United States Patent [19]

Muckelroy

[11] **3,812,442**

[45] **May 21, 1974**

[54] **CERAMIC INDUCTOR**

[76] Inventor: **William L. Muckelroy,** P.O. Box 9685, Washington, D.C. 20016

[22] Filed: **Feb. 29, 1972**

[21] Appl. No.: **230,247**

[52] **U.S. Cl.** **336/83,** 29/602, 336/192, 336/200, 336/232

[51] **Int. Cl.** **H01f 17/06**

[58] **Field of Search** .... 336/83, 200, 232, 221, 336/192; 340/174 CC, 174 JA; 317/258; 174/68.5; 338/308

[56] **References Cited**

UNITED STATES PATENTS

3,483,499	12/1969	Lugten	336/200 X
2,629,860	2/1953	Chesus et al.	336/200 X
3,247,573	4/1966	Loack	336/200
3,665,267	5/1972	Acello	317/258
3,518,756	7/1970	Bennett et al.	336/200 X
2,557,983	6/1951	Linder	174/685
3,400,455	9/1968	Cosgrove	340/174 CC
3,058,078	10/1962	Hoh	336/83 X
3,554,797	1/1971	Coerver, Jr. et al.	336/83
2,966,704	1/1961	O'Brian et al.	336/221 X
3,319,207	5/1967	Davis	336/221 X
3,040,301	6/1962	Howatt et al.	340/174 CC
3,282,730	11/1966	Johnston et al.	338/308 X

FOREIGN PATENTS OR APPLICATIONS

993,265	5/1965	Great Britain	336/200

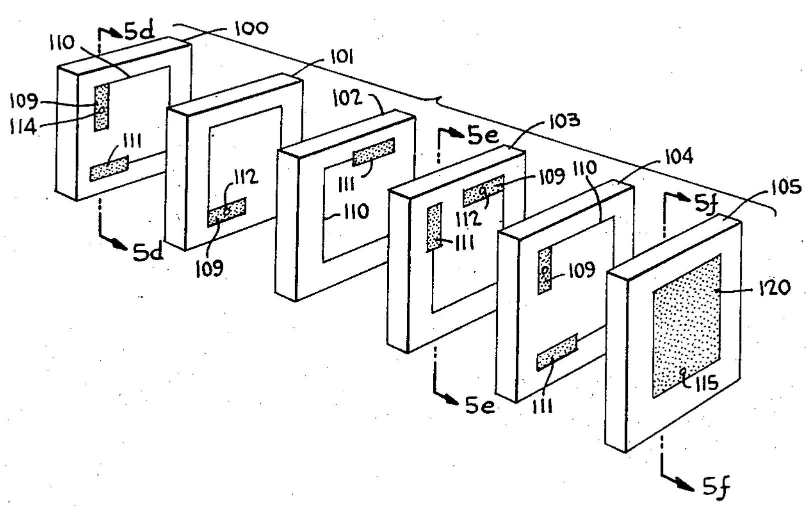
Primary Examiner—Thomas J. Kozma

Attorney, Agent, or Firm—Edward J. Kelly; Herbert Berl; Saul Elbaum

[57] **ABSTRACT**

A nonolithic microminiature inductor comprising a helical conductive path of deposited metal film immersed in a rectangular block of magnetic refractory material. The inductor has metal caps at each end of the block as terminations. These terminations may be soldered to metallized pads located on a substrate. A method for making this inductor wherein loops of conductive metal are deposited onto a thin unsintered magnetically permeable ceramic sheet with holes for interconnection therein and wherein said holes are alligned and said sheets are laminated such that upon sintering said metal forms a helical contiguous conductive path immersed a contiguous block of ceramic.

3 Claims, 19 Drawing Figures



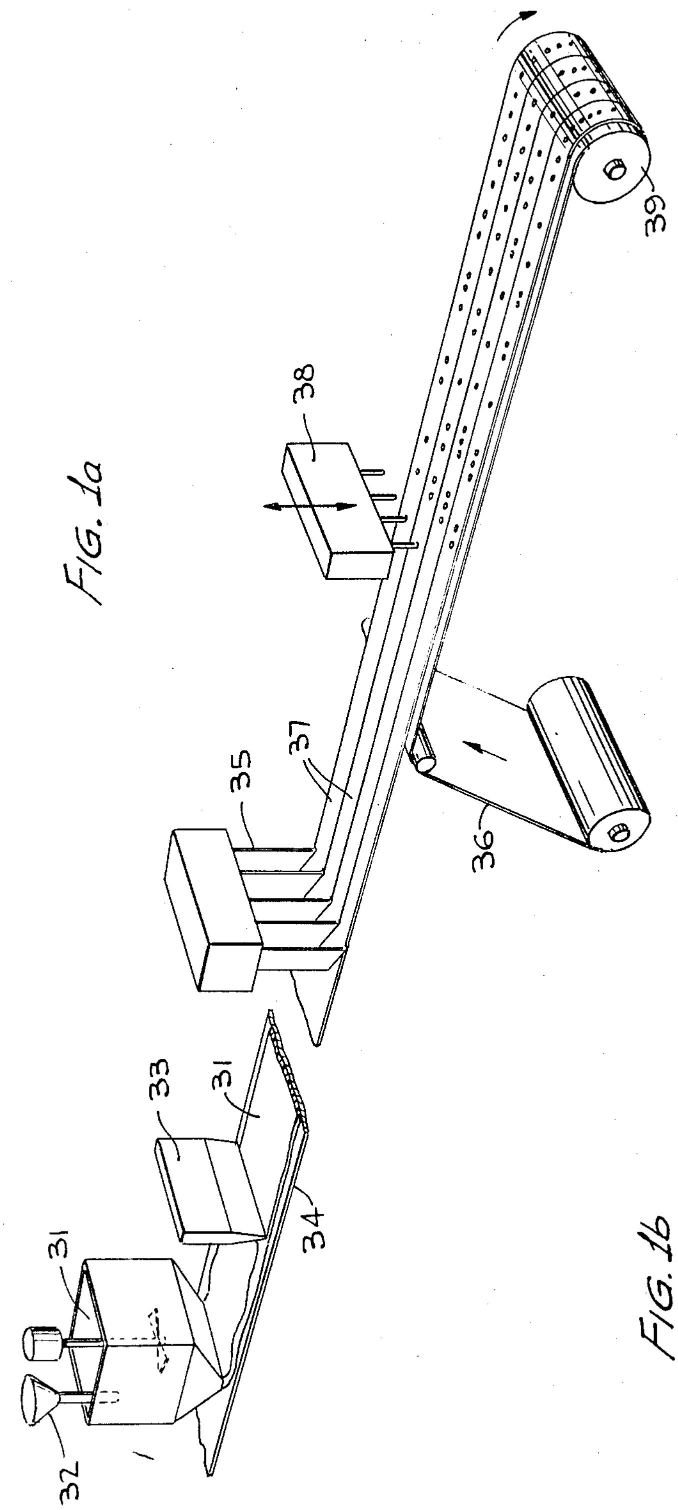

31
32
33
31
34
35
37
36
38
39

FIG. 1a

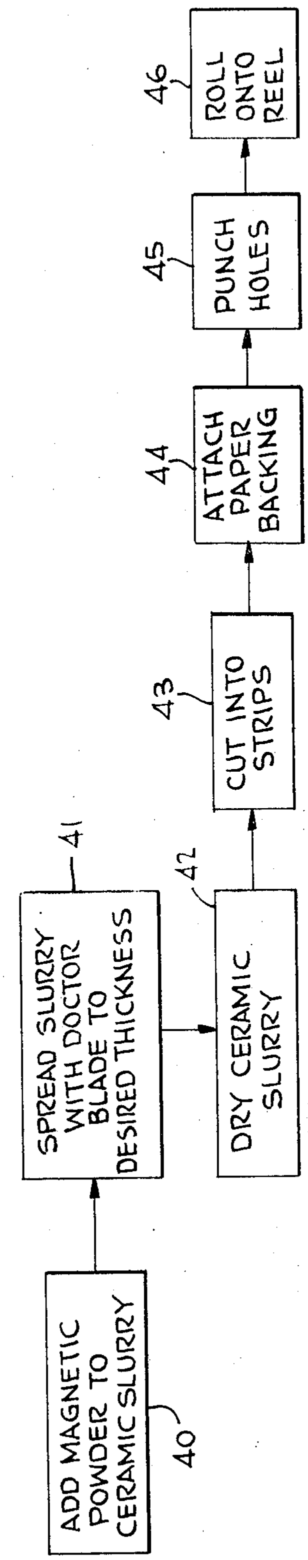

40
ADD MAGNETIC POWDER TO CERAMIC SLURRY
41
SPREAD SLURRY WITH DOCTOR BLADE TO DESIRED THICKNESS
42
DRY CERAMIC SLURRY
43
CUT INTO STRIPS
44
ATTACH PAPER BACKING
45
PUNCH HOLES
46
ROLL ONTO REEL

FIG. 1b

FIG. 2a

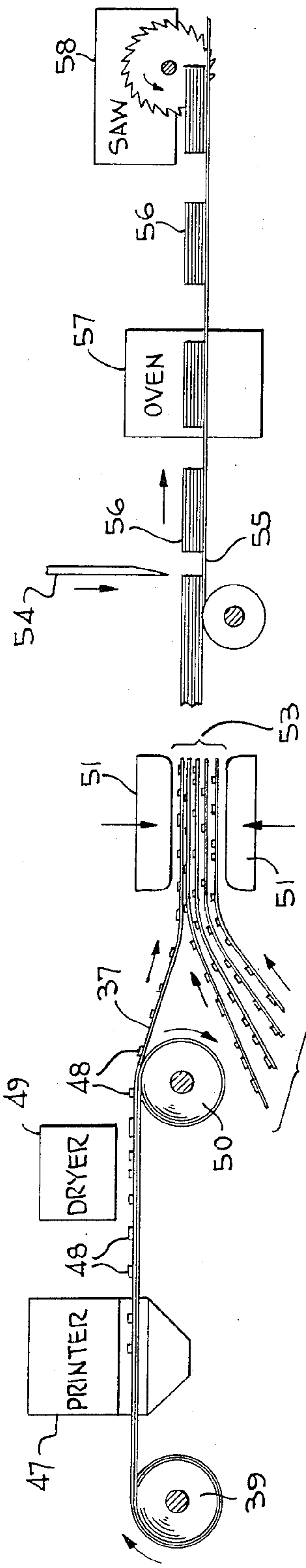
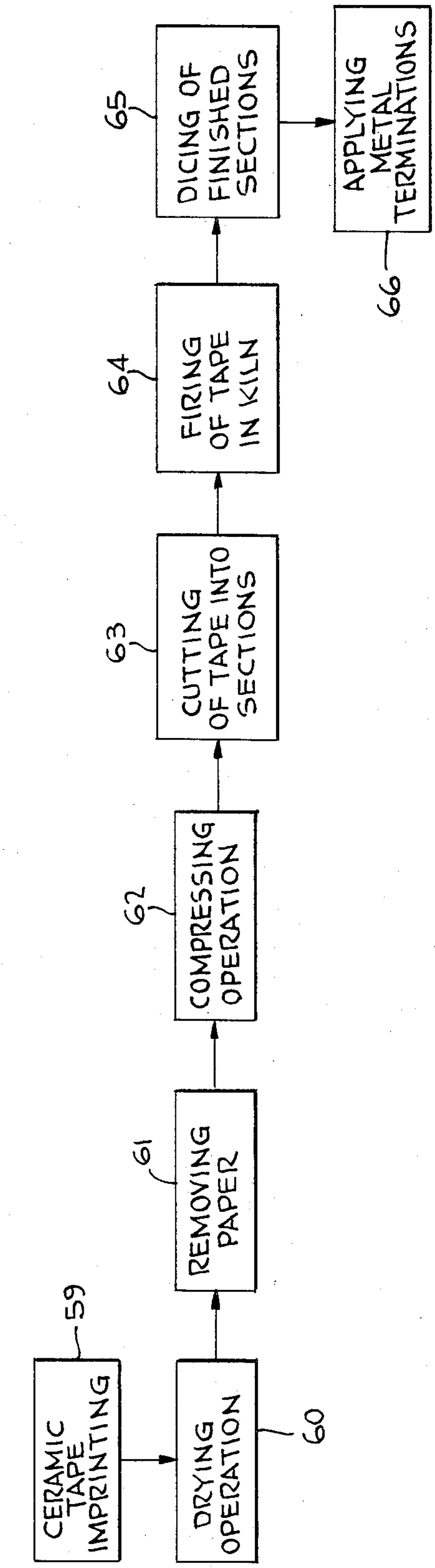

PRINTER
47
39
48
DRYER
49
48
50
37
52
51
51
53
54
55
56
OVEN
57
56
SAW
58

FIG. 2b


CERAMIC TAPE IMPRINTING
59
DRYING OPERATION
60
REMOVING PAPER
61
COMPRESSING OPERATION
62
CUTTING OF TAPE INTO SECTIONS
63
FIRING OF TAPE IN KILN
64
DICING OF FINISHED SECTIONS
65
APPLYING METAL TERMINATIONS
66

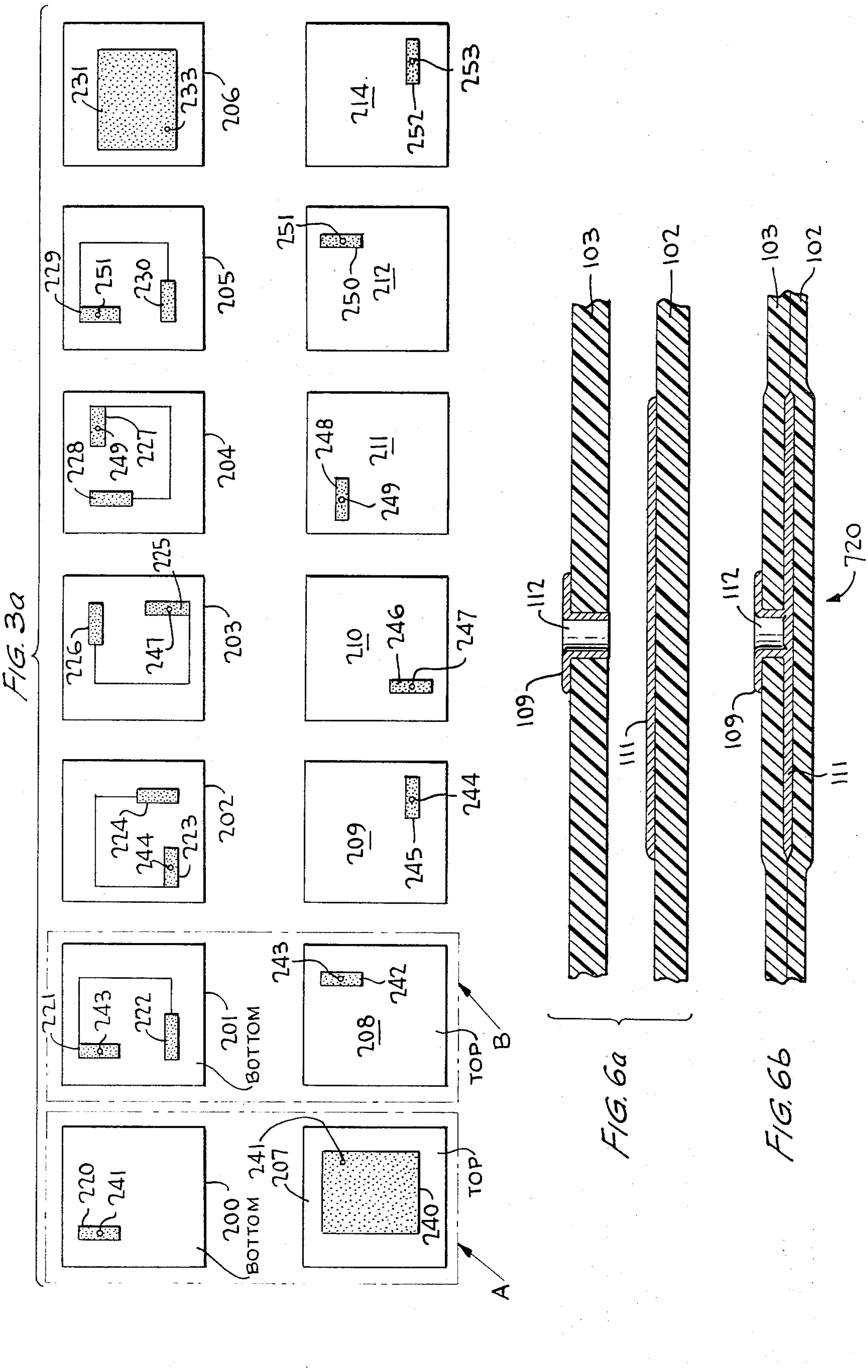


FIG. 3a

FIG. 6a

FIG. 6b

FIG. 3b

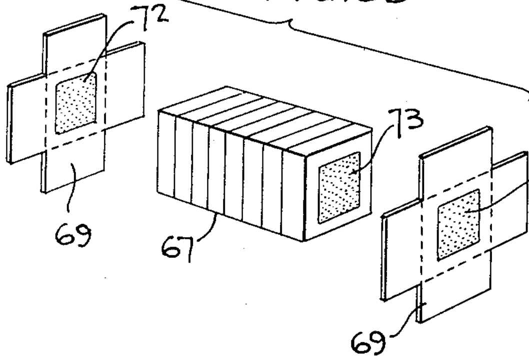


FIG. 3c

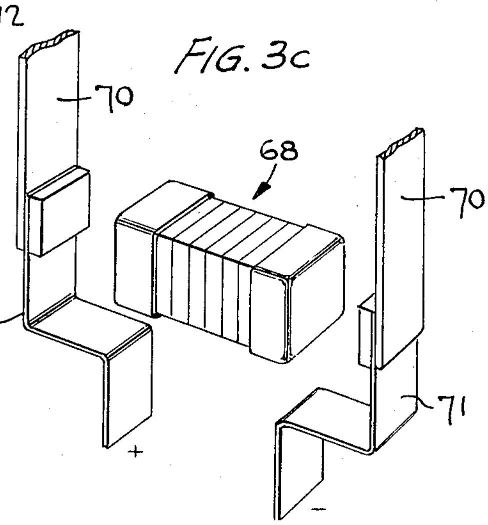


FIG. 3d

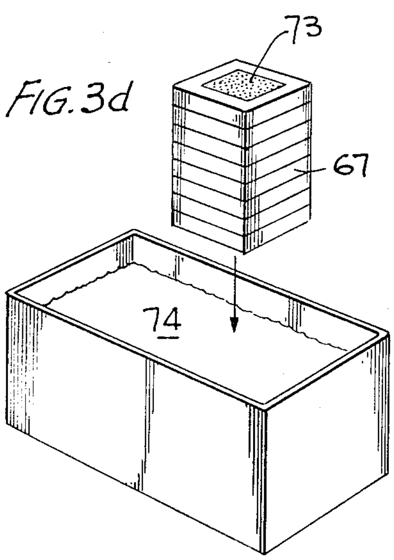
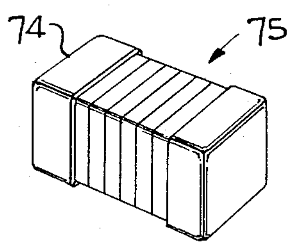


FIG. 3e



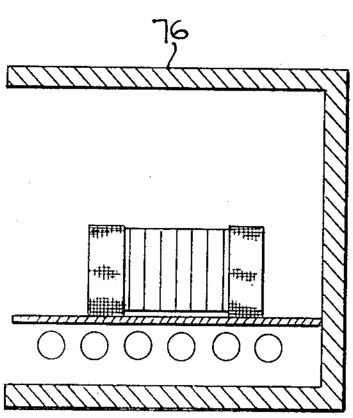
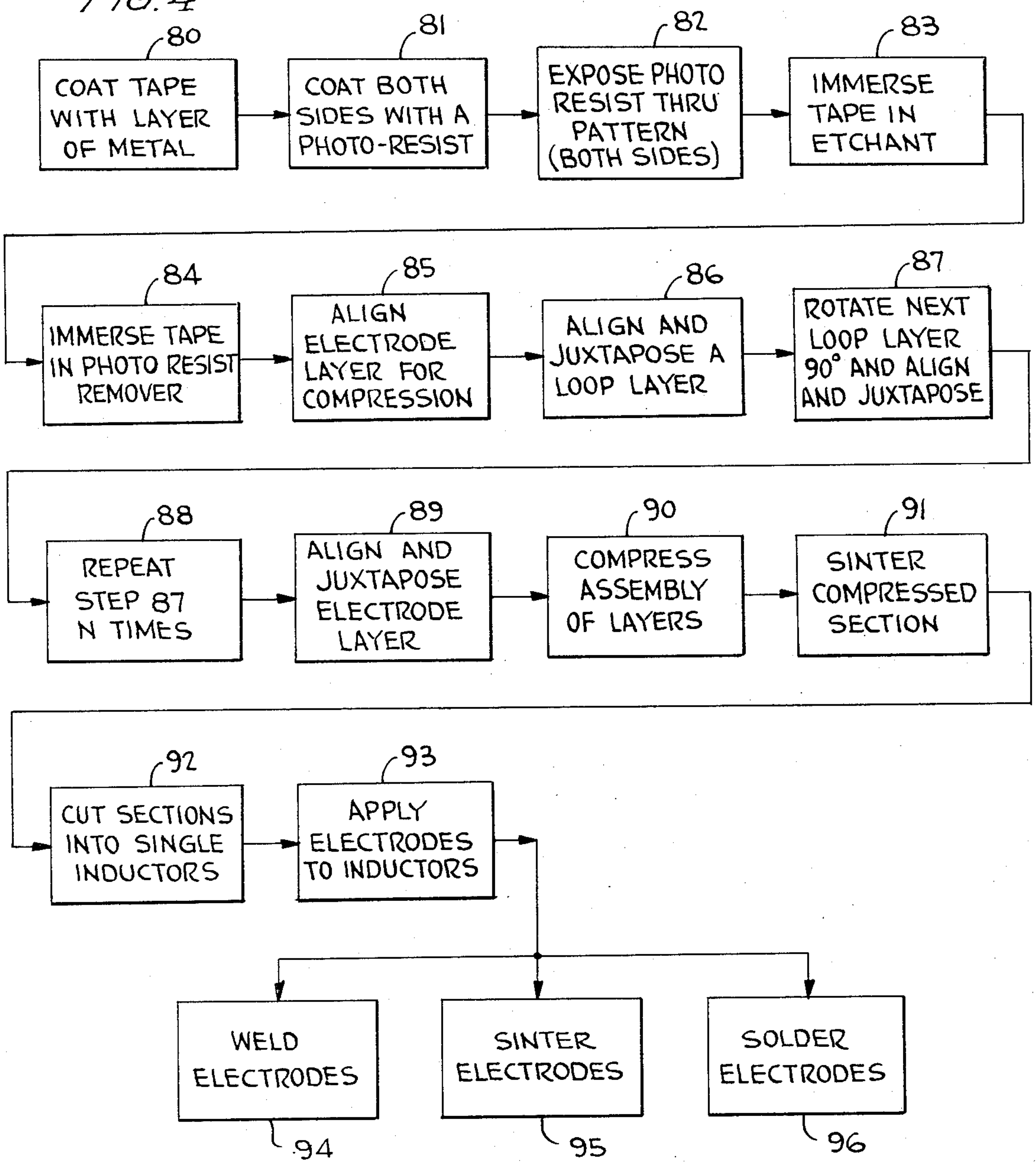


FIG. 3f

FIG. 4


80
COAT TAPE WITH LAYER OF METAL
81
COAT BOTH SIDES WITH A PHOTO-RESIST
82
EXPOSE PHOTO RESIST THRU PATTERN (BOTH SIDES)
83
IMMERSE TAPE IN ETCHANT
84
IMMERSE TAPE IN PHOTO RESIST REMOVER
85
ALIGN ELECTRODE LAYER FOR COMPRESSION
86
ALIGN AND JUXTAPOSE A LOOP LAYER
87
ROTATE NEXT LOOP LAYER 90° AND ALIGN AND JUXTAPOSE
88
REPEAT STEP 87 N TIMES
89
ALIGN AND JUXTAPOSE ELECTRODE LAYER
90
COMPRESS ASSEMBLY OF LAYERS
91
SINTER COMPRESSED SECTION
92
CUT SECTIONS INTO SINGLE INDUCTORS
93
APPLY ELECTRODES TO INDUCTORS
WELD ELECTRODES
94
SINTER ELECTRODES
95
SOLDER ELECTRODES
96

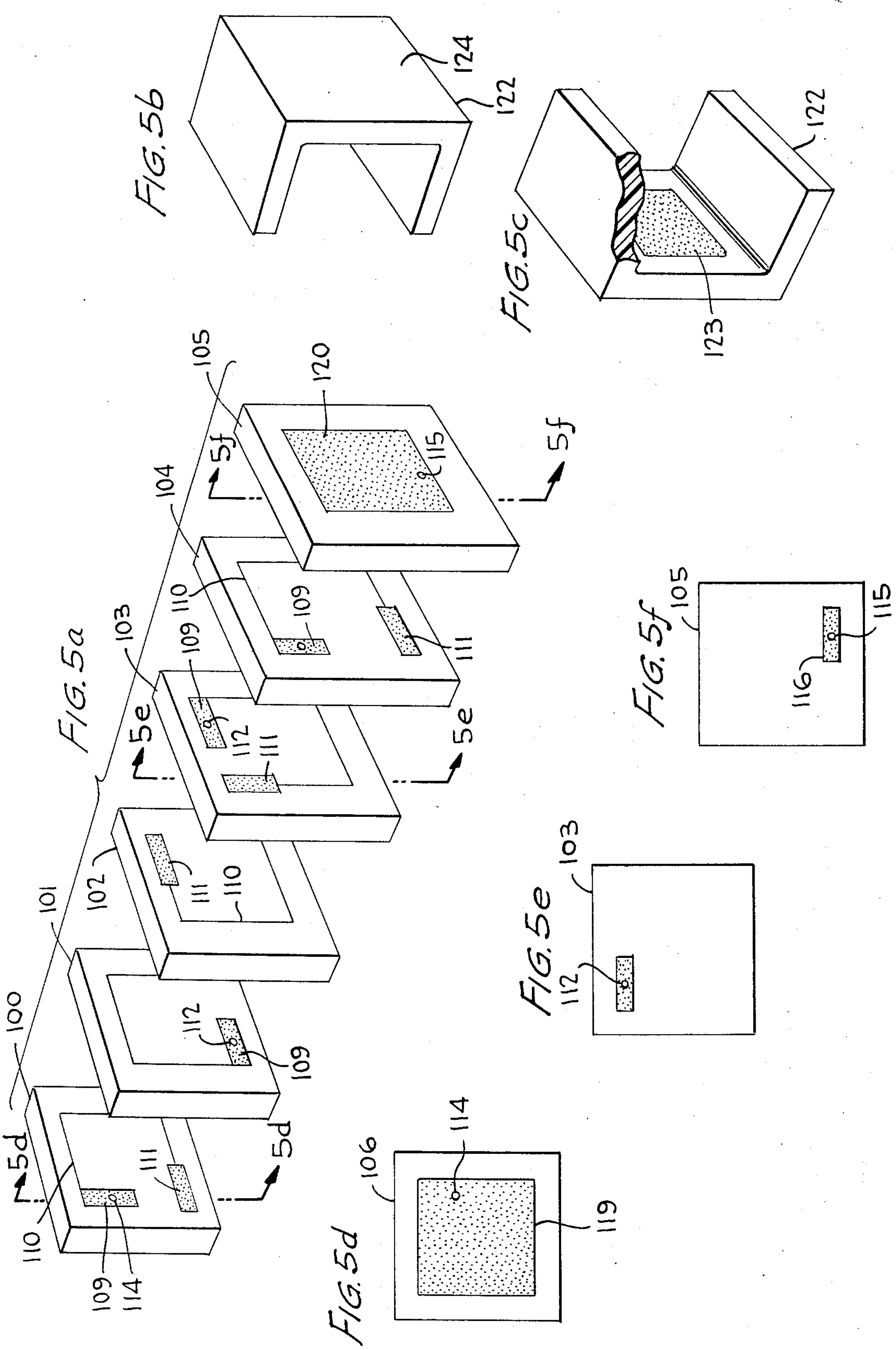


FIG. 5a
FIG. 5b
FIG. 5c
FIG. 5d
FIG. 5e
FIG. 5f
100
101
102
103
104
105
106
109
110
111
112
114
115
116
119
120
122
123
124
5d
5e
5f

CERAMIC INDUCTOR

RIGHTS OF THE GOVERNMENT

The invention described herein may be manufactured, used, and licensed for or by the United States Government for governmental purposes without the payment to the inventor of any royalty thereon.

BACKGROUND OF THE INVENTION

This invention relates generally to monolithic microminiature components for use in the assembly of microcircuitry using substrates as a basis onto which the various types of components are mounted. Less generally this invention relates to a monolithic microminiature inductance element and a method for making same. Specifically this invention relates to a microminiature monolithic inductance element with a magnetically permeable core comprising a magnetically loaded ceramic material and a process for making in mass production large quantities of this device at very economical prices. Moreover, it is related to that class of devices classified as inductors which possess an innercore having the property of significantly enhancing a magnetic field. Among the classes of microelectronic manufacture to which this invention applies are thick film technology, thin film technology, and hybrid multichip technology. In any case, the invention is to be used where reduction in size is required; a large quantity is to be produced; and cost is an essential factor.

Currently spiral inductors made by the application of thick and thin films and by substractively etching the inductor are currently used in manufacturing hybrid microelectronic circuits. Helical miniature inductors have been available for sometime in monolithic form factors having iron cores. However, they comprise fine wire, wound onto iron rods, coated with an epoxy in order to fix the position of the wire to maintain the characteristics of the device. Many problems exist with such a structure, one of which is a possibility of the epoxy breaking down or a particular piece of wire becoming loose. Such flaws in this type of device under abnormal physical condition can cause severe changes in circuit characteristics. This is especially true in military applications where hardware comprising electronic circuity is subjected to large accelerations and shocks.

There are other designs of monolithic inductors essentially the same as the one previously described. The difference is that these other devices are molded into plastic. And naturally, there are the myriad of structures for inductive elements which are not microminiature and which are not monolithic in the sense of this invention in that the various parts of the inductor are not chemically bonded or thermally fuzed to each other. In general, in the past inductors in microminiature form-factors and form-factors easily applicable to hybrid microelectronic circuits have been extremely expensive in relationship to the cost of other functional components to be used in the circuits and therefore offers a cost factor against the use of such components.

Another inherent disadvantage in the structure of the aforesaid components is the nature of the conductive terminations formed onto the device for interconnecting them into the particular circuitry for which it is needed. In most cases, such as that of the plastic device it is best to only epoxy such a device to the substrate using a conductive epoxy material because of the problems involved in raising the temperature of such a device to that necessary for soldering into the circuit. The difference in thermal coefficients between the plastic and the metal terminations at the ends thereof usually precludes the use of high or even moderate soldering temperatures for interconnecting such devices into the circuit. These differences in thermal coefficients are extremely cumbersome when soldering microminiature devices. In general, in assembling hybrid circuits it is desirable to reflow solder chips components. This precludes other sensitive semiconductors from having to be reheating many times. All devices in use today, except spiral depositions onto substrates, have significant thermal mismatches in materials.

In the case of the spiral inductor printed onto a substrate such as alumina or mylar the coupling between the various turns of the spiral are not enhanced significantly. Usually there is free space above the spiral unless some particular type of coating is applied.

One problem with spiral inductors printed on very thin sheets of material is the high probability of changes in the Q-factor by bending of the substrate. Another problem with the spiral is interconnection. When both terminations of the spiral are on the same side of the substrate one of the terminations must be crossed over the respective turns of the spiral. This degrades operation of the device. Even if terminations are brought out on opposite sides of the substrate the problem of traversing the respective windings is still present. Another severe problem with the spiral inductor and the spiral inductor reversed upon itself is that a tremendously large amount of substrate is required.

The term "refractory material" is used herein to mean a substance which will not melt, decompose or materially change under the processing conditions involving in forming the device herein described. Refractory material is generally classified into four broad groups. The group of utility here includes the polycrystalline materials such as ceramics and includes, for example, porcelains, steatites, aluminas, and ferrites. The present invention is described with reference to these ceramics and, more particularly, thin sheets of alumina with ferrites mixed therein. However, it should be understood that the present invention is equally applicable to the other ceramic materials.

The spiral may be formed from a paste of glass, high melting point metal such as platinum and gold, and a decomposable fluid suspending agent applied to the refractory oxide by any convenient method, for example, by dipping, brushing, or spraying. The relative amounts of materials within the paste may vary over fairly wide limits. The main consideration is that the metal content be sufficiently high to insure that the resulting metal film after processing is continuous. The amount of fluid used as a suspending agent depends on the method of application. If spraying is used, a relatively thin suspension is required. If brushing or "squeeze" screen processes are employed, thicker paste suspension should be such as to insure good conductivity of the deposition.

Magnetic materials usable for this device include 2-81 permalloy and carbonyl iron insulated powders, and Ferroxcube III sintered powder.

Generally, a mean particle size range which is suitable is 0.5 to 25 microns for the paste, with the preferred range being between 0.5 and 15 microns. Smaller particles are equally satisfactory.

As for the glass flux, a glass which fuses and bonds to the ceramic at a temperature below the melting point of the metal and resists reduction under the usual processing conditions should be used.

Glasses having these properties are readily compounded from mixtures of silica (SiO_2) and various combination of the oxides of sodium (Na_2O), calcium (CaO), barium (BaO), magnesium (MgO), aluminum (Al_2O_3), boron (B_2O_3), potassium (K_2O) and phosphorus (P_2O_5), among other elements. Table 1 is illustrative of some suitable glasses which can be conveniently compounded from typical oxides specified as to kind and amount in the table. The table is not intended to be exhaustive of suitable glasses but indicates the general composition of some readily fusible nonreductible glasses. It is noted that this table encompasses many common types of glasses such as the borosilicates, phosphates and silicates.

TABLE I

Melt Ingredient:	Parts by Weight
Li_2O	0–15
Na_2O	0–25
CaO	0–10
BaO	0–20
MgO	0–2
Al_2O_3	0–35
SiO_2	5–80
B_2O_3	0–30
K_2O	0–5
P_2O_5	0–80

In the preparation of the glasses, the ingredients are smelted together in a furnace at a temperature sufficient to melt but not volatilize the constituent oxides, for example, between 1,100° and 1,500° C, until a mass of uniform quality has been obtained. The melt is fritted by pouring into cold water, and the resultant frit is ground to the fineness desired. It is desirable for the glass particles to be finely divided, for example, in the order of ½ micron to 25 microns particle size, so that the paste mixture will, under the processing conditions, result in a continuous metal layer adherently bonded to the ceramic.

The glass and metal particles are suspended in a volatile and decomposable fluid suspending agent and applied to the refractory oxide by any of the methods aforementioned. The relative amount of metal and glass used may vary over fairly wide limits. The main consideration is that the metal content be sufficiently high to insure that the resulting metal film after processing is continuous. Generally, between five to 50 parts by weight of metal is used for each part by weight of glass.

The fluid suspending medium serves to disperse the paste mixture in the desired pattern on the substrate and to hold the paste in this pattern until processing commences. During processing the suspending medium should volatilize, leaving no residue. The suspending medium should not react with the metalic or glass components of the coating composition before or during firing.

To insure proper dispersion and bonding of the paste, many of the common suspending media contain two components. The first component acts as a dispersion medium for the paste and as a solvent for the second component which insures proper bonding of the paste to the "green ceramic" or refractory oxide until processing commences. Examples of suitable dispersion media which are solvents for the below listed binders are benzene; the esters of fatty acids; alcohols of low molecular weight such as ethyl, butyl, and amyl; acetates including "Cellosolve acetate" (ethylene glycol monoethyl ether acetate), and "Carbitol acetate" (diethylene glycol monoethyl ether acetate); ketones such as acetone and methyl-ethyl-ketone; and higher ethers such as glycol diethyl ether. Suitable binders are, for example, the vinyl or substituted vinyl polymers such as polymethylmethacrylate, polyethylmethacrylate, polybutylmethacrylate, and polyisobutylmethacrylate and the cellulose esters and ethers such as cellulose nitrate, cellulose acetate, cellulose butyrate, methyl cellulose and ethyl cellulose. Rohm and Haas "Acryloid A-10," a solution of 30 percent polymethylmethacrylate solids in "Cellosolve acetate" has proved a good suspending medium.

In general, any ceramic which is resistant to the usual processing conditions may be used as the refractory substrate. The following table is illustrative of various ceramic compositions that have successfully been used. The compositions are expressed in parts by weight.

TABLE II

	Porcelain				Steatite	Alumina	
Composition	A	B	C	D	E	F	G
Feldspar	35	50	30	25			
Ball clay	15	10	8	10			
Kaolin	30	30	37	40	15		
Talc					60		
Dolomite				2			
$BaCO_3$					17.5		
$MgCO_3$			1		7.5		
SiO_2	20	10	25	22		9–10	2
CaO						1	1
MgO						3–4	1
Na_2O						1–5	½
Al_2O_3						(1)	95.5

1 Remainder.

In order to form a ceramic slurry with good flow property, the forementioned thermoplastic organics are used as flow-promoting binders for the refractory oxide. The prime step is to coat the fine alumina particles with these thermoplastics. This step is facilitated by intense mixing at high temperatures in the range 100° to 400° C. Water emulsions of the organic plastic agents facilitate the initial mixing of the organic with the ceramic particulates, and the initial contact can be made by using an aqueous or non-aqueous slurry and solution. Removal of the volatile constituents provides an intimate mixture of the organic and ceramic most often termed "green ceramic."

In a typical process, firing of the laminate is done in a furnace in which both atmosphere and temperature can be controlled. The firing is done in an reducing atmosphere. This firing step is carried out under conditions sufficient to volatilize the fluid suspending media, and to commence formation of a refractory ceramic-to-glass-to-metal bond. The temperature and firing times are interdependent. The fluid suspending vehicle used and the temperature required commences formation of the refractory ceramic-to-glass-to-metal bond. This temperature is dependent upon the temperature required to sinter the ceramic and to cause wetting of the refractory ceramic and at least part of the metal by the glass in the paste system. Such wetting and sintering temperatures are dependent upon the glass flux used. Temperatures ranging from, for example, 1,400° to 1,600° C have been successfully used.

The maximum temperature is limited by the melting point of the metal while the minimum temperature is again dependent upon the wetting and sintering temperature of the glass flux employed and the temperature required to sinter the ceramic wet by the glass comprising the paste.

The invention described herein overcomes many of the disadvantages of the foregoing constructions.

It is therefore the object of this invention to provide a new and novel process for manufacturing microminiature monolithic inductance elements with a magnetically permeable core.

It is yet another object of this invention to provide a new and novel microminiature inductance element with a magnetically permeable core which is monolithic and comprises materials having coherent thermal coefficients.

It is yet an additional object of this invention to provide a new and novel device and process for manufacturing said device which is economical and easily adaptable to high volume manufacturing.

It is yet an additional object of this invention to provide a monolithic helical inductor emersed in a magnetically permeable ceramic material within terminations suitable for attachment by reflow soldering to thick film circuitry.

It is another object of this invention to provide a microminiature monolithic inductance element which has a form factor compatible with that of other components used in hybrid microelectronics.

It is still additional object of this invention to provide a microminiature monolithic inductance element with a structure made of ceramic and cermet materials.

It is yet another additional object of this invention to provide an inductance device having a surface of refractory material.

It is yet an additional object of this invention to provide a microminiature monolithic inductor with a new and novel core comprising a magnetically permeable alumina ceramic.

It is yet an additional object of this invention to provide a helical inductor imbedded in a magnetically permeable alumina ceramic having a rectangular-solid form-factor.

Yet another additional object of this invention is to provide a new and novel microminiature monolithic inductor whose electrical paths are formed by metalization paths of thick films and thin films.

Still an additional object of this invention is to provide a new and novel method for making a microminiature monolithic inductor in which the electrical conductive paths are formed onto unfired alumina ceramic tape by a subtractive etching technique.

Still yet an additional object of this invention is to provide a new and novel design of metalization which provides a helical spiral that provides inductivity within a compact area.

These and other objects of the present invention will become more fully apparent with the reference to the following specifications and drawings which relate to

several variations of a preferred embodiment of the invention described herein.

SUMMARY

A monolithic microminiature inductor comprising a helical conductive path of deposited metal film immersed in a rectangular block of magnetic refractory material. The inductor has metal caps at each end of the block as terminations. These terminations may be soldered to metallized pads located on a substrate. A method for making this inductor wherein loops of conductive metal are deposited onto a thin unsintered magnetically permeable ceramic sheet with holes for interconnection therein and wherein said holes are aligned and said sheets are laminated such that upon sintering said metal forms a helical contiguous conductive path immersed a contiguous block of ceramic.

BRIEF DESCRIPTION OF THE DRAWINGS

The specific nature of the invention as well as other objects, aspects, uses, and advantages thereof will clearly appear from the following description and from the accompanying drawings, in which:

FIG. **1a** is an illustration of the process of manufacturing magnetically permeable ceramic tape.

FIG. **1b** is a flow chart of the method for manufacturing magnetically permeable ceramic tape.

FIG. **2a** is an illustration of the pattern deposition process by which conductive paths are formed on the ceramic tape.

FIG. **3a** is a view of the underside and top of various layers of the inductor.

FIG. **3b** is an exploded view of a monolithic inductor and unbent metal end terminations.

FIG. **3c** is an illustration of a monolithic inductor with end terminations about to be bonded thereto.

FIG. **3d** is an illustration of a monolithic inductor having end terminations formed by coating the ends thereof.

FIG. **3e** is an illustration of a finished monolithic inductor.

FIG. **3f** is an illustration of a monolithic inductor having its coated end terminations sintered.

FIG. **4** is a flow chart of the manufacturing process by subtracture etching.

FIG. **5a** is an exploded view of the monolithic inductor showing internal structure.

FIG. **5b** is an illustration of a molded metal end termination or cap.

FIG. **5c** is an illustration showing a metal end cap with metal film formed thereon.

FIG. **5d** shows details of a first outside layer of the monolithic inductor.

FIG. **5e** shows details of an interconnector pattern formed on an internal layer of the monolithic inductor.

FIG. **5f** shows details of a second outside layer of the monolithic inductor.

FIG. **6a** is an illustration of two adjacent layers of ceramic tape with conductive patterns thereon before lamination.

FIG. **6b** is an illustration of two adjacent layers laminated with the interconnection of the conductive metalization from one layer to the next.

These and other objects of the present invention will become more fully apparent with reference to the following specifications and the drawings which relate to several variations of a preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The manufacturing process of the present invention will be easily understood in broad aspects by reference to FIG. **1***a* wherein there is illustrated the basic steps in the manufacture of the magnetically permeable ceramic tape. The construction principle of the multilayer ceramic inductor chip begins with the mixing of a slurry **31** of alumina powder and various binders that can be cast in thin layers **31** on a flat surface **34.** However, before casting a magnetically permeable powder **32** is added to the slurry of ceramic material **31.** A doctor-blade **33** is normally used to achieve the required thinness and uniformity. Organic binders in the slurry give enough strength and flexibility to the tape **31** after drying for removal and handling. Strips **37** are cut out of this tape and backed with insulating paper **36** and then holes are punched with tool **38** and the resulted strips are rolled onto roles **39.** The striping or cutting of strips is done with tool **35.** In order that this particular portion of the process may be easily understood it is presented to flow chart form. In FIG. **1***b* step **40** consists of adding a portion of magnetic powder to the ceramic slurry **31.** The proportion of the magnetic material to the ceramic material may vary between 5 and 30 percent of the volume of the ceramic material. The next step of the process **41** is to spread this slurry material by doctor blade to the desired thickness. After step **41** is accomplished the ceramic sheet material is dryed, step **42,** by convection or infrared or other heat transfer means. Once the ceramic sheet material is dry it acquires a plastic and rubber like characteristic and becomes very flexible, yet not brittle. In step **43,** this tape-like, rubber-like material is cut into long strips **37.** In order to prevent the slurry tapes from sticking together due to temperature changes during rolling, a paper or plastic backing is appositioned, step **44,** to the tape and the tape is then in step **45** punched with holes at the required locations. The long strips of tape are next rolled onto reels, step **46.** This completes the process for formation of the tape.

The next phase necessary in the production of these monolithic microminiature inductance elements with magnetically permeable ceramic cores is a formation of conductive paths by pattern deposition as shown in FIG. **2***a*. The reels of ceramic tape **39** are fed through a printer **47** which screens the conductive pattern necessary to form the inductance element onto the tape **37.** The tape **37** is then fed through a drying oven or apparatus **49** which removes the highly volatile components of the metalization silk screened onto the substrate **37.** After the metalization is dryed the paper is separated from the ceramic tape **37** and rolled onto reels **50** for reuse. The ceramic tape **37** is then fed into a compression and lamination apparatus **51** along with reels of tape from other lines similar to the one we have described as illustrated in **52.** Sections of these sheets are alligned and stacked and the stacked structure **53** is compressed and laminated by compression apparatus **51** and the resulting compressed structure is cut from the tape sources and trimmed with cutting apparatus **54.** These large compressed sheets of ceramic tape with metalization thereon contain many inductors. These laminated structures **56** are then carried by a belt **55** to a sintering oven **57** which cures the ceramic at temperatures up to 1,600° C. transforming the laminated structure **56** into a monolithic mass of conductor, ceramic, and magnetically permeable powder immersed and surrounded by the various granules and molecules of alumina ceramic. Once this essential step is completed it is necessary to use a diamond cutter **58** to cut out the various conductors comprised in structure **56.** The above steps are illustrated in flow chart form in FIG. **2***b*. Note that in step **66** of FIG. **2***b* metal terminations are attached to the individual inductive elements. Step **66** is a final increment in the production of these elements. In particular, FIG. **3***a* shows the various steps necessary in order to form the proper pattern and to get the proper interconnections between the various layers to compose a helical inductor. If we were to take an inductor cut from the laminated **56** which, for instance, is comprised of seven individual layers of tape the structure would look as indicated and illustrated in FIG. **3***a*.

In order to appreciate the relationship between the various layers in the laminated structure **56,** continuing reference is made to FIG. **3***a*. Reference character A represents a first layer or lamination that has its top side indicated by **207** and its bottom side indicated by **200.** The top side **207** has a large rectangular metalization or bonding pad **240** thereon. This pad is used to bond the resulting helical inductor to other circuits. A hole **241** is formed in a corner of the pad **240.** The bottom side **200** of the layer A has a small rectangular interconnection pad **220** formed thereon. The hole **241** previously mentioned in connection with the top side **207** is the same hole **241** that passes through the interconnection pad **220.** If one where to flip the layer A from the bottom side **200** to the top side **207,** by rotating the layer to the left as it is being flipped, the configuration as depicted in FIG. **3***a*, for the top side **207** will be seen. The supporting tape between the conductive portions **220** and **240** constitutes the ceramic tape previously discussed which is magnetically permeable but electrically insulative.

A similar relationship between top and bottom sides exists for layer B. The layer B has a single, discontinuous loop formed on the bottom side **201.** Interconnection pads **221** and **222** are positioned in spaced perpendicular relationship to each other. A hole **243** is formed through the interconnection pad **221.** This hole, as well as the previously mentioned hole **241** is formed at **38** in FIG. **1***a*. The top side of the layer B has a single interconnection pad **242** with the hole **243** passing therethrough. Thus, the hole **243** passes through the interconnection pad **242** on the top side as well as the interconnection pad **243** of the loop which is formed on the bottom side of layer B. To visualize the relationship between the top and bottom sides in three dimensions, one must visualize the bottom side **201** being flipped over to the opposite top side, the flipping occuring by turning the layer B over to the left in which case it will be clear that the hole **423** in the top side is positioned in registry with the hole **243** of the bottom side. This relationship between top and bottom sides of the layers in the lamination **56** exists for the upper and lower depicted layers in FIG. **3***a*. As a result, seven layers are shown. When the layers are arranged in juxtaposition with one another, then the following relationship exists between interconnecting members.

The upper most layer 240 is connected with an underside interconnection pad 220, through a conductor existing in the opening 241. In the present invention, the conductor referred to is actually fused metal that is contributed by the bonding pad 240 on the top side and the interconnection pad 220 on the bottom side. The interconnection pad 220 contacts the interconnection pad 242 of top side 208 in the next lower layer B. Fused metal from the hole 243 forms a conductive path between the pad 242 and the pad 221 on the under side 201. A thin loop or conductor in the form of a generally U-shaped configuration continues the conductive path to the pad 222 at the other end of the loop. Thus far, a conductive path has been formed between the bonding pad 240 and the first turn of the resulting helical inductor laminate inductor 56. Next comes the top side 209 of the next layer. When so situated in the laminated structure, contact is made between the pad 222 of the previously mentioned loop and an interconnection pad 245 in 209. A hole 244 passes through the interconnection pad 245 and a similarly situated interconnection pad 223 on the bottom side of this layer. Fused metal during the compression step causes the interconnection of the pads. A second loop exists on the bottom layer 202 which terminates in another interconnection pad 224 at the opposite end of the loop. Thus, a conductive path has been completed through two windings of the helical inductor. The top side of the next layer lays in juxtaposition with the bottom layer 202 of the layer above it. More specifically, the interconnection pad 224 of side 202 contacts the interconnection pad 246 of top side 210 in the forth layer. A hole 247 is formed through the layer and an interconnection pad 225 on the bottom side 203 of this bottom layer. The interconnection pad 225 is connected to a third loop or winding that terminates outwardly in an interconnection pad 226. Thus far described, a conductive pad has been formed between the bonding pad 240 and the interconnection pad 226 thus completing three windings of the helical inductor. The next lower lamination has its top side 211 positioned against the lower side 203 of the lamination above it. Particularly, the previously mentioned interconnection pad 226 contacts the interconnection pad 248 on the top side 211. A hole 249 passes through the interconnection pad 248 and an interconnection pad 227 on the bottom side 204 of the fifth layer. A conductive loop or winding connects the interconnection pad 227 to the interconnection pad 228 at the opposite end of the winding. The hole 249 again permits the fusing of metal between the interconnection pads 248 and 227 on opposite sides of the layer thus creating a conductive path through the layer. Thus far described, an electrical path has been described between the bonding pad 240 and a fourth winding of the helical inductor.

Continuing with the next lower lamination, the top side 212 of the sixth layer includes an interconnection pad 250 with a hole 251 formed therein. This hole passes through a similarly disposed interconnection pad 229 on the bottom side of the sixth layer. As in other cases, an additional winding is formed on this bottom side. The hole 251 again provides space for fused metal from the interconnection pads 250 and 229 to interconnect these pads through the layer. The interconnection pad 230 at one end of the fifth winding contacts an interconnection pad 252 on the top side of the seventh layer. A hole 253 is formed through the interconnection pad 253. This hole passes through the rectangular metalization or bonding pad 231 which exists on the bottom side of the seventh layer. Due to the presence of this hole, metal fuses between the interconnection pad 252 and the bonding pad 206 to complete an electrical path through the complete helical inductor including the five turns on the bottom sides of the second-sixth layers of the structure.

It is most significant to note that the present invention includes the inventive concept of using an identical configuration on the bottom sides of previously discussed second-sixth layers in FIG. 3*a*. Further, the same simple interconnection pad exists on the top side of these layers. Thus, by merely using seven identical layers a helix can be formed by rotating each layer or lamination by 90° with respect to the one above it and below it. The top most or first layer A and the last or bottom most layer, which is the right most layer in FIG. 3*a*, are identical. They only differ in that the top side of the top most layer A is reversed in relationship to the bottom most layer. This type of modular approach expedites the fabrication of the device and results in minimum cost considerations.

Referring now to FIGS. 3*b*, 3*c*, 3*d* and 5*b* we outline two possible methods for providing terminations for the monolithic inductor. One specie comprises one kovar cross-shaped (FIG. 3*b*) or u-shaped (FIGS. 5*b* and 5*c*) sheet attached to each end of the monolithic inductor 67. The kovar metal sheet termination 69 or a sheet made out of a similar metal such as gold or silver or platinum or lead tin is attached to the bonding pad 73 at the end of the inductor either by soldering 69 and binding the tabs around the end of the inductor or welding 69 to the bonding pad 73. Bonding pads 73 and bonding pads 72 can be coated with high temperature solder and then joined. This joining may be accomplished by an electric heating means 70. One way of attaching the terminations 69 formed onto the inductor 67 and thus forming 68 is to use the combination of members 71 and 70 as a high resistance heating element passing current thereinto and thus joining the terminations to the inductor by soldering. Another possibility is to use member 71 as the electrodes of a high resistance weld apparatus and thus weld the end terminations 69 to the attachment pad 73. An alternative process is to dip each end of the monolithic inductor 67 into a thixotropic paste 74 and coat each end thereof as illustrated in 75. The entire structure 75 is then sintered in a high temperature oven. Several compositions of paste 74 are acceptable. Among these are gold, platinum-gold, platinum-silver, copper, palladium-silver, molymanganese, and lead-tin. The final product of this process is so illustrated in FIG. 3*e*.

On FIG. 4 is shown a flow chart of the manufacturing process by substractive etching. Summarizing this process, first the tape is coated with a layer of metal. This may be done either by spraying of a thick-film thixotropic paste or by vacuum deposition of a metal by thin-film technique. Both sides of the tape are coated. Next each side of the tape is coated with photoresist. This may be done by spraying or other dipping or bathing means. The photoresist is exposed in a pattern appositioned to both sides as illustrated in step 82. Next the photoresist is developed in the proper solution and then the tape is immersed in an etchant to remove the unwanted areas of metal. Upon completion of this step 83 the photoresist is removed from the metallization in step **84**.

On step **86** one electrode layer is aligned and juxtaposed to a layer comprising one layer of the inductor. After completion of the previous step **86** the next layer is rotated 90° and alligned and juxtaposed. This step **87** is repeated *n* times, *n* being proportional to the value of the inductance desired. Finally, the top electrode layer is properly alligned and juxtaposed, step **89**. The alligned and juxtaposed layers including the electrode layers are then compressed under pressure. The compressed layers are sintered in a high temperature kiln at temperatures above 1,500° C. The center sections are then cut into single inductors utilizing a diamond saw, step **92**. Next, the electrodes are applied to the inductors, step **93**. In the final step of manufacture of these inductors the electrodes are either welded onto the pad as shown in step **94,** sintered onto the inductor as shown in step **95**, or soldered on as shown in step **96**.

FIG. **5***a* provides an exploded view of the monolithic microminiature inductor without end terminations. FIG. **5***a* also shows the various building blocks necessary to construct a complete inductor. Note that each building block has only one hole for interconnection.

Tracing the electrical path from the termination bonding pad **119** is FIG. **5***d*, the metallization may be followed through hole **114** to the pad **109** in FIG. **5***a* which is connected to the conductive pad **111.** This pad **111** is then connected to inductive pad **109** of the next layer **201.** Pad **112** is connected via hole **112** to pad **109.** Pad **109** of layer **101** is connected via path **110** through a metallized hole in **102** to conductive pad **113.** The conductive pad **113** of layer **102** is connected to pad **109** of layer **103** and then to pad **111** thereon. The conductive pad **111** of layer **103** connects to pad **109** of layer **104** which connects to pad **111** thereon. Pad **111** of layer **104** connects to pad **116** shown in FIG. 5f. Metallized hole **115** interconnects pad **116** of layer **105** with termination bonding pad **120** thereon.

In FIG. **5***b* the end termination comprising kovar metal is illustrated. This end termination **122** has on its inner central face a solder material **123** for connection and joining to a termination bonding pad **120** or **119.** Soldering or welding may be accomplished by applying the appropriate amount of thermal power to the portion **124.** In the case of welding, a current is passed through the termination **122** at the point **124.**

Turning further to FIGS. **6***a* and **6***b* the intricacies of interconnecting a metallization pad on the surface of one layer or segment to a metallization pad on the surface of another layer or segment are described. FIG. **6***a* shows two layers **102** and **103** of ceramic tape with metalizations **109** and **111** thereon and through-hole **112** therein before lamination and interconnection. Ceramic tape **103** is positioned and alligned on top of ceramic tape **102.** Appositioned onto ceramic tape **102** is a metallization connection pad **111.** This metalization connection pad **111** is connected to metalization connection pad **109** through aperture or hole **112.** It is noted that hole **112** is metalized throughout. FIG. **6***b* shows two ceramic tape layers appositioned to each other and appropriately compressed. What is shown in ceramic tape **103** on top of and juxtaposed to the ceramic tape **102.** Metallized hole **112** is compressed into metallized connection layer and pad **111** forming a continuous conductive path from **111** to pad **109** with the metalization in hole **112** serving as the connecting means.

It is to be understood that barium titanate ($BaTiO_3$) may also be used in the slurry to enhance the properties of the refractory ceramic.

The inventor wishes it to be understood furthermore that he does not desire to be limited to the exact detail of construction shown and described herein for obvious modifications will occur to a person skilled in this art.

What is claimed is:

1. A microminiature inductor in the form of a monolithic ceramic block having appositioned layers, each layer comprising:

- a member having a body portion made of magnetically permeable and electrically insulative metal powder immersed in said block;
- a first side of each member having a formation thereon characterized as a discontinuous conductive loop with conductive interconnection pads at the ends thereof;
- a second side of each member having a formation thereon characterized as a conductive interconnection pad, the formation on respective sides of each of said members being identical in configuration, one of the interconnection pads on the end of each loop being positioned in registry with the interconnection pad on the opposite side of the member;
- an opening formed through the interconnection pad on the second side of each member;
- the members stacked so that all first sides face in one direction while the second sides face a second direction;
- each member being rotated substantially 90° with respect to the member above and below it to cause the interconnection pad on the second side of each member to be in contact with an interconnection pad on the first side of a juxtaposing member;
- metal material from contacting interconnection pads fused together through a hole in the interconnection pad of a respective second side thus resulting in a conductive helix formed through the members with the body portions of the members serving as a core for the helix.

2. The subject matter of claim **1** together with two layers having conductive bonding pads thereon, the layers being electrically connected to the helix ends for providing connection terminals to the helix.

3. The subject matter of claim **2** wherein the body of the member comprises an electrically insulated, magnetically permeable metal powder immersed in ceramic, said powder and ceramic forming a contiguous material, whereby said ceramic is made magnetically permeable by the presence of said powder.

* * * * *