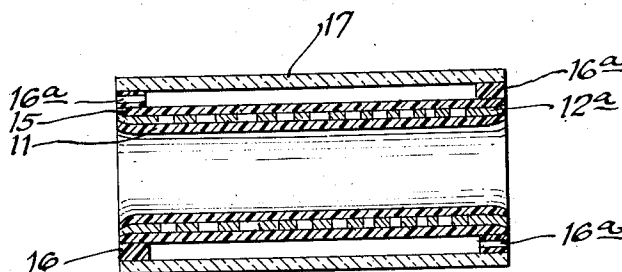


FIG. 3



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METHOD AND APPARATUS FOR MAKING
CYLINDRICAL PRINTED CIRCUITS

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Our invention relates broadly to electrical circuit elements of the type commonly called "printed circuits," and is particularly addressed to the fabrication by photographic techniques of such circuit elements on cylindrical forms.

One of the most popular and successful methods of making "printed circuits" is the photo-etch process, in which the desired circuit conformation is defined on a thin metallic surface in the form of a photographic image, the parts of the metal surface which are not desired in the finished product being then etched away. The etching bath does not attack the parts of the metal surface which are covered by the photographic image. After the etching, the imaged surface is washed away with a suitable solvent.

This technique lends itself to low-cost mass production in applications where the finished product is in the form of a flat or substantially flat surface, since the photographic image can readily be formed on such a surface by contact printing from a negative photographic film. When, however, the finished product is in the form of a cylinder, with the desired metal circuitry extending entirely around its outer surface, the problem of low-cost mass production with good quality control has heretofore defied solution.

To fashion printed circuits on cylindrical forms, it has been necessary to wrap the negative photographic film around the cylinder and to register the overlapping edges of the film with extremely great care. Obviously, any inaccuracy in such registration will produce a product which may be worthless and which will in any event be inferior. Moreover, the carrying out of such a wrapping operation and achievement of the necessary accurate edge registration has necessarily been a hand operation, involving high labor costs and slow production.

The present invention contemplates the formation of a photographic image of the desired printed circuit on a cylindrical form by the use of a transparent cylindrical negative which overlies the form. The entire outer surface of the negative is then illuminated simultaneously, and a photographic image of the desired printed circuit is thus generated simultaneously on the cylindrical surface of the form.

As persons familiar with the art will realize, there are various kinds of circuit elements which can conveniently be fabricated in cylindrical form. Of these, perhaps the most widely used and important are inductance coils. We shall, therefore, describe our invention in this specification in connection with the fabrication of inductance coils and image negatives therefor, it being understood, however, that the various methods of the invention can if desired be employed in the manufacture of other types of electrical circuit elements.

In achieving our method of printing coils on a cylindrical form from a permanent cylindrical negative, we have developed a novel method for producing a suitable cylindrical negative image, and our invention extends to and includes such cylindrical negative-image carrier and the process by which it is formed.

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Accordingly, an important object of our invention is to provide a method for photographically fabricating inductance coils on cylindrical forms by photosensitizing the coil-form surface and then simultaneously exposing its entire operative surface to light through a cylindrical carrier bearing an appropriate negative image.

Another object of our invention is to provide a transparent cylindrical carrier bearing a negative image, by means of which cylindrical coils can be photographically fabricated, such image carrier being readily adapted for use in high-speed, automatic manufacturing processes.

Still another object of the invention is to provide a novel method by which such a transparent negative-image carrier can be made and an appropriate negative image placed thereon.

Other objects and advantages of the invention will appear from the following description of typical applications of our methods and a typical embodiment of our cylindrical image carrier.

In connection with our description, we shall refer to the appended drawing, wherein various stages in the fabrication of our image carrier are illustrated. Figure 1 shows in axial section our image carrier in a preliminary stage of fabrication prior to formation thereon of the negative image. Fig. 2 shows our image carrier after completion of the negative image but prior to elimination therefrom of the temporary mandrel. Fig. 3 shows, likewise in axial section, a completed image carrier in accordance with our invention.

In all three of the figures of the drawing, the thickness of certain layers therein illustrated has been intentionally exaggerated for the sake of clarity. The actual range of thickness of such layers will be described in the specification, it being understood that the drawings are not in that respect drawn to scale.

We shall now describe the method of preparation of a suitable negative-image carrier which may be employed in fabricating inductance coils wherein the helical conductor consists of a thin copper or silver layer on a cylindrical core of low-loss insulating material such as glass.

The negative-image carrier in accordance with our invention is prepared on the temporary mandrel 10, which is a thin-walled metal tube of copper, brass, or aluminum. The tube 10 is cylindrical in shape and somewhat longer than the intended coil. Thus, for a coil which is to have a total length of two inches, the mandrel 10 might be three inches long. The ends of the mandrel 10 are preferably enlarged slightly by swaging or other suitable operation. The purpose of this is to give the central aperture of the negative-image carrier funnel-shaped ends, to facilitate insertion and removal of coil forms to be inserted therethrough. The outer diameter of the tube 10 should be a few thousandths of an inch larger than the outer diameter of the intended coil forms when they are ready for photographic processing—that is, when they have been coated with a thin layer of metal and an overlying layer of light-sensitive material.

The outer surface of tube 10 is polished and then coated with a layer 11 of clear epoxy plastic having a thickness of about .001". It is usually best to apply this epoxy coating in from two to four separate coats, allowing each coat to dry before the next is added.

The epoxy coating 11 on the mandrel 10, which is shown on the drawing with greatly exaggerated thickness, is then prepared for metallizing by having its surface very slightly roughened. This must be done with care, since the coating thickness should not be appreciably changed thereby. A recommended procedure for this step of the process consists in rotating the mandrel 10 in a lathe or drill press and brushing the outer surface of the plastic layer 11 with a gentle abrasive.

After the gloss has been removed from coating 11 in

this manner, the surface of coating 11 should be washed with alcohol and wiped dry to remove all loose dust or other particles. The outer surface of the layer 11 should be metallized by any of the standard methods commercially available, to deposit on the surface of plastic layer 11 a uniform metal layer, preferably copper, having a thickness of from .0005" to .001". This metal layer is shown in the drawings in greatly exaggerated thickness and is marked with the reference numeral 12 on Fig. 1.

After the metallizing step has been completed, the surface of metal coating 12 should be polished to insure freedom from foreign matter. This step should be done carefully to avoid damage to the thin and fragile metallic layer.

The mandrel 10, with its overlying layers 11 and 12, should now be dipped in a bath of a suitable photo-resist compound of the type which is normally soluble in some particular organic solvent but which is rendered insoluble in such solvent by exposure to ultraviolet light. A typical material of this type which we have found very satisfactory is the so-called Kodak photo-resist, sold by the Eastman Kodak Company of Rochester, New York, and commonly abbreviated KPR.

The dipping step just mentioned will result in depositing over the metal layer 12 a layer of photo-resist, marked 13 on Fig. 1. This coat should be dried thoroughly.

Once the photo-resist coating has been applied, care should be taken to avoid exposure of the coated mandrel to any source of ultraviolet light, such as sunlight or untinted fluorescent lamps. The Kodak photo-resist compound above mentioned can be handled in low-level incandescent light without being substantially affected, and the same, we believe, is true of most other types of photo-resist compounds.

At this stage, the structure which is to become a negative-image carrier in accordance with our invention is at the stage of processing at which it is ready to receive a photographic image. For this purpose, the assembly is wrapped with a photographic film 14 which carries, in sheet form, a positive image corresponding to the conformation of the desired coil ultimately to be fabricated. In other words, the image on the film 14 represents a flattened-out version of the desired coil, dark areas on the film corresponding to metal portions of the coil.

When such a film as film 14 is rolled into a cylindrical form, as by wrapping around the outer surface 13 of the mandrel 10, the flattened-out image on the film assumes the cylindrical shape of the coil which it represents. In the wrapping operation, great care should be taken to achieve flawless registration of the overlapping edges of the film, to insure that each portion of the helical coil represented on one edge of the film exactly overlies the corresponding portion on the other edge.

While the products of other manufacturers may be used with satisfactory performance, we suggest, as an illustrative film 14, Eastman Kodalith transparent stripping film.

Once the film 14 has been accurately positioned on the outer surface of photo-resist layer 13, the whole assembly should be exposed to ultraviolet light for a period of time appropriate to the characteristics of the photo-resist composition being used. This exposure produces in the photo-resist layer 13 a negative image corresponding exactly to the positive image contained on film 14.

At this stage, the latent photographic image in the photo-resist layer is developed by the appropriate procedure for the composition being used, the film 14 being of course removed prior thereto. The developing process washes away from the metallic layer 11 the photo-resist composition in all areas not exposed, leaving a layer of insoluble photo-resist composition on the areas which were exposed to light passing through the film 14.

The metal layer 12 is now ready for etching. Before carrying out that step, however, the developed image

defined by the photo-resist should be carefully examined under a low-power microscope to insure that it is free from flaws. Some re-touching may be carried out at this point if necessary. In the course of retouching care must be taken not to scratch through the metal and plastic layers 11 and 12.

The assembly should at this stage be dipped in a suitable etching solution such as ferric chloride. The etching process is best carried out by alternating short periods of immersion in the etching bath with water rinses and inspections. After the etching has progressed sufficiently to remove the portions of exposed metal not covered by the developed photo-resist image, the structure should be washed well in water and then rinsed in a suitable solvent to remove the photo-resist composition and dye deposited therein during developing.

At this point, the metal layer 12 is no longer a continuous coating as shown in Fig. 1 but has taken the form of a negative replica of the printed coils ultimately to be fabricated. The metal layer as thus modified by the etching is marked 12a on Figs. 2 and 3.

By "negative replica" we mean that the modified metallic layer 12a is relieved in all the areas which, on the completed coil, will be occupied by conducting material, whereas the layer 12a has its metal undisturbed in the zones which, on the completed coil, will be occupied by insulating material.

The layer 12a, after being washed and dried, should be covered by a protective coating 15 of epoxy plastic, in a thickness of about .001" or more. This coating, like the base coat 11, should preferably be applied in two or three separate coats.

As the next step in preparation of our negative-image carrier, a pair of ring-shaped spacers 16 are cemented over the ends of the assembly, the spacers being cemented to the outer epoxy coat 15.

Spacers 16 may be made of any suitable hard plastic. Their outer diameter is chosen to fit readily within the interior of a rigid transparent tube 17 made of Lucite, glass, or other suitable material. The outer tube 17 is cemented to the spacers 16, providing a strong protective cover for the delicate plastic cylinder that contains the image.

One or more air vents 16a may be provided in the spacers 16 in order to permit air interchange between the atmosphere and the annulus between the epoxy layer 15 and the outer tube 17.

The thickness of the tube 17 is not exaggerated in the drawing. It will normally be sufficiently thick to possess good mechanical rigidity. Similarly, the wall thickness of the spacers 16, which defines the extent of the annular space between the layer 15 and the transparent tube 17, may be equal or slightly greater than the thickness of the tube 17. These dimensions are not critical, in any event.

If desired, the end portions of the plastic layer 15, beyond the ends of the wall-image proper, may be thickened by depositing additional epoxy thereon. This will strengthen the structure appreciably without reducing its effectiveness, since a high degree of transparency in the layer 15 is needed only for those portions of it which overlie the image-bearing zone of layer 12a.

The final step in preparing our negative-image carrier for use consists in immersing the whole assembly in an etching solution of ferric chloride or other suitable bath, for the purpose of dissolving completely away the brass mandrel 10. This operation usually requires immersion for several hours.

After the brass core has completely dissolved from within the plastic tube defined by layers 12 and 15, the assembly is carefully rinsed and allowed to dry. The carrier may now be used without further processing. The ends of the central bore will be slightly flared to permit easy insertion of the coil forms, since the brass mandrel 10 was so formed.

If the image carrier is to be subjected to relatively

heavy use, it may be desirable to extend the cylindrical assembly for some distance beyond the ends of the photographic image and provide a larger central bore in such extended zones, permitting the insertion therein of a permanent funnel guide made of metal or other rigid material. If this is to be done, the brass mandrel 10 will in the first instance be made substantially longer than is shown in the drawing, the extended ends being larger in diameter so as to produce a larger bore diameter in the completed image carrier. This and other modifications of the basic method and structure of our invention will suggest themselves to skilled readers from the foregoing description.

In making cylindrical printed coils with the aid of our image carrier, the coil forms, made of glass or other low-loss insulating material, are metallized and then coated with photo-resist compound. The outer diameter of the forms after being coated must be slightly less than the inner diameter of the central bore in our negative-image carrier.

A coil form is then inserted in the image carrier, being positioned therein so as to place the image 12a over the desired portion of the form. The image carrier, containing the sensitized form, is then exposed for the appropriate period to the type of radiation for which the photo-resist compound is designed, normally ultraviolet light. The radiation impinges simultaneously on the image carrier and the form from all radial directions, so that the entire image is formed simultaneously on the coil form.

After exposure, the coil form is removed and subjected to the usual treatment to develop the photographic image thereon, after which it may be etched.

Our cylindrical negative-image carrier is particularly well adapted to high-speed mass production of printed coils and other circuit elements. When our image carrier is used, the forms may be fed through the carrier in a continuous process, each coil form remaining within the carrier long enough to be imaged and then being pushed on to the next step of the process by the following coil form. Alternatively, long rods of the coil-form material may be coated with photo-resist compound and fed through the image carrier in progressive steps, so that a large number of distinct coil images are formed on a single rod of core material, the rod being cut into individual coil lengths at a later stage of the process.

Whatever type of manufacturing process is used, our integral cylindrical negative-image carriers afford greatly improved quality control and reduced manufacturing costs, since the need for hand-wrapping of sheet negatives around the cylindrical coil forms is entirely eliminated.

The detailed description herein of a typical embodiment of our cylindrical image carrier and of the method of making it is intended to be illustrative rather than limiting. Many variations in and departures from the specific apparatus and method steps described may be made by

skilled readers without departing from the scope and spirit of our invention.

We claim:

1. As an article of manufacture, a cylindrical image carrier comprising a thin laminated cylinder of transparent plastic, said image being defined by a thin metal layer sandwiched between said laminations, and an outer protective holder for said image-carrying cylinder, said outer holder being transparent in the portion thereof overlying said image and being apertured to define with said image-carrying cylinder a continuous passage coaxial with said cylinder.

2. As an article of manufacture, a cylindrical image carrier for use in fabricating printed-circuit elements on cylindrical forms, comprising a thin integral cylinder made of transparent plastic, a thin metal layer defining said image being embedded within said plastic, and an outer protective holder for said cylinder, said holder being substantially rigid and being transparent in the portion thereof overlying said metal layer, said holder being apertured to define with said cylinder a continuous bore dimensioned to receive slidably said cylindrical forms.

3. The method of making a transparent photographic image carrier for use in fashioning cylindrical printed-circuit elements such as inductance coils, comprising the steps of depositing a thin coating of transparent plastic on a cylindrical mandrel, metalizing the surface of said plastic coating, depositing a layer of photo-resist compound over said metalized surface, exposing said layer to light through an image-carrying film to produce therein a latent image representing said printed-circuit element, developing the latent image in said photo-resist layer, etching said metalized surface to remove the same in all areas thereof not covered by said developed image, coating said etched metalized surface with a thin layer of transparent plastic, thus sandwiching said etched surface between said first and second layers of plastic, mounting said coated mandrel within a rigid transparent protective cover wholly enclosing said etched metalized surface and circumferentially abutting said second plastic layer in two spaced zones, sealing said cover circumferentially to said second plastic layer in both of said zones, and dissolving away said mandrel.

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