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(54) **MECHANICALLY-COMPLIANT AND ELECTRICALLY AND THERMALLY CONDUCTIVE LEADFRAMES FOR COMPONENT-ON-PACKAGE CIRCUITS**

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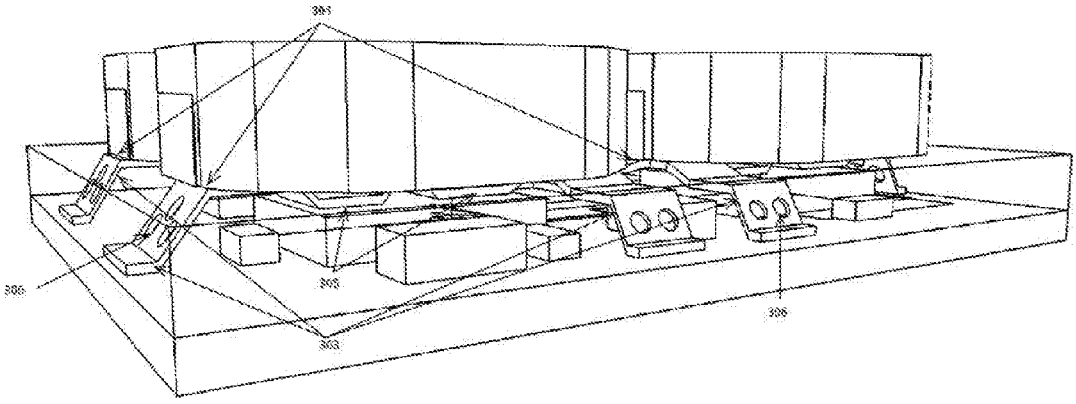
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(57) **ABSTRACT**

A component-on-package circuit may include a component for an electrical circuit and a circuit module attached to the component. The circuit module may have circuitry and at least one leadframe which connects the circuitry to the component both electrically and thermally. The leadframe may have a high degree of both electrical and thermal conductivity and a non-planar shape that provides spring-like cushioning of force applied to the component in the direction of the circuit module.

A method of making a component-on-package circuit may include attaching a component for an electrical circuit to a circuit module. The circuit module may have circuitry and at least one leadframe which connects the circuitry to the component after the attachment both electrically and thermally. The leadframe may have a high degree of both electrical and thermal conductivity and a non-planar shape that provides a spring-like cushioning of force applied to the component in the direction of the circuit module. The circuit module may be encapsulated in molding material after the circuit module has been attached to the component, without encapsulation the component at the same time.



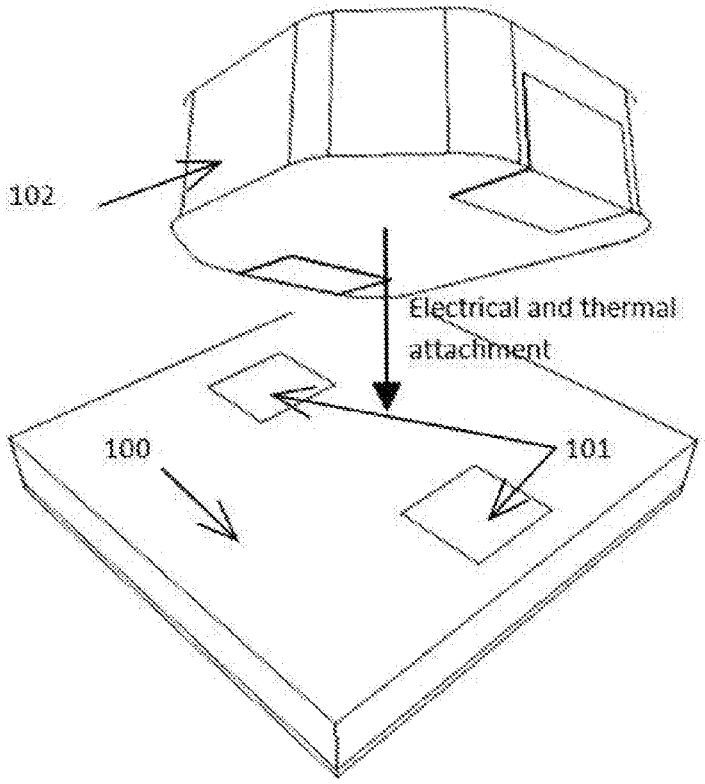


FIG. 1A

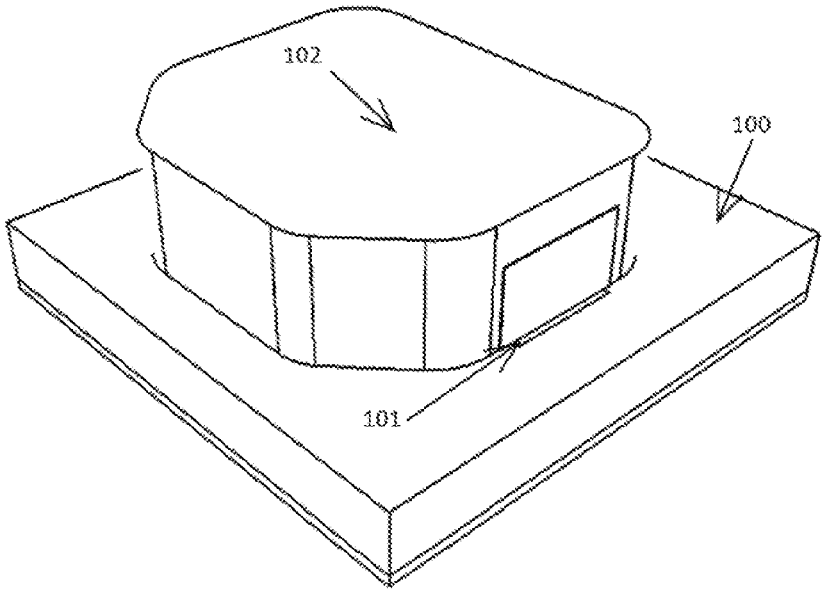


FIG. 1B

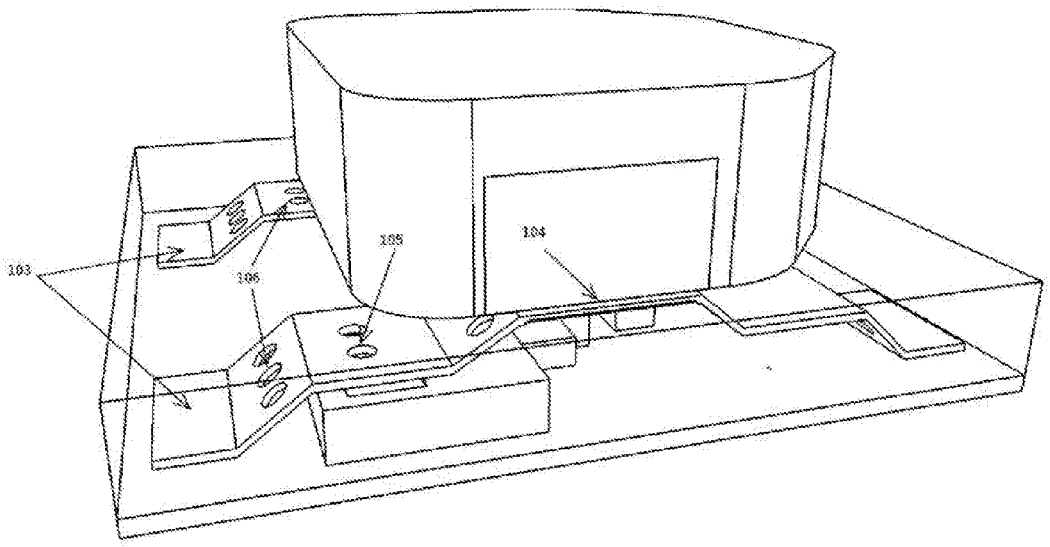
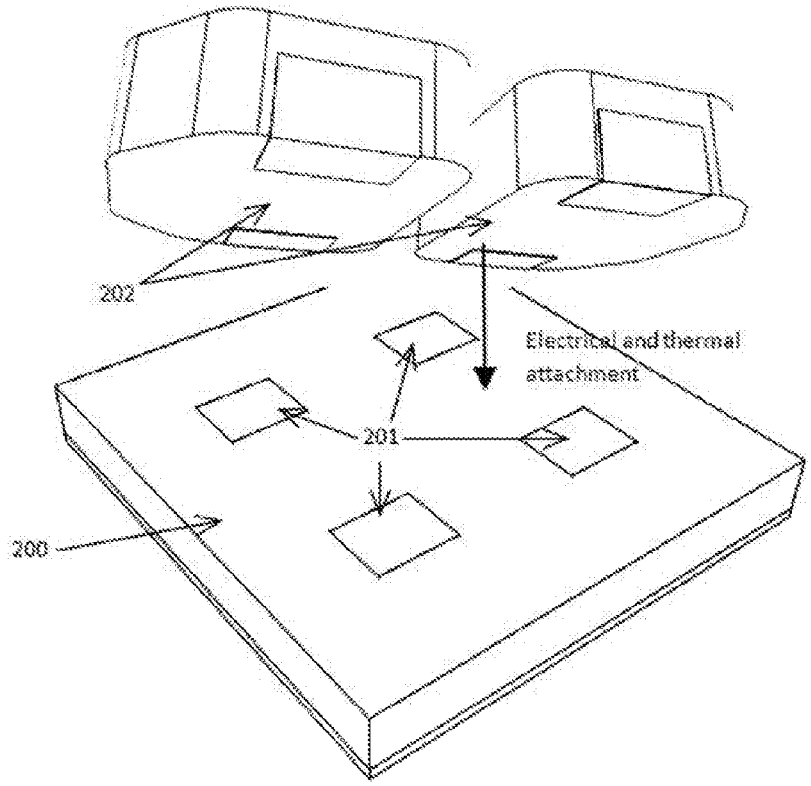


FIG. 2

FIG. 3A



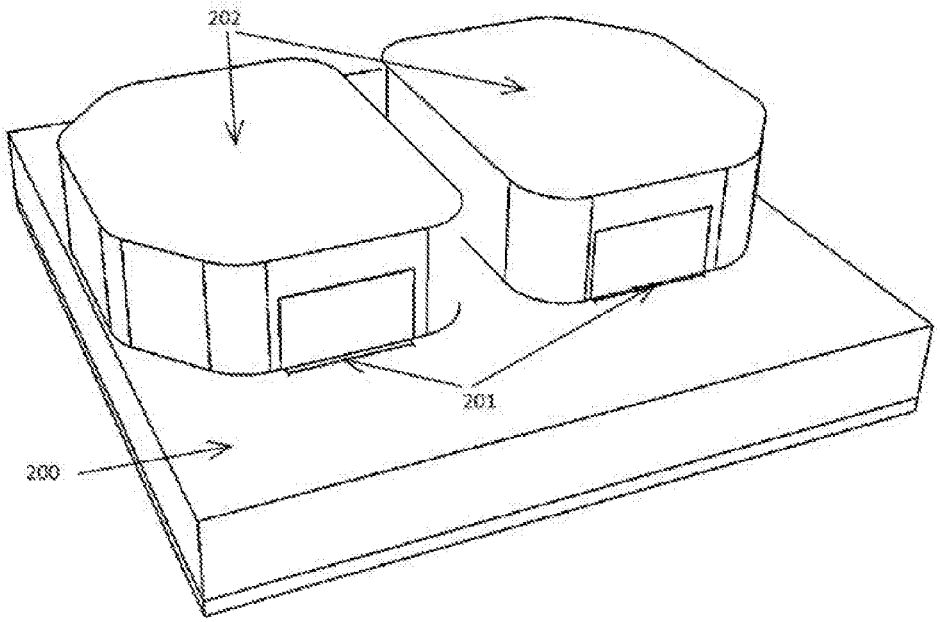


FIG. 3B

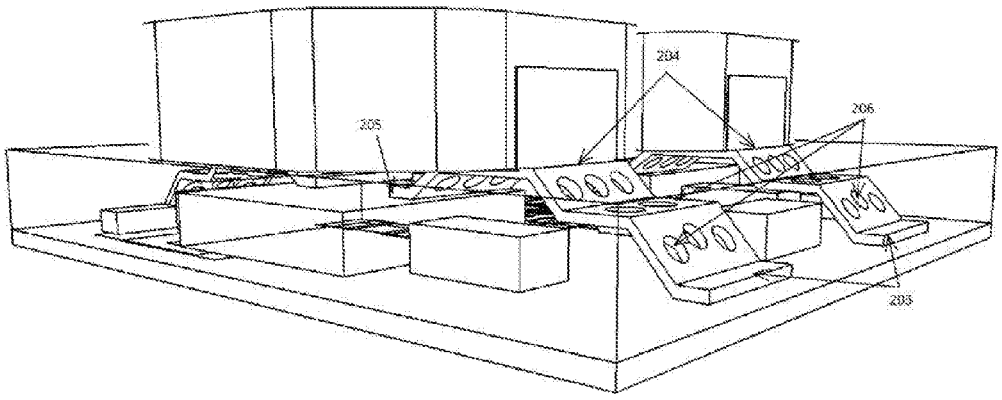


FIG. 4

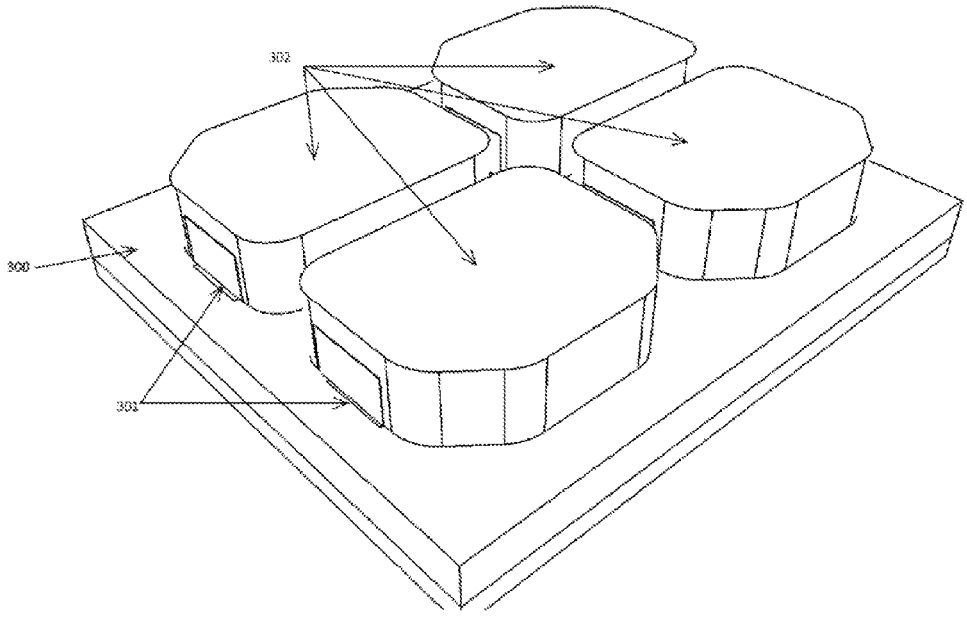


FIG. 5

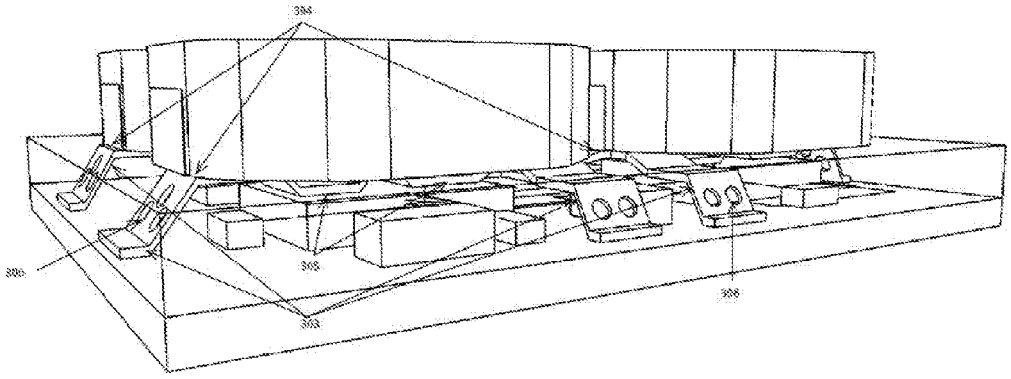


FIG. 6

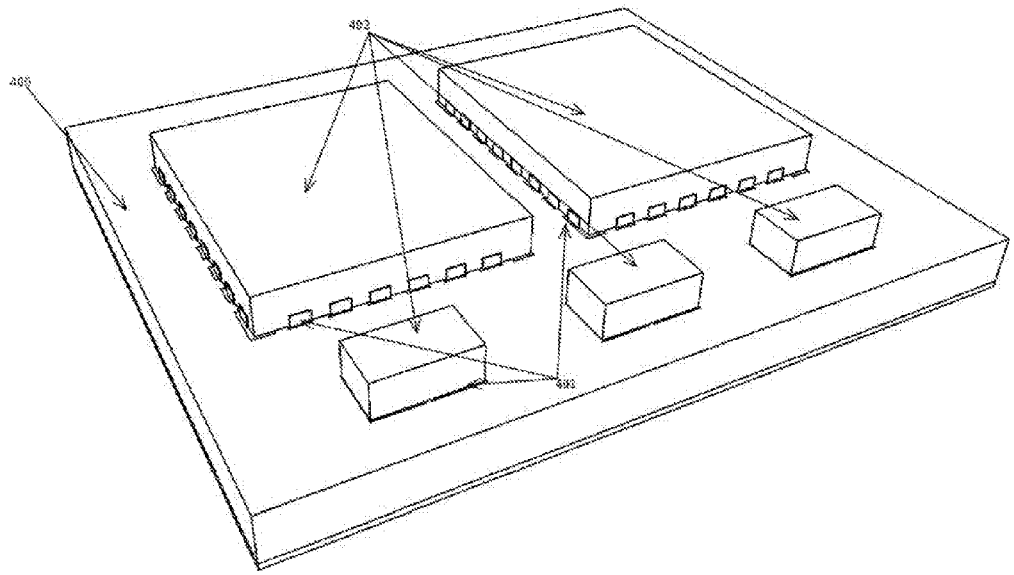


FIG. 7

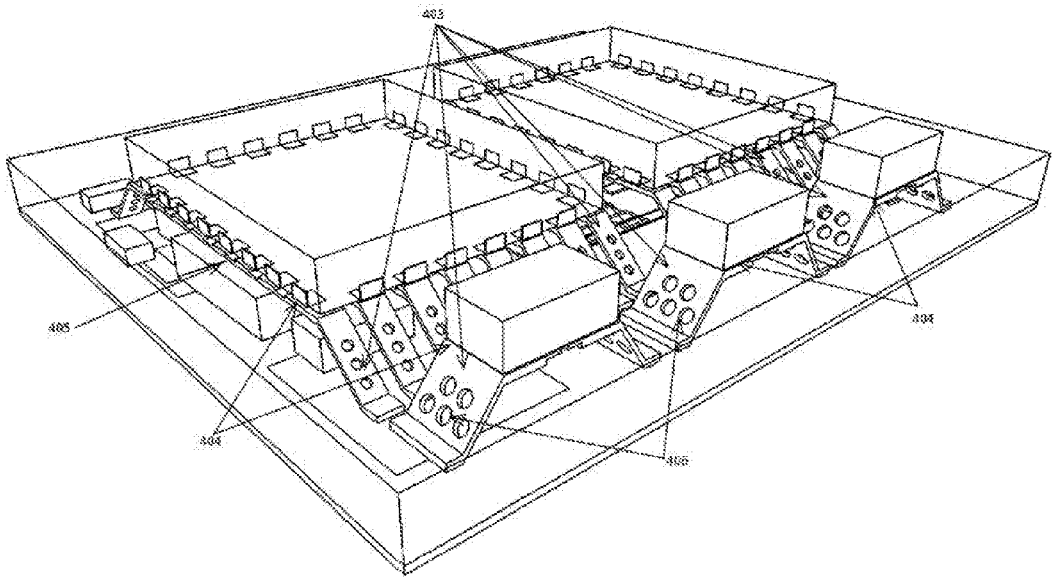


FIG. 8

MECHANICALLY-COMPLIANT AND ELECTRICALLY AND THERMALLY CONDUCTIVE LEADFRAMES FOR COMPONENT-ON-PACKAGE CIRCUITS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based upon and claims priority to U.S. provisional patent application 62/327,875, entitled "MECHANICALLY-COMPLIANT AND ELECTRICALLY AND THERMALLY CONDUCTIVE LEADFRAMES FOR COMPONENT-ON-PACKAGE CIRCUITS," filed Apr. 26, 2016, attorney docket number 081318-1003. The entire content of this application is incorporated herein by reference.

BACKGROUND

Technical Field

[0002] This disclosure relates to high power density systems-in-packages (SIPs) or modules, packages that require low impedance, and packages with high thermal performance requirements. This disclosure also relates to module packages with high power/high current applications that require large externally mounted components and/or improved heat dissipation.

Description of Related Art

[0003] The desire for SIPs to have increased power and current capabilities, while at the same time minimizing their footprint within a system board design, can present a multitude of design constraints and limitations on the designer and module package engineer.

[0004] Higher power components may require a large amount of board space and may have a large thermal mass. Large inductors, for example, can be integrated into an SIP, but size limitations of the molded package may prevent the use of larger and more power-capable components. Due to their size, these large components may not be able to be enclosed within the SIP. They may also require attachments on the system board as near to the SIP as possible to minimize loss or noise in the circuit. For this reason, a package design and assembly methodology may need to integrate larger high power external active and passive components with the molded SIP, while maintaining minimal impact to real estate on the board.

[0005] Additionally, higher power packages and components may dissipate larger amounts of heat into their surroundings, primarily into the system board, distributing heat into adjacent packages and components. This may affect overall system efficiency and reliability. These high power packages may require high current pathways that may exceed the heat and current carrying capacity of package substrates and system boards, without the use of additional metal layers, solid metal vias, and costly heat sink apparatus. For this additional demand on the high power module package, a technology may be needed that provides a highly conductive thermal and electrical pathway within the SIP package body that is not dependent upon limitations of substrate and system board architectures.

SUMMARY

[0006] A component-on-package circuit may include a component for an electrical circuit and a circuit module attached to the component. The circuit module may have circuitry and at least one leadframe which connects the circuitry to the component both electrically and thermally. The leadframe may have a high degree of both electrical and thermal conductivity and a non-planar shape that provides spring-like cushioning of force applied to the component in the direction of the circuit module.

[0007] A method of making a component-on-package circuit may include attaching a component for an electrical circuit to a circuit module. The circuit module may have circuitry and at least one leadframe which connects the circuitry to the component after the attachment both electrically and thermally. The leadframe may have a high degree of both electrical and thermal conductivity and a non-planar shape that provides a spring-like cushioning of force applied to the component in the direction of the circuit module. The circuit module may be encapsulated in molding material after the circuit module has been attached to the component, without encapsulation the component at the same time.

[0008] These, as well as other components, steps, features, objects, benefits, and advantages, will now become clear from a review of the following detailed description of illustrative embodiments, the accompanying drawings, and the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0009] The drawings are of illustrative embodiments. They do not illustrate all embodiments. Other embodiments may be used in addition or instead. Details that may be apparent or unnecessary may be omitted to save space or for more effective illustration. Some embodiments may be practiced with additional components or steps and/or without all of the components or steps that are illustrated. When the same numeral appears in different drawings, it refers to the same or like components or steps.

[0010] FIGS. **1**A and **1**B illustrate an external view of an example of a partially assembled (FIG. **1**A) and fully assembled (FIG. **1**B) components-on-package (CoP) device.

[0011] FIG. **2** illustrates internal construction details of an example of a CoP module package with internal leadframes forming electrical and/or thermal pathways for an externally attached component.

[0012] FIGS. **3**A and **3**B illustrate an external view of an example of a partially assembled (FIG. **3**A) and fully assembled (FIG. **3**B) multiple components-on-package (mCoP) device.

[0013] FIG. **4** illustrates internal construction details of another example of an mCoP module package that may have one or more internal leadframes that may form electrical and/or thermal pathways to one or more externally attached component connections.

[0014] FIG. **5** illustrates an external view of another example of a multiple components-on-package (mCoP) device with four separate components that may be attached to the top of a mCoP module package.

[0015] FIG. **6** illustrates internal construction details of another example of an mCoP module package with mechani-

cally compliant internal leadframes that may form electrical and/or thermal pathways for externally attached component connections.

[0016] FIG. **7** illustrates an external view of another example of a multiple components-on-package (mCoP) device that may have multiple active and/or passive components attached to the top of a module package.

[0017] FIG. **8** illustrates internal construction details of another example of an mCoP module package that may have internal leadframes forming electrical and/or thermal pathways for externally attached component connections.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0018] Illustrative embodiments are now described. Other embodiments may be used in addition or instead. Details that may be apparent or unnecessary may be omitted to save space or for a more effective presentation. Some embodiments may be practiced with additional components or steps and/or without all of the components or steps that are described.

[0019] Disclosed is a package design and assembly methodology that may integrate mechanically compliant through-mold conductive leadframes for thermal and/or electrical interconnection of large high power externally attached active and passive components.

[0020] Active and/or passive components may be attached to the top of molded and/or unmolded SIPs and modules with full electrical functionality by use of internal leadframes embedded within the module package. These externally mounted components may combine with highly conductive leadframes to provide additional thermal pathways for dissipation of heat and may enhance thermal characteristics and improve power efficiency.

[0021] The highly conductive leadframes may be mechanically compliant and spring-like. Their spring-like action may absorb compressive forces placed on the externally mounted components in the direction of the module during or after assembly and/or may redirect these forces away from the substrate, internal components, and/or exposed component pads.

[0022] Electrical and/or thermal pathways may be provided by use of a mechanically compliant leadframe. The leadframe may extend from within the molded module substrate contact through the mold compound to make contact with internal components. The leadframe may extend through to the top of the module to form a contact pad for connection to top mounted active or passive components.

[0023] FIGS. **1**A and **1**B illustrate an external view of an example of a partially assembled (FIG. **1**A) and fully assembled (FIG. **1**B) components-on-package (CoP) device. A component **102** may be an inductor or other type of passive or active component or a set of components attached to a top of a CoP module package **100**. The CoP module package **100** may be a fully molded electrical circuit and may be constructed with internal leadframes to form one or more exposed metal pads **101** for electrical and/or thermal connection to the externally mounted component **102**. The component **102** may be electrically, thermally, and/or mechanically attached to the package.

[0024] The component **102** may have two contact terminals and may be electrically, thermally, and/or mechanically attached to the top of the module package. Electrical connection from the module to the component may be provided by an internal leadframe that may be embedded within the module package during a plastic molding process.

[0025] FIG. **2** illustrates internal construction details of an example of a CoP module package with internal leadframes **103** forming electrical and/or thermal pathways for an externally attached component **104**. The example may be the same as the example shown in FIG. **1**. The leadframes **103** may each be a mechanically compliant through-mold leadframe that completes the electrical circuit from a substrate up to the component **104** and may provide additional thermal and electrical connections **105** for internal components, such as a quad flat no-lead (QFN) package with exposed pad. One or more of the leadframes may also contain one or more openings **106** that may each be round, oval, rectangular, or any other shape. The openings **106** may improve plastic mold compound flow during the molding process and/or mold compound interlocking.

[0026] The internal leadframes **103** that are illustrated in FIG. **2** may each form a solderable contact region at the top surface of the module following the mold process. They may also each provide a high current electrical connection from the externally attached component **104** down through the mold compound to connect to the electrical circuit.

[0027] This leadframe electrical circuit connection may be soldered down to the module substrate and may also be connected to multiple internal components. This electrical pathway may provide a thermal pathway for heat to escape the module package.

[0028] The component **104** may be affixed to the top of the module by use of solder and/or epoxy attach materials using a post-mold SMT assembly process. Adhesive or other type of attaching material may be used to attach the body of the component to the plastic body of the module for additional mechanical stability.

[0029] The solder and epoxy materials used to attach the component may be electrically and/or thermally conductive to provide a high current (e.g., >50 amps) and a highly thermally conductive connection (e.g., >25 watts per meter per degree celsius) to the molded SIP. The attachment process and materials may combine to provide hold down strength and heat working characteristics sufficient to survive high temperature thermal cycling during operation and reliability testing.

[0030] The component **104** or multiple components may be passive and/or active. Their number may depend on the number of through mold connections provided by the leadframe design.

[0031] FIGS. **3**A and **3**B and FIG. **5** show examples of multiple components-on-package (mCoP) devices that may include multiple passive components that are electrically and/or thermally attached to the top of the fully molded SIP or Module.

[0032] FIGS. **3**A and **3**B illustrate an external view of an example of a partially assembled (FIG. **3**A) and fully assembled (FIG. **3**B) multiple components-on-package (mCoP) device. Attached external components **202** may each be an inductor and/or other type of component or components which may be attached to the top of a mCoP module package **200**. The mCoP module package **200** may be a full molded electrical circuit with internal leadframes that form one or more exposed pads **201** for electrical and/or thermal connection to the external components **202**. The external components may be electrically, thermally, and/or mechanically attached to the module package **200**.

[0033] FIG. **4** illustrates internal construction details of another example of an mCoP module package that may have one or more internal leadframes **203** that may form electrical and/or thermal pathways to one or more externally attached component connections **204**. The example may be the same as the example shown in FIGS. **3**A and **3**B. One or more mechanically compliant through-mold leadframes **206** may complete the electrical circuit from the substrate up to each of the component connections **204** and may provide additional thermal and/or electrical connections **205** to internal components, such as to a QFN. The one or more of the leadframes **206** may also contain one or more openings **206** that may each be circular, oval, rectangular, or any other shape. The opening **206** may improve plastic mold compound flow during the molding process and/or improve mold compound interlocking.

[0034] FIG. **5** illustrates an external view of another example of a multiple components-on-package (mCoP) device with four separate components **302** that may be attached to the top of a mCoP module package **300**. The mCoP Module package **300** may be a full molded electrical circuit with internal leadframes that form exposed pads **301** for electrical and/or thermal connection to all of the external components **302**. All of the external components **302** may be electrically, thermally, and/or mechanically attached to the package through the leadframes. A different number of components may be used instead.

[0035] FIG. **6** illustrates internal construction details of another example of an mCoP module package with mechanically compliant internal leadframes **303** that may form electrical and/or thermal pathways for externally attached component connections **304**. The example may be the same as the example shown in FIG. **5**. The mechanically compliant through-mold leadframes may complete the electrical circuit from the substrate up to the components and may provide additional thermal and/or electrical connections **305** for internal components. One or more of the leadframes may also contain openings **306** that may be circular, oval, rectangular or any other shape. These openings **306** may improve plastic mold compound flow during the molding process and/or mold compound interlocking.

[0036] The leadframes employed (FIGS. **4** and **6**) may provide electrical and/or thermal pathways for each attached component and may have openings that may assist in the assembly process by enhancing mold flow during the plastic molding process and/or providing additional mechanical stability by mold locking of the leadframe within the molded structure. The leadframe design may also provide for isolated and individual connection of all component leads for full functionality of each component, as required by the function of the electrical circuits within the module package.

[0037] FIG. **7** illustrates an external view of another example of a multiple components-on-package (mCoP) device **400** that may have multiple active and/or passive components **402** attached to the top of a module package **400**. The mCoP Module package **400** may be a fully molded electrical circuit with internal leadframes that form exposed pads **401** for electrical and/or thermal connections to one or more externally attached components **402**.

[0038] FIG. **8** illustrates internal construction details of another example of an mCoP module package that may have internal leadframes **403** forming electrical and/or thermal pathways for externally attached component connections **404**. The example may be the same as the example shown in FIG. **7**. Mechanically compliant through-mold leadframes **406** may complete the electrical circuit from the substrate up to the component and may provide additional thermal and/or electrical connections for internal components **405**. One or more of the leadframes **406** may contain openings **406** that may each be circular, oval, rectangular or any other shape. These openings **406** may improve plastic mold compound flow during the molding process and/or mold compound interlocking.

[0039] FIGS. **7** and **8** show an example of an mCoP device with multiple active and/or passive components attached to the top surface of the module package. This device may require more complex leadframe designs and/or post-mold processing and/or post-mold machining, but may provide all the same functional characteristics as previously disclosed herein.

[0040] Additional machining and/or etching of the leadframe can be performed once the leadframe is embedded within the mold compound in case further electrical isolation is required for proper circuit operation of the mCoP. This machining may include both additive and subtractive modification to the imbedded/attached leadframe by means of mechanical and electrical means. For example, a milling machine, laser machining, chemical etching, and/or sawing the leadframe may be used to obtain isolated and/or routed connections for externally mounted components.

[0041] The mechanically compliant internal leadframes that have been described may provide electrically and/or thermally conductive pathways that distribute between the internal components and circuit within the module and the attached external components. Angular bends may be at precise locations and may act to decouple and redistribute any downward force due to assembly and mold packing pressures that might otherwise damage the substrate and/or attached components. The openings in the leadframe may be circular, oval, rectangular, or any other shape and may facilitate mold locking, mold flow, and/or minimize mold voids and/or prevent large areas of delamination.

[0042] The leadframe may also have a multiplicity of areas along the length on each side containing thinned regions, typically half the thickness being removed by machining and/or etching. These half-etch features may be provided at specific locations to further reduce the chance of delamination during subsequent reflows and other reliability related concerns.

[0043] The components, steps, features, objects, benefits, and advantages that have been discussed are merely illustrative. None of them, nor the discussions relating to them, are intended to limit the scope of protection in any way. Numerous other embodiments are also contemplated. These include embodiments that have fewer, additional, and/or different components, steps, features, objects, benefits, and/or advantages. These also include embodiments in which the components and/or steps are arranged and/or ordered differently.

[0044] For example, internal leadframes could be used to redistribute electrical signals within the module package, effectively providing an additional signal layer between components. These internal leadframes would not necessarily require exposure to the top surface of the package. These leadframes could be considered to be intermediate conductive layers that could act to bridge electrical signals from components at one side of the package and extend over many internal components to make high current connections

to other components at the other side of the package. Leadframes forming internal connections from the backside of flip chip silicon die to other internal components would be one example. Connecting vertical FET's together and to the substrate would be another. Another example would be a leadframe spanning the entire distance of the package length to provide electrical and thermal connections for any number of components.

[0045] Internal leadframes that are exposed and/or revealed for surface connection of components can also form connections to external heat sinking materials, such as a heatsink, thermal pipes, and/or other electrically and/or thermally conductive materials. Connections such as these may further enhance heat dissipation from within the package and potentially allow for operation at higher power densities and currents.

[0046] Variations of what have been described may include a variety of attach methods to the substrate, internal components, and/or external components. These methods may include but are not limited to epoxy, solder, and/or any adhesive that is either conductive or non-conductive to heat and/or electricity. Furthermore, the internal leadframe may include any multiple of leadframes and/or structures that may form conductive pathways for relevant operation of the package. Leadframe structures may connect/attach to interposers, clips, metallic stand-offs, and/or any variation of material structure capable of providing a conductive pathway for heat and/or electricity. Externally mounted/attached components may include but are not limited to passive components, active components, and/or any variation of thermally and/or electrically conductive material to include heat sinking devices, heat pipes, intercoolers, and/or externally attached Peltier and/or energy harvesting and control devices.

[0047] Unless otherwise stated, all measurements, values, ratings, positions, magnitudes, sizes, and other specifications that are set forth in this specification, including in the claims that follow, are approximate, not exact. They are intended to have a reasonable range that is consistent with the functions to which they relate and with what is customary in the art to which they pertain.

[0048] All articles, patents, patent applications, and other publications that have been cited in this disclosure are incorporated herein by reference.

[0049] The phrase "means for" when used in a claim is intended to and should be interpreted to embrace the corresponding structures and materials that have been described and their equivalents. Similarly, the phrase "step for" when used in a claim is intended to and should be interpreted to embrace the corresponding acts that have been described and their equivalents. The absence of these phrases from a claim means that the claim is not intended to and should not be interpreted to be limited to these corresponding structures, materials, or acts, or to their equivalents.

[0050] The scope of protection is limited solely by the claims that now follow. That scope is intended and should be interpreted to be as broad as is consistent with the ordinary meaning of the language that is used in the claims when interpreted in light of this specification and the prosecution history that follows, except where specific meanings have been set forth, and to encompass all structural and functional equivalents.

[0051] Relational terms such as "first" and "second" and the like may be used solely to distinguish one entity or action from another, without necessarily requiring or implying any actual relationship or order between them. The terms "comprises," "comprising," and any other variation thereof when used in connection with a list of elements in the specification or claims are intended to indicate that the list is not exclusive and that other elements may be included. Similarly, an element proceeded by an "a" or an "an" does not, without further constraints, preclude the existence of additional elements of the identical type.

[0052] None of the claims are intended to embrace subject matter that fails to satisfy the requirement of Sections 101, 102, or 103 of the Patent Act, nor should they be interpreted in such a way. Any unintended coverage of such subject matter is hereby disclaimed. Except as just stated in this paragraph, nothing that has been stated or illustrated is intended or should be interpreted to cause a dedication of any component, step, feature, object, benefit, advantage, or equivalent to the public, regardless of whether it is or is not recited in the claims.

[0053] The abstract is provided to help the reader quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, various features in the foregoing detailed description are grouped together in various embodiments to streamline the disclosure. This method of disclosure should not be interpreted as requiring claimed embodiments to require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus, the following claims are hereby incorporated into the detailed description, with each claim standing on its own as separately claimed subject matter.

The invention claimed is:

1. A component-on-package circuit comprising:
a component for an electrical circuit; and
a circuit module attached to the component, the circuit module having:
circuitry; and
at least one leadframe which connects the circuitry to the component both electrically and thermally, the leadframe having a high degree of both electrical and thermal conductivity and a non-planar shape that provides spring-like cushioning of force applied to the component in the direction of the circuit module.

2. The component-on-package circuit of claim **1** wherein the leadframe has at least one foot electrically connected to the circuitry.

3. The component-on-package circuit of claim **2** wherein the leadframe has at least two distinct feet.

4. The component-on-package circuit of claim **1** wherein the leadframe has at least one top surface electrically and thermally connected to the component.

5. The component-on-package circuit of claim **4** wherein the leadframe has at least two, separated top surfaces that are each attached to the component.

6. The component-on-package circuit of claim **1** wherein the leadframe has:
at least one foot electrically connected to the circuitry;
at least one top surface electrically and thermally connected to the component; and
at least one step between the foot and the top surface.

7. The component-on-package circuit of claim **6** wherein the leadframe has at least two distinct steps.

8. The component-on-package circuit of claim **7** wherein the at least two distinct steps are at different elevations between the at least one foot and the at least one top surface.

9. The component-on-package circuit of claim **7** wherein the at least two distinct steps are at the same elevation.

10. The component-on-package circuit of claim **1** wherein:

the circuit module has a second leadframe that connects the circuitry to the component both electrically and thermally; and

the second leadframe has a high degree of both electrical and thermal conductivity and a non-planner shape that provides spring-like cushioning of force applied to the component in the direction of the circuit module.

11. The component-on-package circuit of claim **1** wherein:

the circuit module, including the leadframe, is encapsulated in molding material; and

the leadframe has a top surface that is not covered by the molding material.

12. The component-on-package circuit of claim **11** wherein the component is not also encapsulated by the molding material.

13. The component-on-package circuit of claim **1** wherein the component is a passive component.

14. The component-on-package circuit of claim **13** wherein the passive component is an inductor.

15. A method of making a component-on-package circuit comprising:

attaching a component for an electrical circuit to a circuit module, the circuit module having circuitry and at least one leadframe which connects the circuitry to the component after the attachment both electrically and thermally, the leadframe having a high degree of both electrical and thermal conductivity and a non-planar shape that provides spring-like cushioning of force applied to the component in the direction of the circuit module; and

encapsulating the circuit module in molding material after the circuit module has been attached to the component, without encapsulation the component at the same time.

* * * * *