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Coupled Inductor

Abstract

A coupled inductor includes a first conductive body, a second conductive body, and a molding body. The first conductive body includes a first lateral portion, a first top portion, and a second lateral portion. The first conductive body extends from the first lateral portion to the second lateral portion via the first top portion. The second conductive body includes a third lateral portion, a second top portion, and a fourth lateral portion. The second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion. The molding body encapsulates the first lateral portion, the first top portion, and the second lateral portion of the first conductive body. At least one material is filled in a first space between a first bending portion of the first conductive body and a first bending portion of the second conductive body.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application continuation-in-part of U.S. application Ser. No. 18/918,160, filed on Oct. 17, 2024, which claims the benefit of U.S. Provisional Application No. 63/649,331, filed on May 18, 2024, and claims the benefit of U.S. Provisional Application No. 63/544,450, filed on Oct. 17, 2023. The contents of these applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION
1. Field of the Invention
[0002] The present invention relates to a coupled inductor, and in particular to, a structure of coupled inductor.
2. Description of the Related Art
[0003] A conventional coupled inductor has two laterally-placed pillars, wherein a coil is wound on each of the two laterally-placed pillars. Such a design sacrifices the volume of the magnetic material to achieve the desired coefficient value. As a result, it is not suitable for a design that requires a smaller size.
[0004] Leakage inductance is an inherent characteristic of transformers or inductors, caused by imperfect magnetic coupling between windings, which reduces signal transfer efficiency. Although often considered undesirable, leakage inductance has practical applications in resonant converters, radio frequency (RF) transformers, magnetic amplifiers, and inductive sensors.
[0005] Therefore, a better solution for controlling leakage inductance is needed to resolve the issues mentioned above.
SUMMARY OF THE INVENTION
[0006] The present invention provides a coupled inductor. The coupled inductor includes a first conductive body, a second conductive body, and a molding body.
[0007] The first conductive body includes a first lateral portion, a first top portion, and a second lateral portion. The first conductive body extends from the first lateral portion to the second lateral portion via the first top portion. The first conductive body further includes a first terminal portion that is bent from the first lateral portion and extends in a direction away from the second lateral portion and a second terminal portion that is bent from the second lateral portion and extends in a direction away from the first lateral portion.
[0008] The second conductive body includes a third lateral portion, a second top portion, and a fourth lateral portion. The second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion. The second conductive body further includes a third terminal portion that is bent from the third lateral portion and extends in a direction towards the fourth lateral portion and a fourth terminal portion that is bent from the fourth lateral portion and extends in a direction towards the third lateral portion.
[0009] The molding body encapsulates the first lateral portion, the first top portion, and the second lateral portion of the first conductive body.
[0010] At least one material is filled in a first space between an inner surface of a first bending

portion of the first conductive body and an outer surface of a first bending portion of the second conductive body.
[0011] These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0012] FIG. **1** shows a view of a coupled inductor according to one embodiment of the present invention.
[0013] FIG. **2** shows a view of a coupled inductor according to one embodiment of the present invention.
[0014] FIG. **3** shows a view of a coupled inductor according to one embodiment of the present invention.
[0015] FIG. **4** shows a view of a coupled inductor according to one embodiment of the present invention.
[0016] FIG. **5** shows a view of an electrode structure of a coupled inductor according to one embodiment of the present invention.
[0017] FIG. **6** shows a view of an electrode structure of a coupled inductor according to one embodiment of the present invention.
[0018] FIG. **7**A shows a view of a first space of a coupled inductor according to one embodiment of the present invention.
[0019] FIG. **7**B shows a view of the coupled inductor in FIG. **7**A.
[0020] FIG. **7**C shows a view of the first space of a coupled inductor according to one embodiment of the present invention.
[0021] FIG. **7**D shows a view of the first space of a coupled inductor according to one embodiment of the present invention.
[0022] FIG. **8** shows a view of a cuboid of a coupled inductor according to one embodiment of the present invention.
[0023] FIG. **9** shows a view of the side surfaces of terminal portions of a second conductive body of a coupled inductor according to one embodiment of the present invention.
[0024] FIG. **10** shows a view of the side surfaces of terminal portions of a second conductive body of a coupled inductor according to one embodiment of the present invention.
[0025] FIG. **11**A shows a coupled inductor according to another embodiment of the present invention.
[0026] FIG. **11**B is a U-shape leakage inductance control device for controlling the leakage inductance of the coupled inductor in FIG. **11**A.
[0027] FIG. **12** shows a view of a coupled inductor according to one embodiment of the present invention.
[0028] FIG. **13** shows that the magnetic core and the molding body of a coupled inductor are made of the same material according to one embodiment of the present invention.
[0029] FIG. **14** shows that the magnetic core and the molding body of a coupled inductor are made of the different materials according to one embodiment of the present invention.
[0030] FIG. **15**A shows that a plurality of coupled inductors are packed in a single package according to one embodiment of the present invention.
[0031] FIG. **15**B shows that a plurality of coupled inductors are packed in a single package according to one embodiment of the present invention.
[0032] FIG. **16** shows a design to avoid short circuits of a plurality of coupled inductors according

to one embodiment of the present invention.
[0033] FIG. **17** shows a design to avoid short circuits of a plurality of coupled inductors according to one embodiment of the present invention.
[0034] FIG. **18** shows a view of the side filleting of two adjacent coupled inductors according to one embodiment of the present invention.
[0035] FIG. **19**A shows a view of a coupled inductor according to one embodiment of the present invention.
[0036] FIG. **19**B shows a view of a coupled inductor according to one embodiment of the present invention.

DETAILED DESCRIPTION

[0037] FIG. **1** shows a view of a coupled inductor according to one embodiment of the present invention. FIG. **2** shows a view of a coupled inductor according to one embodiment of the present invention. As shown in FIG. **1** and FIG. **2**, the present invention discloses a coupled inductor. The coupled inductor includes a first conductive body **130**, a second conductive body **160**, a molding body **102**. The first conductive body **130** includes a first lateral portion **130***a*, a first top portion **130***b*, and a second lateral portion **130***c*, wherein the first conductive body **130** extends from the first lateral portion **130***a* to the second lateral portion **130***c* via the first top portion **130***b*, and the first conductive body **130** further includes a first terminal portion **130***d* that is bent from the first lateral portion **130***a* and extends in a direction away from the second lateral portion **130***c* and a second terminal portion **130***e* that is bent from the second lateral portion **130***c* and extends in a direction away from the first lateral portion **130***a*.
[0038] A second conductive body **160** includes a third lateral portion **160***a*, a second top portion **160***b*, and a fourth lateral portion **160***c*. The second conductive body **160** extends from the third lateral portion **160***a* to the fourth lateral portion **160***c* via the second top portion **160***b*. The second conductive body **160** further includes a third terminal portion **160***d* that is bent from the third lateral portion **160***a* and extends in a direction towards the fourth lateral portion **160***c* and a fourth terminal portion **160***e* that is bent from the fourth lateral portion **160***c* and extends in a direction towards the third lateral portion **160***a*.
[0039] The molding body **102** encapsulates the first lateral portion **130***a*, the first top portion **130***b*, and the second lateral portion **130***c* of the first conductive body **130**.
[0040] In one embodiment, as shown in FIG. **1**, on a horizontal plane HP passing through the first lateral portion **130***a* and the third lateral portion **160***a*, a cross sectional area **130**TA of the first lateral portion **130***a* cutting through a horizontal plane HP is larger than a cross sectional area **160**TA of the third lateral portion **160***a* cutting through the horizontal plane.
[0041] In one embodiment, as shown in FIG. **1**, the width of the first conductive body **130** is equal to the width of the second conductive body **160**.
[0042] In one embodiment, as shown in FIG. **2**, a magnetic core **190** is disposed in a hollow space of the second conductive body **160**. In one embodiment, the molding body **102** encapsulates the first conductive body **130**, the second conductive body **160** and the magnetic core **190**.
[0043] In one embodiment, as shown in FIG. **2**, the first conductive body **130** is fully encapsulated by a first insulating layer **130***k*, and the second conductive body **160** is fully encapsulated by a second insulating layer **160***k*. The first insulating layer **130***k* is attached to the second insulating layer **160***k* by an adhesive material **180**.
[0044] FIG. **3** shows a view of a coupled inductor according to one embodiment of the present invention. In one embodiment, as shown in FIG. **3**, a bottom surface of the first terminal portion **130***d* is not covered by the first insulating layer **130***k* to expose a first inner metal portion **130**M**1** for forming a first electrode of the first conductive body **130**.
[0045] In one embodiment, as shown in FIG. **3**, a bottom surface of the second terminal portion **130***e* is not covered by the first insulating layer **130***k* to expose a second inner metal portion **130**M**2** for forming a second electrode of the first conductive body **130**.

[0046] In one embodiment, as shown in FIG. **3**, a bottom surface of the third terminal portion **160***d* is not covered by the second insulating layer **160***k* to expose a third inner metal portion **160**M**1** for forming a third electrode of the second conductive body **160**.
[0047] In one embodiment, as shown in FIG. **3**, a bottom surface of the fourth terminal portion **160***e* is not covered by the second insulating layer **160***k* to expose a fourth inner metal portion **160**M**2** for forming a fourth electrode of the second conductive body **160**.
[0048] In one embodiment, the curvature radius of the inner surface of a first bending portion of the first conductive body **130** is greater than or equal to the curvature radius of the outer surface of a first bending portion of the second conductive body **160**. The first bending portion of the first conductive body **130** is between the first terminal portion **130***d* and the first lateral portion **130***a*. The first bending portion of the second conductive body **160** is between the third terminal portion **160***d* and the third lateral portion **160***a*.
[0049] In one embodiment, the curvature radius of the inner surface of the second bending portion of the first conductive body **130** is greater than or equal to the curvature radius of the outer surface of the second bending portion of the second conductive body **160**. The second bending portion of the first conductive body **130** is between the first top portion **130***b* and the first lateral portion **130***a*. The second bending portion of the second conductive body **160** is between the second top portion **160***b* and the third lateral portion **160***a*.
[0050] FIG. **4** shows a view of a coupled inductor according to one embodiment of the present invention. In one embodiment, as shown in FIG. **4**, the length L**1** of the fourth terminal portion **160***e* of the second conductive body **160** is greater or equal to the length L**2** of the second terminal portion **130***e* of the first conductive body **130**. In one embodiment, the length of the third terminal portion **160***d* of the second conductive body **160** is greater or equal to the length of the first terminal portion **130***d* of the first conductive body **130**. The length L**1** is greater or equal to the length L**2**, increasing the pressure resistance of the first conductive body **130** and the second conductive body **160**.
[0051] FIG. **5** shows a view of an electrode structure of a coupled inductor according to one embodiment of the present invention. As shown in FIG. **5**, the present invention discloses the coupled inductor. A fourth electrode structure **160**E**1** is disposed on the fourth inner metal portion **160**M**2** and electrically connected to the second conductive body **160**. A fourth top portion **160**E**1**T**1** of the fourth electrode structure **160**E**1** is located on a first lateral side of the fourth inner metal portion **160**M**2**. The fourth top portion **160**E**1**T**1** of the fourth electrode structure **160**E**1** is attached to an insulating layer **027** of the molding body **102** through a silver-glue layer **028**. In one embodiment, the fourth electrode structure **160**E**1** includes three metal layers Cu, Ni, Sn with Cu layer at the bottom and Sn layer at the top. In one embodiment, three metal layers Cu, Ni, Sn are formed by electroplating. In one embodiment, the fourth top portion **160**E**1**T**1** of the fourth electrode structure **160**E**1** is attached to the second insulating layer **160***k* of the second conductive body **160** and the insulating layer **027** of the molding body **102** through the silver-glue layer **028**.
[0052] In the same way, a third electrode structure is disposed on the third inner metal portion **160**M**1** and electrically connected to the second conductive body **160**. A third top portion of the third electrode structure is located on a first lateral side of the third inner metal portion **160**M**1**. The third top portion of the third electrode structure is attached to an insulating layer **027** of the molding body **102** through a silver-glue layer **028**. In one embodiment, the third electrode structure includes three metal layers Cu, Ni, Sn with Cu layer at the bottom and Sn layer at the top. In one embodiment, three metal layers Cu, Ni, Sn are formed by electroplating. In one embodiment, the third top portion of the third electrode structure is attached to the second insulating layer **160***k* of the second conductive body **160** and the insulating layer **027** of the molding body **102** through the silver-glue layer **028**.
[0053] In the same way, a first electrode structure is disposed on the first inner metal portion **130**M**1** and electrically connected to the first conductive body **130**. A first top portion of the first

electrode structure is located on a first lateral side of the first inner metal portion **130**M**1**. The first top portion of the first electrode structure is attached to an insulating layer **027** of the molding body **102** through a silver-glue layer **028**. In one embodiment, the first electrode structure includes three metal layers Cu, Ni, Sn with Cu layer at the bottom and Sn layer at the top. In one embodiment, three metal layers Cu, Ni, Sn are formed by electroplating. In one embodiment, the first top portion of the first electrode structure is attached to the first insulating layer **130***k* of the first conductive body **130** and the insulating layer **027** of the molding body **102** through the silver-glue layer **028**.

[0054] In the same way, a second electrode structure is disposed on the second inner metal portion **130**M**2** and electrically connected to the first conductive body **130**. A second top portion of the second electrode structure is located on a first lateral side of the second inner metal portion **130**M**2**. The second top portion of the second electrode structure is attached to an insulating layer **027** of the molding body **102** through a silver-glue layer **028**. In one embodiment, the second electrode structure includes three metal layers Cu, Ni, Sn with Cu layer at the bottom and Sn layer at the top. In one embodiment, three metal layers Cu, Ni, Sn are formed by electroplating. In one embodiment, the second top portion of the second electrode structure is attached to the first insulating layer **130***k* of the first conductive body **130** and the insulating layer **027** of the molding body **102** through the silver-glue layer **028**.

[0055] FIG. **6** shows a view of an electrode structure of a coupled inductor according to one embodiment of the present invention. Another insulating layer **029** is disposed under the insulating layer **027** between an inner surface of the first bending portion of the first conductive body **130** and an outer surface of the first bending portion of the second conductive body **160**. In one embodiment, at least one material is filled in a first space **100** between an inner surface of a first bending portion of the first conductive body **130** and an outer surface of a first bending portion of the second conductive body **160**.

[0056] FIG. **7**A shows a view of a first space **100** of a coupled inductor according to one embodiment of the present invention. At least one material **100**A, **100**B, and **100**C is filled in the first space **100** between the inner surface **103**B of a first bending portion of the first conductive body **130** and the outer surface **103**A of a first bending portion of the second conductive body **160**. The first space **100** may be surrounded by the inner surface **103**B of the first bending portion of the first conductive body **130**, the outer surface **103**A of the first bending portion of the second conductive body **160**, and a bottom surface **102**A of the molding body **102**. The first space **100** may be filled with a plurality of materials **100**A, **100**B, and **100**C, but the embodiment is not limited thereto. The depth and the composition of the materials can be modified to control the leakage inductance of the coupled inductor of the embodiment. In an embodiment, the plurality of materials **100**A, **100**B, and **100**C include different compositions. In one embodiment, the materials **100**A, **100**B, and **100**C may comprise members selected from a group comprising polymer, oxide, ceramic material and magnetic material. In an embodiment, the magnetic permeability (μ) of the material **100**A, **100**B, and **100**C may be 1.0-60.0 and may be smaller than the magnetic permeability (μ) of the molding body.

[0057] FIG. **7**B shows a view of the coupled inductor in FIG. **7**A. In one embodiment, the width W**100** of the first space **100** is greater than or equal to the width W**130** of the first conductive body **130**. In one embodiment, the width W**100** of the first space **100** is greater than or equal to the width W**160** of the second conductive body **160**. In one embodiment, the width W**130** of the first conductive body **130** may be equal to the width W**160** of the second conductive body **160**.

[0058] FIG. **7**C shows a view of the first space **100** of a coupled inductor according to one embodiment of the present invention. At least one material **100**A and **100**B is filled in the first space **100** between the inner surface **103**B of a first bending portion of the first conductive body **130** and the outer surface **103**A of a first bending portion of the second conductive body **160**. The first space **100** may be surrounded by the inner surface **103**B of the first bending portion of the first conductive body **130**, the outer surface **103**A of the first bending portion of the second conductive

body **160**, and a bottom surface **102**A of the molding body **102**. The first space **100** may be filled with a plurality of materials **100**A and **100**B, but the embodiment is not limited thereto. The depth and the composition of the materials can be modified to control the leakage inductance of the coupled inductor of the embodiment. In one embodiment, the materials **100**A and **100**B may comprise members selected from a group comprising polymer, oxide, ceramic material and magnetic material.

[0059] FIG. **7**D shows a view of the first space **100** of a coupled inductor according to one embodiment of the present invention. At least one material **100**A and **100**B is filled in the first space **100** between the inner surface **103**B of a first bending portion of the first conductive body **130** and the outer surface **103**A of a first bending portion of the second conductive body **160**. The first space **100** may be surrounded by the inner surface **103**B of the first bending portion of the first conductive body **130**, the outer surface **103**A of the first bending portion of the second conductive body **160**, and a bottom surface **102**A of the molding body **102**. The first space **100** may be filled with a plurality of materials **100**A and **100**B, but the embodiment is not limited thereto. The depth and the composition of the materials can be modified to control the leakage inductance of the coupled inductor of the embodiment. In one embodiment, the materials **100**A and **100**B may comprise members selected from a group comprising polymer, oxide, ceramic material and magnetic material.

[0060] FIG. **8** shows a view of a cuboid **120** of a coupled inductor according to one embodiment of the present invention. In one embodiment, the cuboid **120** is disposed between the first top portion **130***b* and the second top portion **160***b*. In one embodiment, the width W**120** of the cuboid **120** is less than or equal to the width W**160** of the second conductive body **160**. In one embodiment, the width W**120** of the cuboid **120** is less than or equal to the width W**130** of the first conductive body **130**. The cuboid **120** can be attached to the first insulating layer **130***k* by an adhesive material and attached to the second insulating layer **160***k* by the adhesive material. The depth D**120** and material of the cuboid **120** may be modified to control the leakage inductance of the coupled inductor. In one embodiment, the material of the cuboid **120** may be a polymer, an oxide, a ceramic material or a magnetic material.

[0061] FIG. **9** shows a view of the side surfaces of terminal portions of a second conductive body of a coupled inductor according to one embodiment of the present invention. FIG. **10** shows a view of the side surfaces of terminal portions of a second conductive body of a coupled inductor according to one embodiment of the present invention. In one embodiment, as shown in FIG. **9** and FIG. **10**, the first terminal side portion **174**A inside the second conductive body **160** and the second terminal side portion **175**A inside the second conductive body **160** are coated with an insulating material. The insulating material may be a polymer material, an oxide, a ceramic material or a magnetic material. The insulating material helps to insulate the second conductive body **160** from the molding body **102**.

[0062] FIG. **11**A shows a coupled inductor according to another embodiment of the present invention. FIG. **11**B is a U-shape leakage inductance control device **122** for controlling the leakage inductance of the coupled inductor in FIG. **11**A. As shown in FIG. **11**A, the U-shape leakage inductance control device **122** for controlling leakage inductance is placed inside the molding body **102**, where the U-shape leakage inductance control device **122** is between the first conductive body **130** and the second conductive body **160**. In one embodiment, the width W**122** of the U-shape leakage inductance control device **122** is less than or equal to the width W**130** of the first conductive body **130**. In one embodiment, the width W**122** of the U-shape leakage inductance control device **122** is less than or equal to the width W**160** of the second conductive body **160**. Leakage inductance, transient inductance and/or coupling coefficient between the first conductive body **130** and the second conductive body **160** may be adjusted through modifying the thickness T**122** and material of the U-shape leakage inductance control device **122**. The U-shape leakage inductance control device **122** may be made from polymer materials, oxides, ceramics, magnetic

materials or insulating materials. In an embodiment, the magnetic permeability (μ) of the U-shape leakage inductance control device **122** may be 1.0-60.0, and the thickness T**122** of the U-shape leakage inductance control device **122** may be 0.05-1.0 mm.

[0063] FIG. **12** shows a view of a coupled inductor according to one embodiment of the present invention. As shown in FIG. **12**, the width W**160** of the second conductive body **160** is less than the width W**130** of the first conductive body **130**. In one embodiment, the width W**100** of the first space **100** is equal to the width W**160** of the second conductive body **160**. Therefore, the leakage inductance or coupling coefficient can be finely adjusted by modifying the width W**123** of the non-overlapping area between the first conductive body **130** and the second conductive body **160**.

[0064] FIG. **13** shows that the magnetic core **190** and the molding body **102** of a coupled inductor are made of the same material according to one embodiment of the present invention. FIG. **14** shows that the magnetic core **190** and the molding body **102** of a coupled inductor are made of the different materials according to one embodiment of the present invention. As shown in FIG. **13**, the magnetic core **190** and molding body **102** are made by the same material, wherein the material can be amorphous powder, nanocrystalline powder, carbonyl iron powder, alloy powder, Hi-Flux, Sendust, MPP or Ferrite. The composition can be C, Si, Cr, Fe, B, Co, Nb (Niobium) or Ni. The magnetic core **190** and molding body **102** are formed by pressure molding at room temperature. As shown in FIG. **14**, the magnetic core **190** and the molding body **102** are made by the different material. There is an insulating adhesive layer all around for assembly and adhesion of the first conductive body **130** and the second conductive body **160**. The material of the magnetic core **190** can be amorphous powder, nanocrystalline powder, carbonyl iron powder, alloy powder, Hi-Flux, Sendust, MPP or Ferrite. The composition can be C, Si, Cr, Fe, B, Co, Nb (niobium) or Ni. The magnetic core **190** is usually formed by pressing the mold at normal temperature and then sintering it at high temperature. The molding body **102** can be amorphous powder, nanocrystalline powder, carbonyl iron powder, alloy powder, Hi-Flux, Sendust, MPP or Ferrite. The composition can be C, Si, Cr, Fe, B, Co, Nb (niobium) or Ni. It is formed by pressure molding at room temperature.

[0065] FIG. **15**A shows that a plurality of coupled inductors are packed in a single package according to one embodiment of the present invention. The plurality of coupled inductors can be arranged in a row, in a column, or in a matrix as shown in FIG. **15**A. However, if the gaps of the coupled inductors are too small, short circuits of the first conductive body **130** or the second conductive body **160** may occur. Therefore, a design for the electrodes is desired.

[0066] FIG. **15**B shows that a plurality of coupled inductors are packed in a single package according to one embodiment of the present invention. The plurality of coupled inductors can be arranged in a row, in a column, or in a matrix as shown in FIG. **15**A. When the plurality of coupled inductors are connected in series, the current can flow through the third electrode, the third lateral portion **160***a*, the second top portion **160***b*, the fourth lateral portion **160***c*, and the fourth electrode. Then, after the fourth electrode of the coupled inductor and the third electrode of the adjacent coupled inductor are welded together, the current may flow from the fourth electrode of the coupled inductor to the third electrode of the adjacent coupled inductor, and thus the plurality of coupled inductors are series connected as shown in FIG. **15**B.

[0067] FIG. **16** shows a design to avoid short circuits of a plurality of coupled inductors according to one embodiment of the present invention. In one embodiment, a bottom surface of the first terminal portion **130***d* and the second terminal portion **130***e* is not covered by the first insulating layer **130***k* to expose a first inner metal portion **130**M**1** and a second inner metal portion **130**M**2** for forming first and second electrodes **01**A of the first conductive body **130**. In one embodiment, a bottom surface of the third terminal portion **160***d* and the fourth terminal portion **160***e* is not covered by the second insulating layer **160***k* to expose a third inner metal portion **160**M**1** and a fourth inner metal portion **160**M**2** for forming third and fourth electrodes **02**A of the second conductive body **160**. A short circuit between two third electrodes **02**A or two fourth electrodes **02**A may occur if the gap between two adjacent coupled inductors is too small. To prevent this, the

widths W**130** of the third and fourth electrodes **02**A are reduced to new widths W**02**A, creating non-overlapping areas **02**B**4** and avoiding short circuits among the plurality of coupled inductors. In an embodiment, the third electrode includes a third rectangular portion and the fourth electrode includes a fourth rectangular portion. A first gap **02**B**4** is formed between a lower edge of the third rectangular portion and a lower edge of the molding body **102**, and a second gap **02**B**4** is formed between an upper edge of the fourth rectangular portion and an upper edge of the molding body **102**.

[0068] FIG. **17** shows a design to avoid short circuits of a plurality of coupled inductors according to one embodiment of the present invention. In one embodiment, a bottom surface of the first terminal portion **130***d* and the second terminal portion **130***e* is not covered by the first insulating layer **130***k* to expose a first inner metal portion **130**M**1** and a second inner metal portion **130**M**2** for forming first and second electrodes **03**A of the first conductive body **130**. In one embodiment, a bottom surface of the third terminal portion **160***d* and the fourth terminal portion **160***e* is not covered by the second insulating layer **160***k* to expose a third inner metal portion **160**M**1** and a fourth inner metal portion **160**M**2** for forming third and fourth electrodes **04**A of the second conductive body **160**. A short circuit between two third electrodes **04**A or two fourth electrodes **04**A may occur if the gap between two adjacent coupled inductors is too small. To prevent this, the widths W**130** of the third and fourth electrodes **04**A are reduced to new widths **02**B**1**, creating non-overlapping areas **02**B**4** and avoiding short circuits among the plurality of coupled inductors. In one embodiment, the shape of the third and fourth electrodes **04**A are L-type, combined by a first rectangle with length **02**B**1** and width **02**B**2** and a second rectangle with length **02**B**2-1** and width **02**B**1-1**. The L-type electrodes avoid short circuits and make the layout of the plurality of coupled inductors more efficient in constant area. Due to the L-type electrodes, the third electrode of the coupled inductance can be welded with the fourth electrode of the adjacent coupled inductor easily. Therefore, the current may flow through the third electrode, the third lateral portion **160***a*, the second top portion **160***b*, the fourth lateral portion **160***c*, and the fourth electrode. Then, the current flow from the fourth electrode of the coupled inductor to the third electrode of the adjacent coupled inductor, and thus the plurality of coupled inductors using L-type electrodes are series connected as shown in FIG. **15**B.

[0069] In an embodiment, the lengths of the first and second electrodes **03**A of the first conductive body **130** are larger than the width of the first conductive body **130**. The lengths of the third and fourth electrodes **04**A of the second conductive body **160** are larger than the width of the second conductive body **160**. In an embodiment, the lengths of the first and second electrodes **03**A of the first conductive body **130** are smaller than the width W**130** of the molding body **102**, and the lengths **02**B**1** of the third and fourth electrodes **04**A of the second conductive body **160** are smaller than the width W**130** of the molding body **102**. In an embodiment, the lengths of the first and second electrodes **03**A of the first conductive body **130** are larger than the lengths **02**B**1** of the third and fourth electrodes **04**A of the second conductive body **160**. The third and fourth electrodes **04**A of the second conductive body **160** cover partially or completely the bottom surface of the second conductive body **160**. The third and fourth electrodes **04**A of the second conductive body **160** may include bottom groove of the molding body **102**.

[0070] In an embodiment, the curvature angle of a first side of the bottom surface of the molding body **102** is larger than or equal to the curvature angle of the first terminal portion **130***d* of the first conductive body **130**. In an embodiment, the curvature angle of a second side of the bottom surface of the molding body **102** is larger than or equal to the curvature angle of the second terminal portion **130***e* of the first conductive body **130**. In an embodiment, the bottom curvature angle of the first terminal portion **130***d* of the first conductive body **130** is larger than or equal to the top curvature angle of the first terminal portion **130***d* of the first conductive body **130**. The bottom curvature angle of the second terminal portion **130***e* of the first conductive body **130** is larger than or equal to the top curvature angle of the second terminal portion **130***e* of the first conductive body

130. In an embodiment, the curvature angles of the first side and the second side of the bottom surface of the molding body **102** are larger than or equal to 0.3. The bottom curvature angles of the first terminal portion **130***d* and the second terminal portion **130***e* of the first conductive body **130** are larger than the width W**130** of the first conductive body **130**, thus effectively saving the spacing between two adjacent coupled inductors in a layout.

[0071] FIG. **18** shows a view of the side filleting of two adjacent coupled inductors according to one embodiment of the present invention. A bottom surface of the first terminal portion **130***d* is not covered by the first insulating layer **130***k* to expose a first inner metal portion **130**M**1** for forming a first electrode of the first conductive body **130**. In one embodiment, a bottom surface of the second terminal portion **130***e* is not covered by the first insulating layer **130***k* to expose a second inner metal portion **130**M**2** for forming a second electrode of the first conductive body **130**. Side filleting occurs between the first electrode of the first conductive body **130** of a coupled inductor and the second electrode of the first conductive body **130** of the adjacent coupled inductor. A curved portion of the first electrode spans less than 70 degrees of a curvature angle R**1** of the first terminal portion **130***d*. The curvature angle R**1** in the first electrode of the first conductive body **130** of a coupled inductor is set to 70 degree to reduce side filleting and to efficiently use the PCB (printed circuit board) landpattern. The coupled inductor and the adjacent coupled inductor should not be short circuited through the first electrode of the coupled inductor and the second electrode of the adjacent coupled inductor. Therefore, the limited curvature angle R**1** make the weld side filleting short to not beyond the boundary of the coupled inductor and the adjacent coupled inductor.

[0072] FIG. **19**A shows a view of a coupled inductor according to one embodiment of the present invention. In one embodiment, the first conductive body **130** and second conductive body **160** are overlapped through a leakage inductance control device **120**A for controlling leakage inductance, and the leakage inductance control device **120**A is disposed between the first conductive body and the second conductive body. In one embodiment, the shape of the leakage inductance control device **120**A is the same as the second conductive body **160** with different width.

[0073] FIG. **19**B shows a view of a coupled inductor according to one embodiment of the present invention. In one embodiment, a bottom surface of the first terminal portion **130***d* is not covered by the first insulating layer **130***k* to expose a first inner metal portion **130**M**1** for forming a first electrode **01**A of the first conductive body **130**. In one embodiment, a bottom surface of the second terminal portion **130***e* is not covered by the first insulating layer **130***k* to expose a second inner metal portion **130**M**2** for forming a second electrode **01**A of the first conductive body **130**. In one embodiment, a bottom surface of the third terminal portion **160***d* is not covered by the second insulating layer **160***k* to expose a third inner metal portion **160**M**1** for forming a third electrode **02**A of the second conductive body **160**. In one embodiment, a bottom surface of the fourth terminal portion **160***e* is not covered by the second insulating layer **160***k* to expose a fourth inner metal portion **160**M**2** for forming a fourth electrode **02**A of the second conductive body **160**.

[0074] In one embodiment, the curvature radius of the inner surface of a first bending portion of the first conductive body **130** is greater than or equal to the curvature radius of the outer surface of a first bending portion of the second conductive body **160**. The first bending portion of the first conductive body **130** is between the first terminal portion **130***d* and the first lateral portion **130***a*. The first bending portion of the second conductive body **160** is between the third terminal portion **160***d* and the third lateral portion **160***a*.

[0075] In one embodiment, the curvature radius of the inner surface of the second bending portion of the first conductive body **130** is greater than or equal to the curvature radius of the outer surface of the second bending portion of the second conductive body **160**. The second bending portion of the first conductive body **130** is between the first top portion **130***b* and the first lateral portion **130***a*. The second bending portion of the second conductive body **160** is between the second top portion **160***b* and the third lateral portion **160***a*.

[0076] In summary, the leakage inductance of the coupled inductor can be finely controlled by

using the coupled inductors in FIG. **7**A, FIG. **7**B, FIG. **7**C, FIG. **7**D, FIG. **8**, FIG. **11**A, FIG. **11**B, FIG. **12**, FIG. **19**A and/or FIG. **19**B. Moreover, the widths W**130** of the third and fourth electrodes **02**A are reduced to new widths W**02**A or **02**B**1**, creating non-overlapping areas **02**B**4** and preventing short circuits among the plurality of coupled inductors.

[0077] Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

1. A coupled inductor, comprising: a first conductive body, comprising a first lateral portion, a first top portion, and a second lateral portion, wherein the first conductive body extends from the first lateral portion to the second lateral portion via the first top portion, wherein the first conductive body further comprises a first terminal portion that is bent from the first lateral portion and extends in a direction away from the second lateral portion and a second terminal portion that is bent from the second lateral portion and extends in a direction away from the first lateral portion; a second conductive body, comprising a third lateral portion, a second top portion, and a fourth lateral portion, wherein the second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion, wherein the second conductive body further comprises a third terminal portion that is bent from the third lateral portion and extends in a direction towards the fourth lateral portion and a fourth terminal portion that is bent from the fourth lateral portion and extends in a direction towards the third lateral portion; and a molding body, encapsulating the first lateral portion, the first top portion, and the second lateral portion of the first conductive body; wherein at least one material is filled in a first space between an inner surface of a first bending portion of the first conductive body and an outer surface of a first bending portion of the second conductive body.

2. The coupled inductor according to claim 1, wherein a magnetic core is disposed in a hollow space of the second conductive body.

3. The coupled inductor according to claim 2, wherein the molding body encapsulates the first conductive body, the second conductive body and the magnetic core.

4. The coupled inductor according to claim 1, wherein the at least one material comprises a magnetic material.

5. The coupled inductor according to claim 1, wherein the at least one material is selected from a group consisting of a polymer, an oxide, a ceramic material, and a magnetic material.

6. The coupled inductor according to claim 1, wherein the first conductive body is fully encapsulated by a first insulating layer, and the second conductive body is fully encapsulated by a second insulating layer, wherein the first insulating layer is attached to the second insulating layer by an adhesive material.

7. The coupled inductor according to claim 1, wherein a cross sectional area of the first lateral portion cutting through a horizontal plane is larger than a cross sectional area of the third lateral portion cutting through the horizontal plane.

8. The coupled inductor according to claim 1, wherein a width of the first conductive body is equal to a width of the second conductive body.

9. The coupled inductor according to claim 1, wherein a curvature radius of the inner surface of the first bending portion of the first conductive body is greater than or equal to a curvature radius of the outer surface of the first bending portion of the second conductive body.

10. The coupled inductor according to claim 1, wherein a curvature radius of an inner surface of a second bending portion of the first conductive body is greater than or equal to a curvature radius of an outer surface of a second bending portion of the second conductive body.

11. The coupled inductor according to claim 1, wherein a length of the third terminal portion of the second conductive body is greater or equal to a length of the first terminal portion of the first conductive body.
12. The coupled inductor according to claim 1, wherein two materials are filled in the first space between the inner surface of the first bending portion of the first conductive body and the outer surface of the first bending portion of the second conductive body.
13. The coupled inductor according to claim 12, wherein the two materials are selected from a group consisting of a polymer, an oxide, a ceramic material, and a magnetic material.
14. The coupled inductor according to claim 1, wherein three materials are filled in the first space between the inner surface of the first bending portion of the first conductive body and the outer surface of the first bending portion of the second conductive body.
15. The coupled inductor according to claim 14, wherein the three materials are selected from a group consisting of a polymer, an oxide, a ceramic material, and a magnetic material.
16. A coupled inductor, comprising: a first conductive body, comprising a first lateral portion, a first top portion, and a second lateral portion, wherein the first conductive body extends from the first lateral portion to the second lateral portion via the first top portion, wherein the first conductive body further comprises a first terminal portion that is bent from the first lateral portion and extends in a direction away from the second lateral portion and a second terminal portion that is bent from the second lateral portion and extends in a direction away from the first lateral portion; a second conductive body, comprising a third lateral portion, a second top portion, and a fourth lateral portion, wherein the second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion, wherein the second conductive body further comprises a third terminal portion that is bent from the third lateral portion and extends in a direction towards the fourth lateral portion and a fourth terminal portion that is bent from the fourth lateral portion and extends in a direction towards the third lateral portion; and a molding body, encapsulating the first lateral portion, the first top portion, and the second lateral portion of the first conductive body; wherein a leakage inductance control device is disposed between the first conductive body and the second conductive body.
17. The coupled inductor according to claim 16, wherein the leakage inductance control device is a U-shape leakage inductance control device, the leakage inductance control device is located between the first top portion and the second top portion, and extends along a direction toward the first terminal portion.
18. A coupled inductor, comprising: a first conductive body, comprising a first lateral portion, a first top portion, and a second lateral portion, wherein the first conductive body extends from the first lateral portion to the second lateral portion via the first top portion, wherein the first conductive body further comprises a first terminal portion that is bent from the first lateral portion and extends in a direction away from the second lateral portion and a second terminal portion that is bent from the second lateral portion and extends in a direction away from the first lateral portion; a second conductive body, comprising a third lateral portion, a second top portion, and a fourth lateral portion, wherein the second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion, wherein the second conductive body further comprises a third terminal portion that is bent from the third lateral portion and extends in a direction towards the fourth lateral portion and a fourth terminal portion that is bent from the fourth lateral portion and extends in a direction towards the third lateral portion; and a molding body, encapsulating the first lateral portion, the first top portion, and the second lateral portion of the first conductive body; wherein a third electrode and a fourth electrode of the second conductive body are formed on the third terminal portion and the fourth terminal portion respectively; wherein the third electrode comprises a third rectangular portion and the fourth electrode comprises a fourth rectangular portion; wherein a first gap is formed between a lower edge of the third rectangular portion and a lower edge of the molding body, and a second gap is formed between an upper edge

of the fourth rectangular portion and an upper edge of the molding body.

19. The coupled inductor according to claim 18, wherein a third flank is extended from an upper side of the third rectangular portion towards the second gap, and a fourth flank is extended from a lower side of the fourth rectangular portion towards the first gap.

20. A coupled inductor, comprising: a first conductive body, comprising a first lateral portion, a first top portion, and a second lateral portion, wherein the first conductive body extends from the first lateral portion to the second lateral portion via the first top portion, wherein the first conductive body further comprises a first terminal portion that is bent from the first lateral portion and extends in a direction away from the second lateral portion and a second terminal portion that is bent from the second lateral portion and extends in a direction away from the first lateral portion; a second conductive body, comprising a third lateral portion, a second top portion, and a fourth lateral portion, wherein the second conductive body extends from the third lateral portion to the fourth lateral portion via the second top portion, wherein the second conductive body further comprises a third terminal portion that is bent from the third lateral portion and extends in a direction towards the fourth lateral portion and a fourth terminal portion that is bent from the fourth lateral portion and extends in a direction towards the third lateral portion; and a molding body, encapsulating the first lateral portion, the first top portion, and the second lateral portion of the first conductive body; wherein the first terminal portion comprises a curved portion, the curved portion comprise a curvature angle and is less than 70 degrees to vertical, wherein a first electrode of the first conductive body is formed on the first terminal portion along a surface of the curved portion based on the curvature angle.