Ferromagnetic structures formed of ferromagnetic via fills in a unitized multilayer microcircuit structure that is formed of a plurality of insulating tape layers.
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MAGNETIC VIAS WITHIN MULTI-LAYER,
3-DIMENSIONAL STRUCTURES/SUBSTRATES

BACKGROUND OF THE INVENTION

The disclosed invention is directed generally to hybrid multilayer circuit structures, and is directed more particularly to hybrid multilayer circuit structures having ferromagnetic via structures formed therein.

Hybrid multilayer circuit structures, also known as hybrid microcircuits, implement the interconnection and packaging of discrete circuit devices, and generally include a unitized multilayer circuit structure either formed on a single substrate layer using thick film or thin film techniques, or as a multilayer substrate comprising a plurality of integrally fused insulating layers (e.g., ceramic layers) having conductor traces disposed therebetween. The discrete circuit devices (e.g., integrated circuits) are commonly mounted on the top insulating layer so as not to be covered by another insulating layer or on a insulating layer having die cutouts formed thereon to provide cavities for the discrete devices. Passive components such as capacitors, inductors, and resistors can be formed on the same layer that supports the discrete devices, for example, by thick film processes, or they can be formed between the insulating layers, for example, also by thick film processes. Electrical interconnection of the conductors and components on the different layers is
achieved with vias or holes appropriately located and formed in the insulating layers and filled with conductive material, whereby the conductive material is in contact with predetermined conductive traces between the layers that extend over or under the vias.

A traditional manner for incorporating ferromagnetic structures with unitized multilayer circuit structures is the use of discrete ferromagnetic material in components or structures external to the unitized multilayer circuit structure, which makes the resulting product relatively large and heavy.

SUMMARY OF THE INVENTION

It would therefore be an advantage to provide for ferromagnetic structures that can be implemented in unitized multilayer circuit structures.

Another advantage would be to provide for ferromagnetic structures that can be implemented with unitized multilayer circuit structure fabrication processes.

The foregoing and other advantages are provided by the invention with ferromagnetic structures comprising ferromagnetic via fills in a unitized multilayer circuit structure.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages and features of the disclosed invention will readily be appreciated by persons skilled in the art from the following detailed description when read in conjunction with the drawing wherein:

FIGS. 1A and 1B schematically depict ferromagnetic via structures in accordance with the invention arranged along a microstrip inductance.
FIG. 2 schematically depicts a 3-dimensional ferromagnetic via structure in accordance with the invention for increasing mutual coupling between coupled lines.

FIGS. 3A and 3B schematically depict ferromagnetic via structures in accordance with the invention for EMI isolation and shielding.

FIGS. 4A and 4B schematically depict an isolation ferromagnetic via structure in accordance with the invention.

FIG. 5 schematically depicts a further isolation ferromagnetic via structure in accordance with the invention.

FIG. 6 schematically depicts an isolation ferromagnetic via structure in accordance with the invention which provides for vertical as well as lateral isolation.

FIG. 7 schematically depicts a ferromagnetic via band in accordance with the invention which encircles a conductive trace for changing line impedance.

FIGS. 8A and 8B schematically depict a further ferromagnetic band in accordance with the invention which includes vias of different lateral dimensions.

DETAILED DESCRIPTION OF THE DISCLOSURE

In the following detailed description and in the several figures of the drawing, like elements are identified with like reference numerals.

Ferromagnetic via structures in accordance with the invention are implemented in a unitized multilayer circuit structure that is utilized for interconnecting various discrete circuits mounted on the outside thereof. The unitized multilayer circuit structure is formed from a plurality of insulating layers (comprising ceramic, for
example), conductive traces disposed between the insulating layers, and conductive vias formed in the layers which together with any buried elements (e.g., elements formed on the top of an insulating layer and covered by an overlying insulating layer) are processed to form an integrally fused unitized multilayer structure. The discrete circuits are typically mounted and electrically connected on the outside of the unitized multilayer circuit structure after the unitizing fabrication.

In accordance with the invention, 3-dimensional ferromagnetic structures that include ferromagnetic coatings or via fills are formed in a unitized multilayer structure in different arrangements to achieve a variety of purposes. Appropriate via openings for the ferromagnetic structures are formed in individual layers, for example by conventional techniques such as mechanical or laser drilling, together with via openings for other types of materials such as conductive via fills. As used herein, "ferromagnetic" refers to materials such as iron, nickel, cobalt, and various alloys, that exhibit extremely high magnetic permeability, the ability to acquire high magnetization in relatively weak magnetic fields, a characteristic saturation point, and magnetic hysteresis.

The via openings for the ferromagnetic via structures can be of different sizes and shapes to achieve a variety of special purposes, and can include narrow elongated via openings for line via structures. Large via openings may require radiused corners to maintain structural integrity of the ultimate unitized multilayer circuit structure. The via openings for the ferromagnetic structures can be coated or filled with ferromagnetic material by conventional via fill techniques such as screen printing, for example. Via coating may be appropriate only for relatively small volumes of magnetic material. The ferromagnetic material used to fill the via openings must be compatible with the
material of the insulating layers throughout the fabrication process, and the ferromagnetic structures must not introduce major structural weakness into the unitized multilayer structure. An example of a compatible low temperature co-fired ceramic (LTCC) tape and ferrite ink combination is Dupont 851AT ceramic tape and ESL-EX2000 ferrite ink. The tape manufacturers recommended processing can be used including the burn-out and firing profile.

The incorporation of 3-dimensional ferromagnetic structures into a unitized multilayer circuit offers a wide variety of benefits and expanded capabilities including improved inductors and transformers, reduction of electromagnetic interference (EMI), magnetic field concentration and control, and non-linear devices (such as circulators, isolators, phase shifters, directional couplers and other saturating magnetic devices), while minimizing the need to add discrete external ferromagnetic components. Improved transformer performance is achieved by (i) minimizing leakage inductance by controlling the magnetic flux path, and (ii) reducing conductor loss for a given inductance value since fewer turns are required.

Referring now to FIGS. 1A and 1B, schematically depicted therein are ferromagnetic structures utilized with and distributed along the length of a ring shaped microstrip inductance 11. Each ferromagnetic structure comprises a pair of ferromagnetic via columns 13a, 13b located on each side of the microstrip inductance 11. The via columns 13a, 13b of each ferromagnetic structure are generally co-planar and extend several layers above and below the microstrip inductance 11. As specifically shown in FIG. 1B, the ferromagnetic columns 13a, 13b of each ferromagnetic structure comprise respective stacks of ferromagnetic vias that include narrow vias 15a and inwardly extending vias 15b that are above the microstrip inductance 11 and inwardly extending lower wider vias below
the microstrip inductance. The narrow vias 15a can comprise, for example, circular vias. The inwardly extending vias 15b comprise, for example, circular vias or line vias whose length is represented in FIG. 1A and whose width is perpendicular to the plane of the figure and can be about equal to the diameter of narrow vias 15a.

Inwardly extending vias 15b and the intervening narrow vias 15a of each ferromagnetic structure generally form opposing C-shaped ferromagnetic structures that partially circumscribe the microstrip inductance 11. Further narrow ferromagnetic vias 15a can extend upwardly from the inwardly extending vias 15b. Essentially, each ferromagnetic structure comprises a plurality of ferromagnetic vias 15 arranged to partially circumscribe the microstrip inductance 11. The smaller gaps between the inwardly extending vias 15b may be advantageous in a particular application.

While the foregoing 3-dimensional ferromagnetic via structure has been described in the context of a ring shaped microstrip inductance, it should be appreciated that the ferromagnetic structures can be implemented with other inductance structures wherein the partially circumscribing ferromagnetic via structures are distributed along the contour of a microstrip or stripline inductance.

The ferromagnetic structure depicted in FIGS. 1A and 1B functions to enhance inductance and minimize losses due to circulating currents induced in the ground planes. The presence of ferromagnetic vias provides a preferential media and concentration of magnetic field lines, which minimizes filed line interception by the ground plane of the unitized multilayer circuit structure and the resulting induced currents and losses. As a result of the ferromagnetic structure, higher inductance values are achieved, inductors for a specific value can be shorter, and higher Q is obtained.
Referring now to FIG. 2, set forth therein is a 3-dimensional ferromagnetic via structure for increasing mutual coupling between coupled lines 27, 29. The ferromagnetic via structure includes a plurality of short ferromagnetic via columns 23 formed in the overlap region of coupled lines 27, 29 that are on different insulating layers. Each of the ferromagnetic via columns 23 comprises a stack of ferromagnetic vias 25. The ferromagnetic structure allows for improved power transfer, improved impedance transformation, as well as feedback mechanisms and paths within the multilayer circuit structure, in a smaller structure.

A further application of 3-dimensional ferromagnetic via structures in accordance with the invention is for EMI isolation and shielding. Schematically depicted in FIGS. 3A and 3B is an isolation ferromagnetic via structure that includes a plurality of rows 31 of ferromagnetic via columns 33, wherein each column comprises a stack of ferromagnetic vias 35. The rows 31 of ferromagnetic columns 33 essentially form a ferromagnetic isolation region whose vertical and longitudinal extent (which is normal to plane of FIG. 3A) will depend on the required isolation. The rows of ferromagnetic via columns can be arranged linearly with or without bends or along a contour that is non-linear as viewed in plan view. Depending upon the application, the ferromagnetic via columns can extend from the bottom insulating layer through the top insulating layer, or they can be contained in certain contiguous internal layers.

Schematically depicted in FIGS. 4A and 4B is an isolation ferromagnetic via structure line structure that includes a vertical stack 43 of line vias 45 each of which has a length that is greater than its width. Depending upon the specific application, a plurality of vertical stacks of line vias 45 can be used to provide isolation.
The line vias 45 can be configured to have bends and/or follow non-linear contours.

FIG. 5 schematically depicts a further isolation ferromagnetic via structure that includes a plurality ferromagnetic vias 55, which can be circular vias or line vias, for example, arranged in an interlinked grid wherein a ferromagnetic via in a given layer is partially overlapping and staggered relative to any overlying or underlying ferromagnetic via. For example, the grid includes vertically aligned vias in first alternating layers and vertically aligned vias in second layers, such that the vias in the first alternating layers overlap the vias in the second alternating layers. As shown in FIG. 5 the first or second alternating layers can have one more group of vertically aligned vias than the other alternating layers. The grid can also be extended in the direction normal to the plane of FIG. 4. The isolation structure of FIG. 4 essentially forms a ferromagnetic isolation region whose specific dimensions will depend on the required isolation, similarly to the isolation ferromagnetic structure of FIGS. 3A and 3B. The interlinked grid can be arranged to follow a planar surface or a non-planar surface.

The isolation structures of FIGS. 3-5 can be used to provide shielding on the edges of the substrate, or to isolate circuits in one portion of the multilayer structure from circuits in another portion of the multilayer structure. A ferromagnetic structure can be arranged with bends and/or curves to partially or fully enclose circuits in the multilayer structure.

Referring now to FIG. 6, schematically depicted therein is a ferromagnetic isolation structure that provides for vertical as well as lateral isolation. A row of ferromagnetic via columns 63 is located between corresponding terminal edges of first and second planar ferromagnetic layers 67, 69, wherein such row includes a plurality of via
columns arranged similarly to one of the via column rows in
the structure of FIG. 3B. The ferromagnetic layers 67, 69
are formed by screen printing a compatible ferrite ink on
the associated insulating layers. Depending upon the
application, the isolation structure between the first and
second planar ferromagnetic layers can extend along further
corresponding edges of the planar layers as required. The
isolation structure between the first and second planar
ferromagnetic layers can also comprise multiple rows of
ferromagnetic via columns as described above relative to
FIGS. 3A and 3B, or an interlinked ferromagnetic via grid
as described above relative to FIG. 4. As a further
alternative, a ferromagnetic line via wall structure as
described above relative to FIG. 5 could also be utilized
with the first and second planar ferromagnetic layers.

Referring now to FIG. 7, schematically depicted
therein is a ferromagnetic via band that encircles a
conductive trace 71 for changing line impedance. The
ferromagnetic via band comprises a plurality of interlinked
ferromagnetic vias 75a, 75b, 75c of different lateral
dimensions arranged so that a continuous band of ferromag-
netic material fully encircles the conductive trace. For
increased current handling, parallel conductor traces can
be utilized with common ferromagnetic bands or separate
ferromagnetic bands. The vias 75a, 75b, 75c can comprise
circular vias of different diameters or a combination of
line vias for the vias 75a, 75b of greater lateral dimen-
sion, and circular vias for the vias 75c of lesser lateral
dimension, as depicted in FIG. 7B. In the configuration
that includes line vias and circular vias, the widths of
the line vias can be about the same as the diameter of the
circular vias, for example.

FIGS. 8A and 8B schematically depict a further embodi-
ment of a ferromagnetic band that includes vias of
different lateral dimensions, wherein top and bottom vias
81a have greater lateral dimensions than vias 81b arranged in respective columns at the lateral ends of the top and bottom vias 81a. As particularly depicted in FIG. 88B, the vias 81b can comprise circular vias, and the top and bottom vias 81a can comprise line vias whose widths are about the same as the diameter of the interposed circular vias.

It should be appreciated that one or more of the ferromagnetic bands could be used on a particular line, depending upon the application and its requirements, current, frequency, material properties, and so forth. Particular applications include high frequency noise filtering, harmonic control, radiation suppression, and wave shaping.

Ferromagnetic via structures in accordance with the invention are made, for example, pursuant to low temperature co-fired processing such as disclosed in "Development of a Low Temperature Co-fired Multilayer Ceramic Technology," by William A. Vitriol et al., 1983 ISHM Proceedings, pages 593-598; "Processing and Reliability of Resistors Incorporated Within Low Temperature Co-fired Ceramic Structures," by Ramona G. Pond et al., 1986 ISHM Proceedings, pages 461-472; and "Low Temperature Co-Fireable Ceramics with Co-Fired Resistors," by H. T. Sawhill et al., 1986 ISHM Proceedings, pages 268-271.

In accordance with low temperature co-fired processing, vias are formed in a plurality of green thick film tape layers at locations defined by the desired via configurations of the desired multilayer circuit. The vias are coated or filled with the appropriate fill material, for example, by screen printing. Conductor metallization for conductive traces including the stripline conductors and the embedded ground planes are then deposited on the individual tape layers by screen printing, for example, and materials for forming passive components are deposited on the tape layers. The tape layers are laminated and fired
at a temperature below 1200 degrees Celsius (typically 850 degrees Celsius) for a predetermined length of time which drives off organic materials contained in the green ceramic tape and forms a solid ceramic substrate. External metallization including the lower ground plane metallization and any side wall metallization can then be applied by known techniques.

Ferromagnetic via structures in accordance with the invention can also be implemented with other technologies for forming unitized multilayer circuit structures, including for example high temperature co-fired ceramics, hard ceramic multilayer single firing technology, and a laminated soft substrate approach.

The foregoing has been a disclosure of ferromagnetic structures that are advantageously incorporated in unitized multilayer circuit structures and are fabricated utilizing processes for forming unitized multilayer circuit structures.

Although the foregoing has been a description and illustration of specific embodiments of the invention, various modifications and changes thereto can be made by persons skilled in the art without departing from the scope and spirit of the invention as defined by the following claims.
CLAIMS

What is claimed is:

1. A ferromagnetic structure comprising:
   a plurality of insulating layers; and
   a plurality of ferromagnetic vias formed in said
   insulating layers and defining a ferromagnetic materi-
   al containing region, said insulating layers and said
   ferromagnetic vias forming part of a unitized multi-
   layer circuit structure.

2. The ferromagnetic structure of Claim 1 wherein
   said plurality of ferromagnetic vias includes a plurality
   of columns of ferromagnetic vias.

3. The ferromagnetic structure of Claim 1 wherein
   said plurality of ferromagnetic vias includes a grid of
   interlinked ferromagnetic vias.

4. The ferromagnetic structure of Claim 1 wherein
   said plurality of ferromagnetic vias includes a plurality
   of stacked ferromagnetic line vias.

5. The ferromagnetic structure of Claim 1 wherein
   said plurality of ferromagnetic vias are formed in the
   overlap region between coupled striplines disposed between
   said insulating layers.

6. The ferromagnetic structure of Claim 1 wherein
   said plurality of ferromagnetic vias comprises first
   interlinked ferromagnetic vias and second interlinked
   ferromagnetic vias for partially circumscribing a portion
   of a microstrip inductance.
7. The ferromagnetic structure of Claim 1 wherein said plurality of ferromagnetic vias comprises interlinked ferromagnetic vias circumscribing a portion of a conductor.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 5 H05K1/00  H05K1/02  H05K9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 H05K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>PATENT ABSTRACTS OF JAPAN vol. 13, no. 333 (E-794)26 July 1989 &amp; JP,A,01 096 991 (TDK CORP) 14 April 1989 see abstract ---</td>
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<td>IBM TECHNICAL DISCLOSURE BULLETIN. vol. 33, no. 7, December 1990, NEW YORK US pages 243 - 246 'Electromagnetic noise suppression for electronics cards and boards' see the whole document ---</td>
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* Special categories of cited documents:

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Y. document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

&. document member of the same patent family

Date of the actual completion of the international search 17 January 1994

Date of mailing of the international search report

03.02.94

Name and mailing address of the ISA

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<td>PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY,</td>
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<td>Washington, DC, USA, 21-23 August 1990, IEEE, New York, USA, pages 1-4,</td>
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<td>Y. Trenkler and L.E. McBride: &quot;Shielding improvement by multi-layer design&quot;</td>
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