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(19) **United States**(12) **Patent Application Publication****Cady et al.**(10) **Pub. No.: US 2004/0235222 A1**(43) **Pub. Date: Nov. 25, 2004**(54) **INTEGRATED CIRCUIT STACKING SYSTEM AND METHOD**

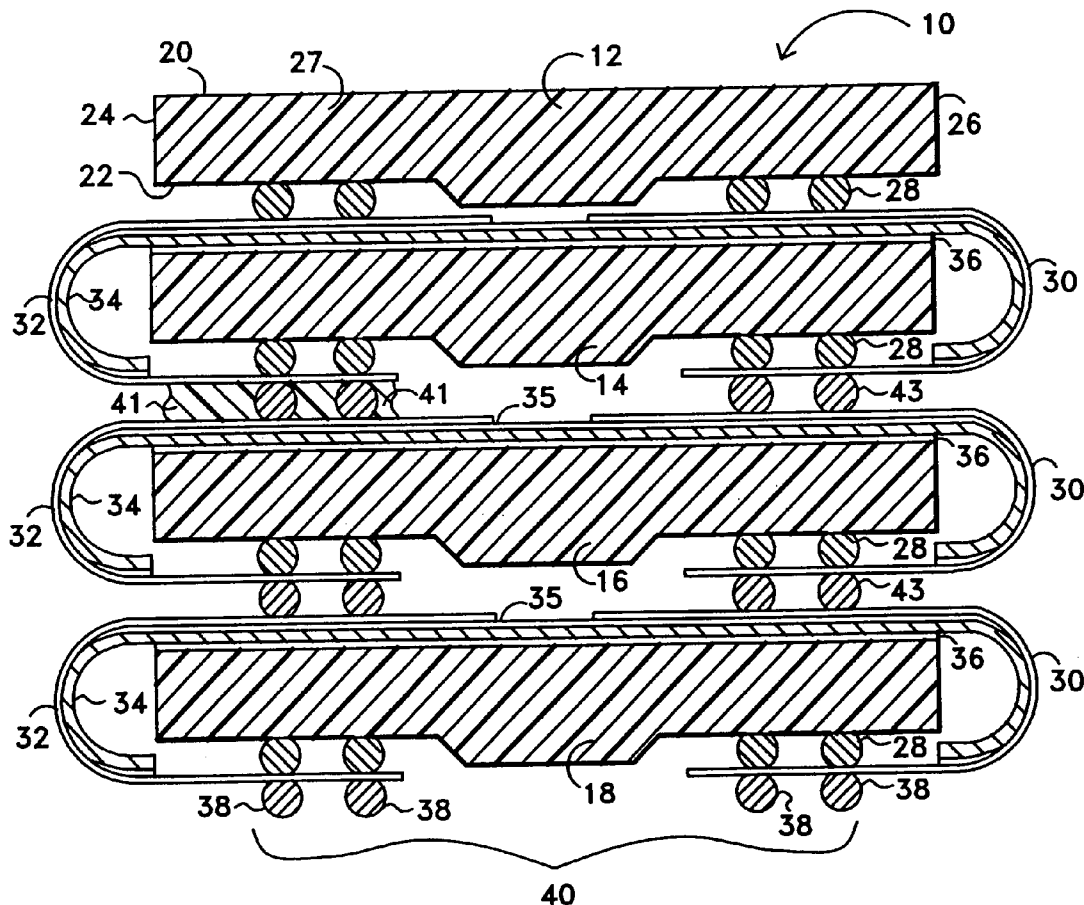
continuation-in-part of application No. 10/005,581, filed on Oct. 26, 2001, now Pat. No. 6,576,992.

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Austin, TX 78701 (US)(73) Assignee: **Staktek Group, L.P.**(21) Appl. No.: **10/872,897**(22) Filed: **Jun. 21, 2004****Related U.S. Application Data**

(63) Continuation of application No. 10/814,532, filed on Mar. 31, 2004, which is a continuation-in-part of application No. PCT/US03/29000, filed on Sep. 15, 2003, and which is a continuation-in-part of application No. 10/453,398, filed on Jun. 3, 2003, which is a

(57) **ABSTRACT**

The present invention stacks integrated circuits (ICs) into modules that conserve PWB or other board surface area. In another aspect, the invention provides a lower capacitance memory expansion addressing system and method and preferably with the CSP stacked modules provided herein. In a preferred embodiment in accordance with the invention, a form standard provides a physical form that allows many of the varying package sizes found in the broad family of CSP packages to be used to advantage while employing a standard connective flex circuitry design. In a preferred embodiment, the form standard will be devised of heat transference material such as copper to improve thermal performance. In an alternative embodiment, the form standard may include a heat spreader portion with mounting feet. In a preferred embodiment of the memory addressing system, a high speed switching system selects a data line associated with each level of a stacked module to reduce the loading effect upon data signals in memory access.



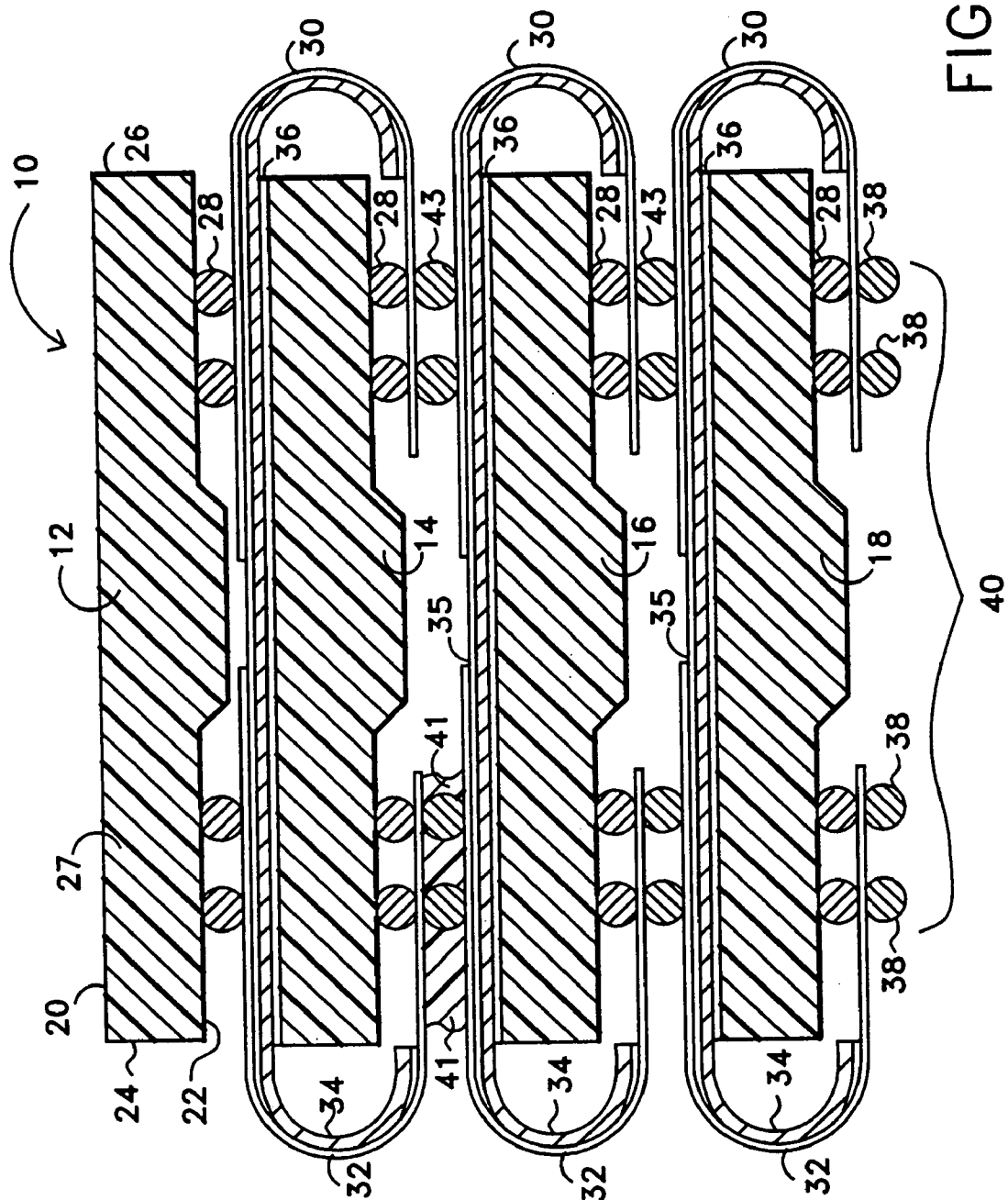


FIG. 1

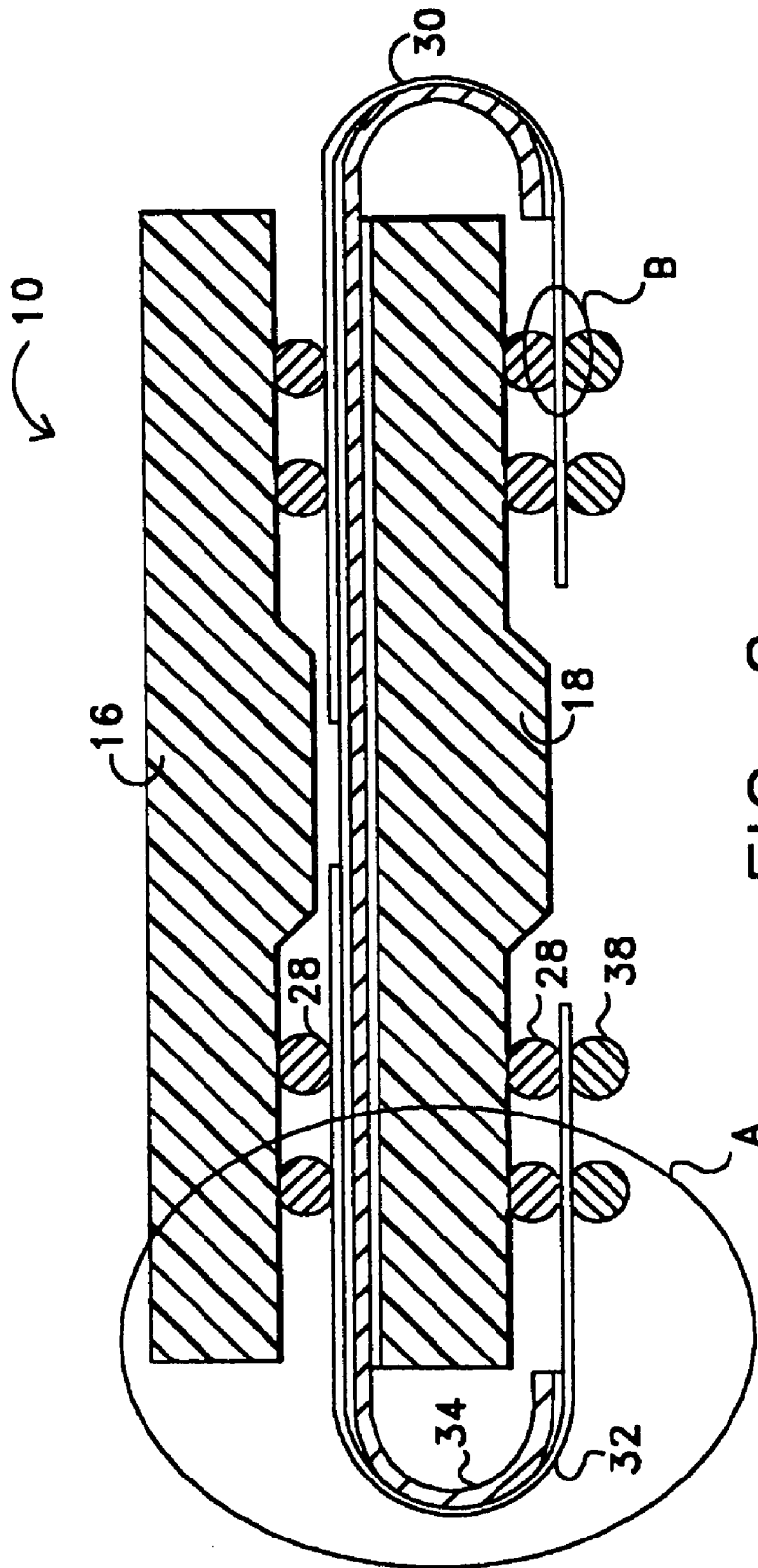


FIG. 2

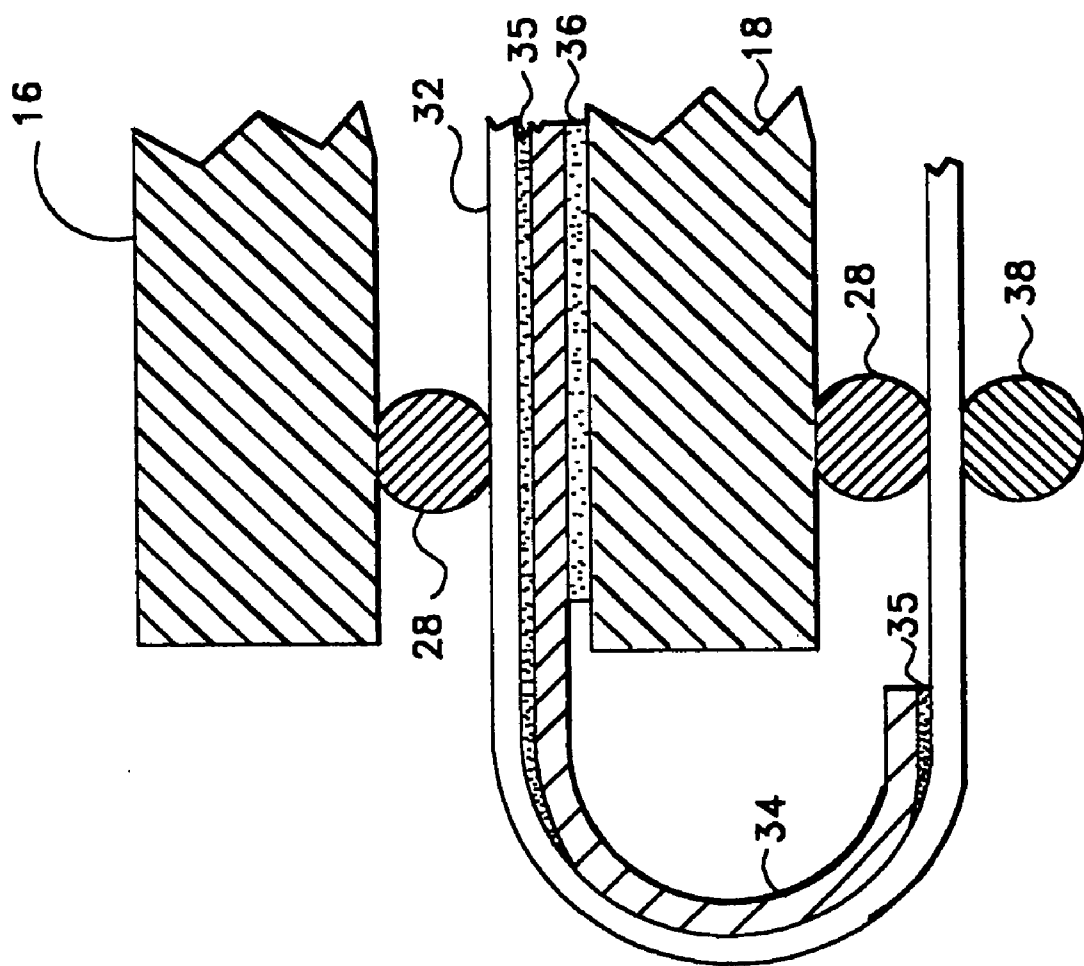


FIG. 3

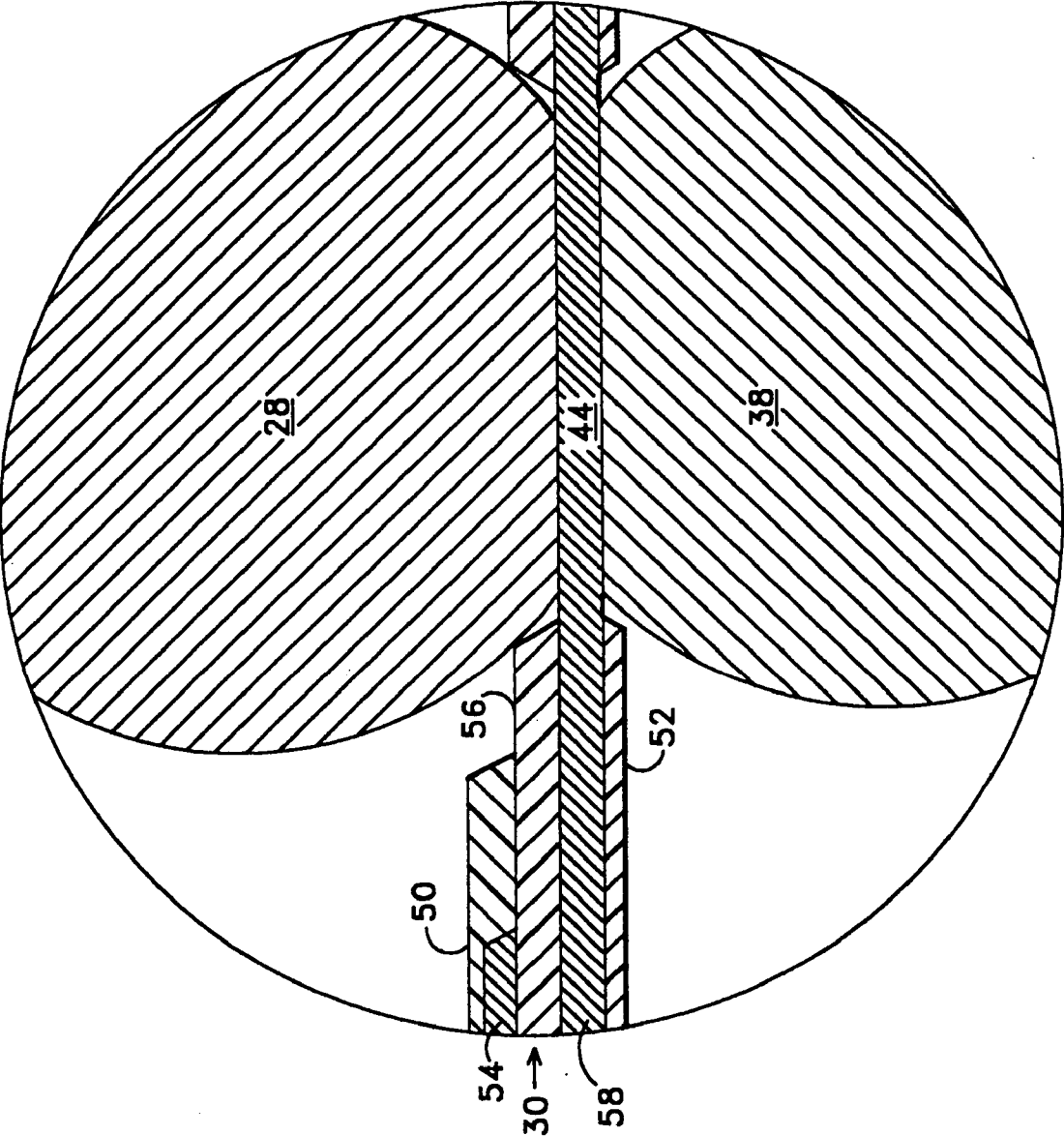


FIG. 4

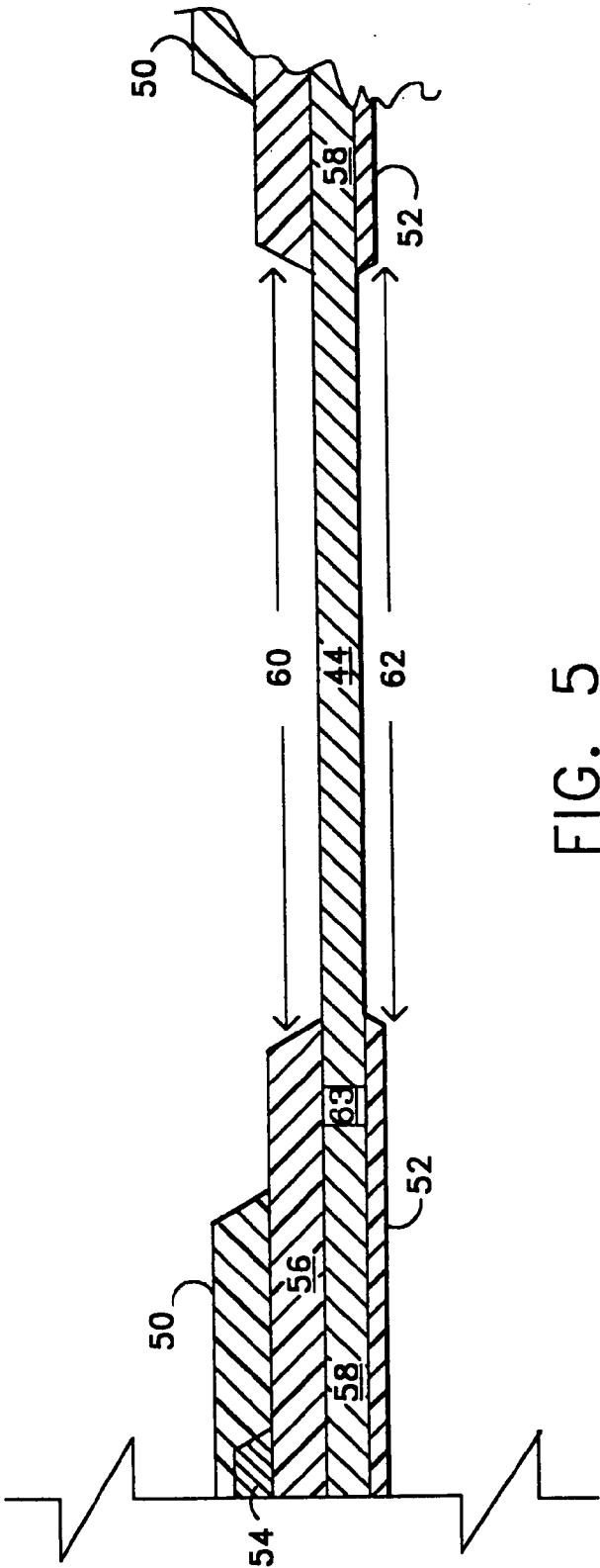


FIG. 5

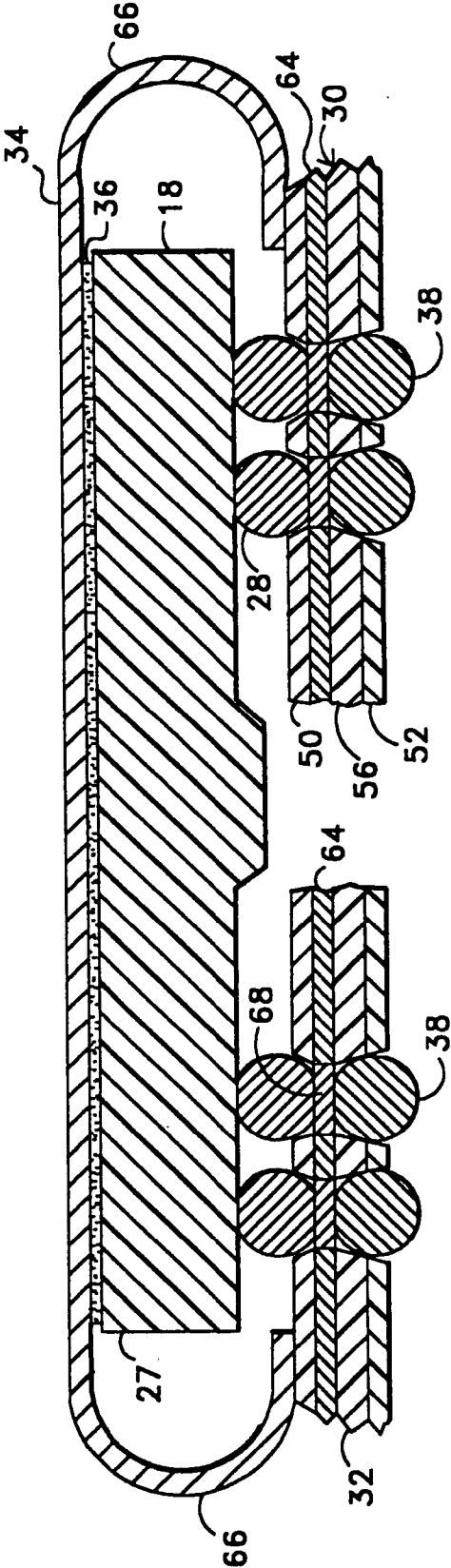


FIG. 6

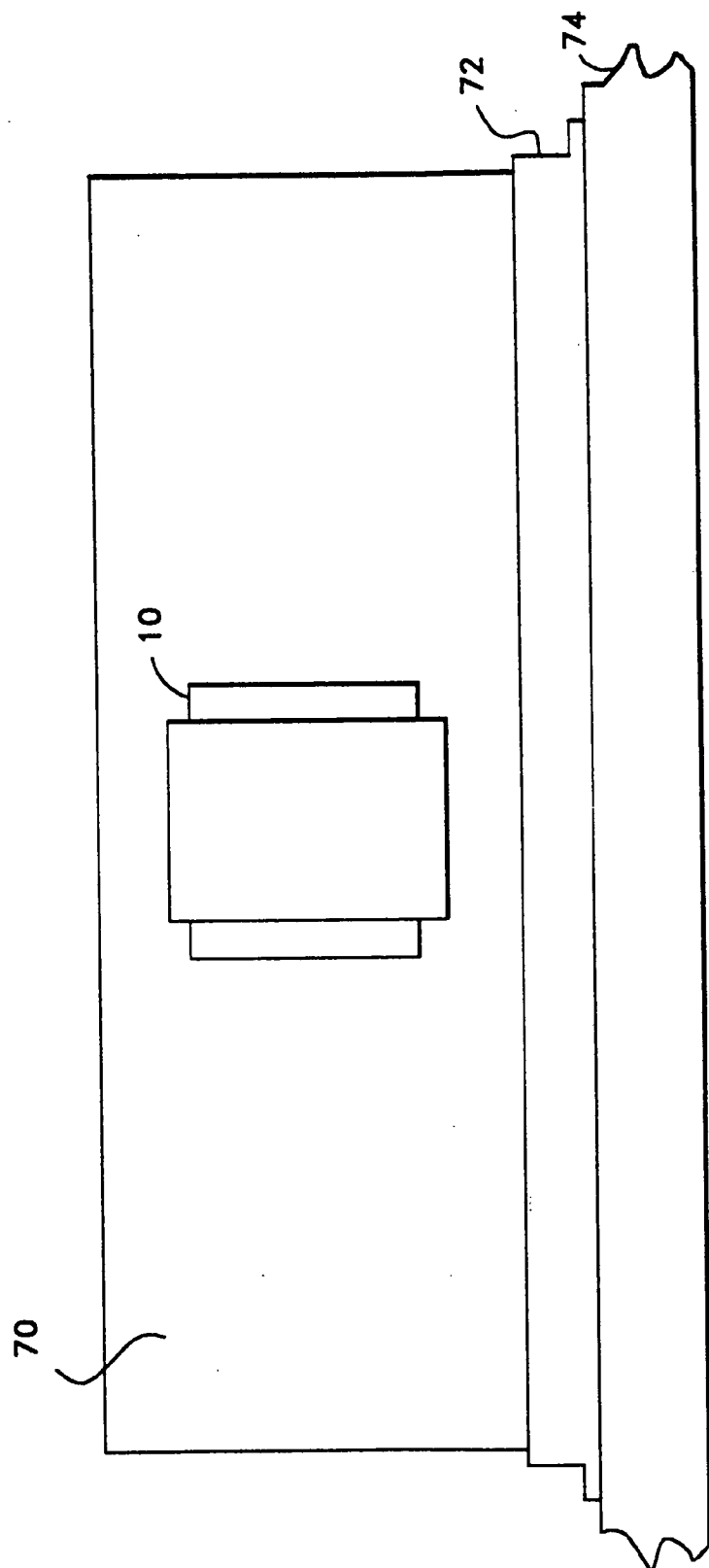


FIG. 7

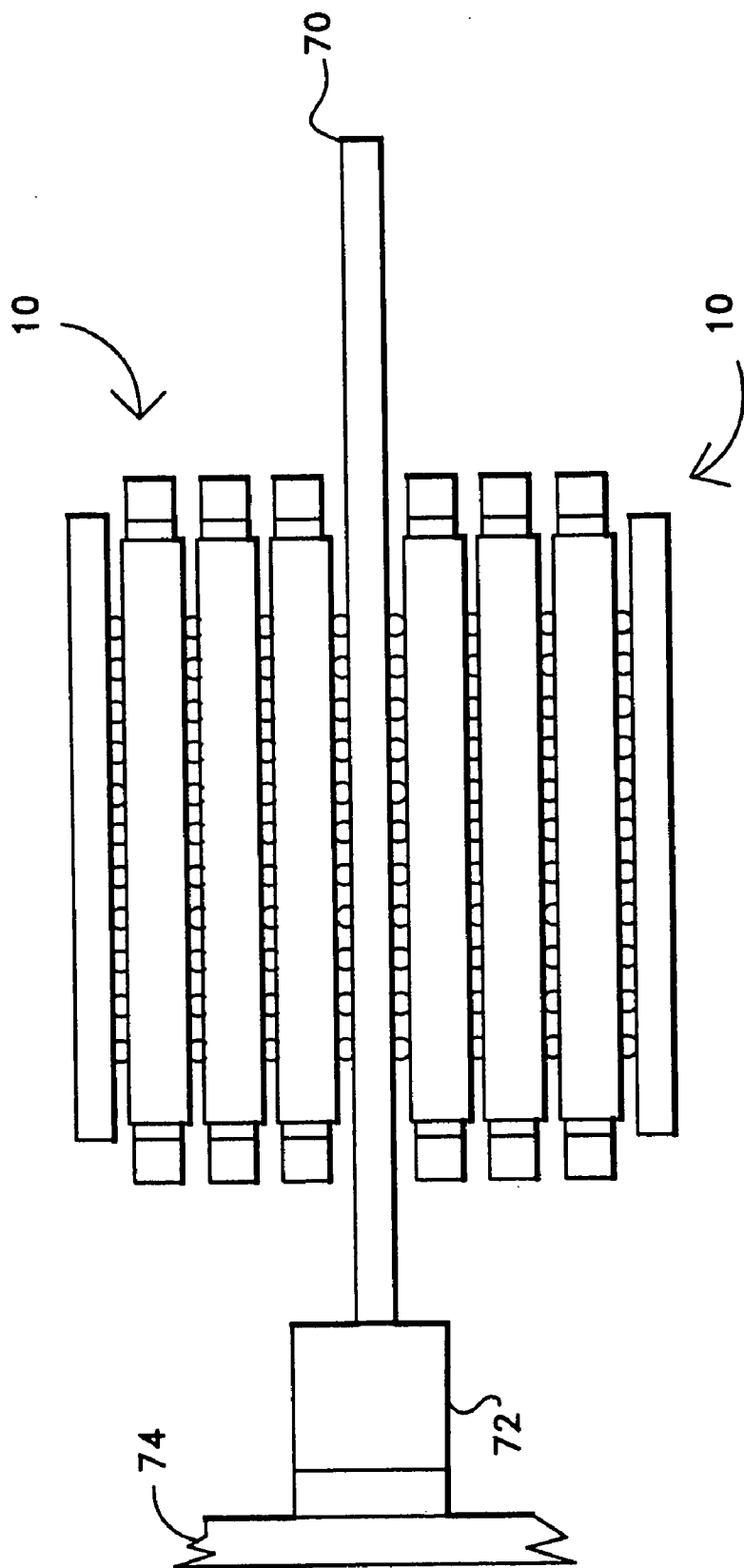


FIG. 8

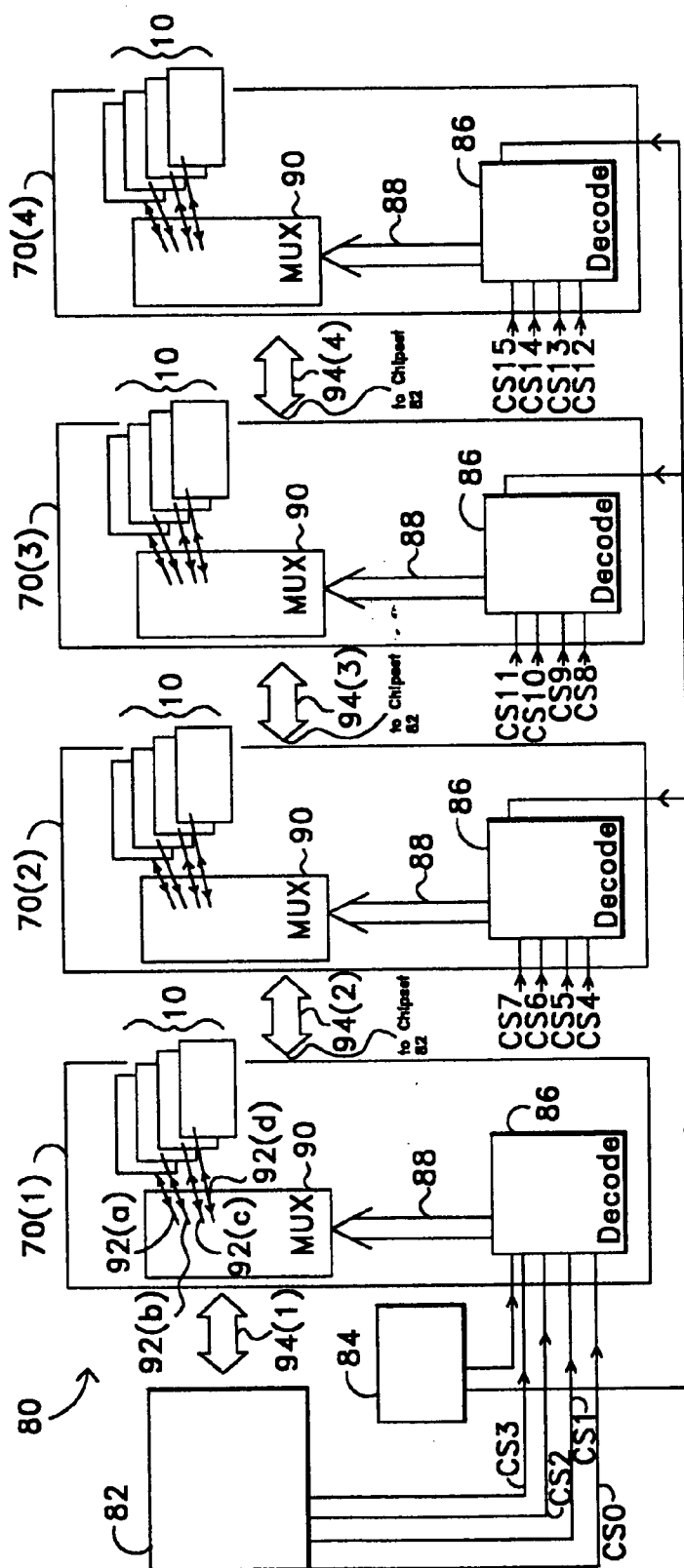


FIG. 9

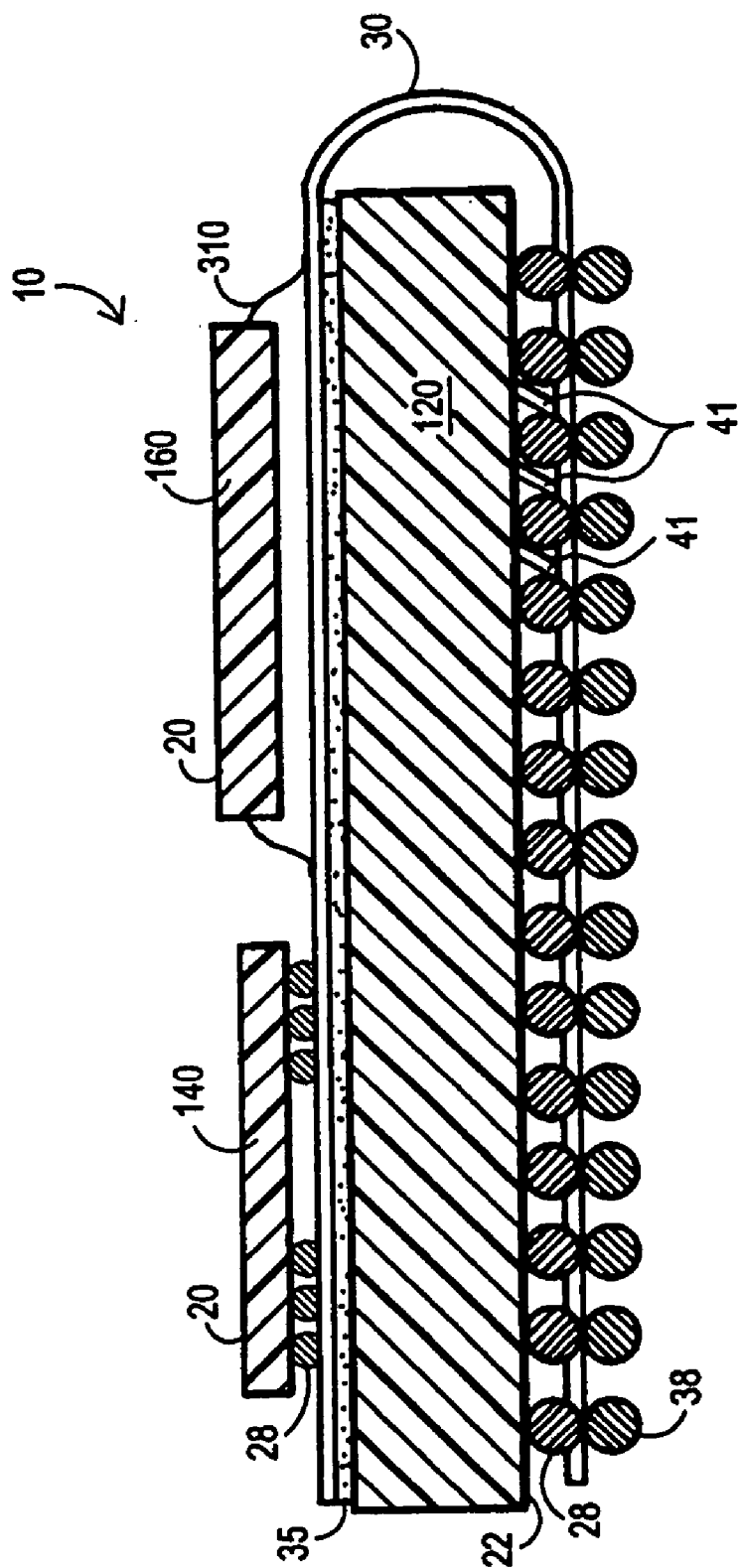


FIG. 11

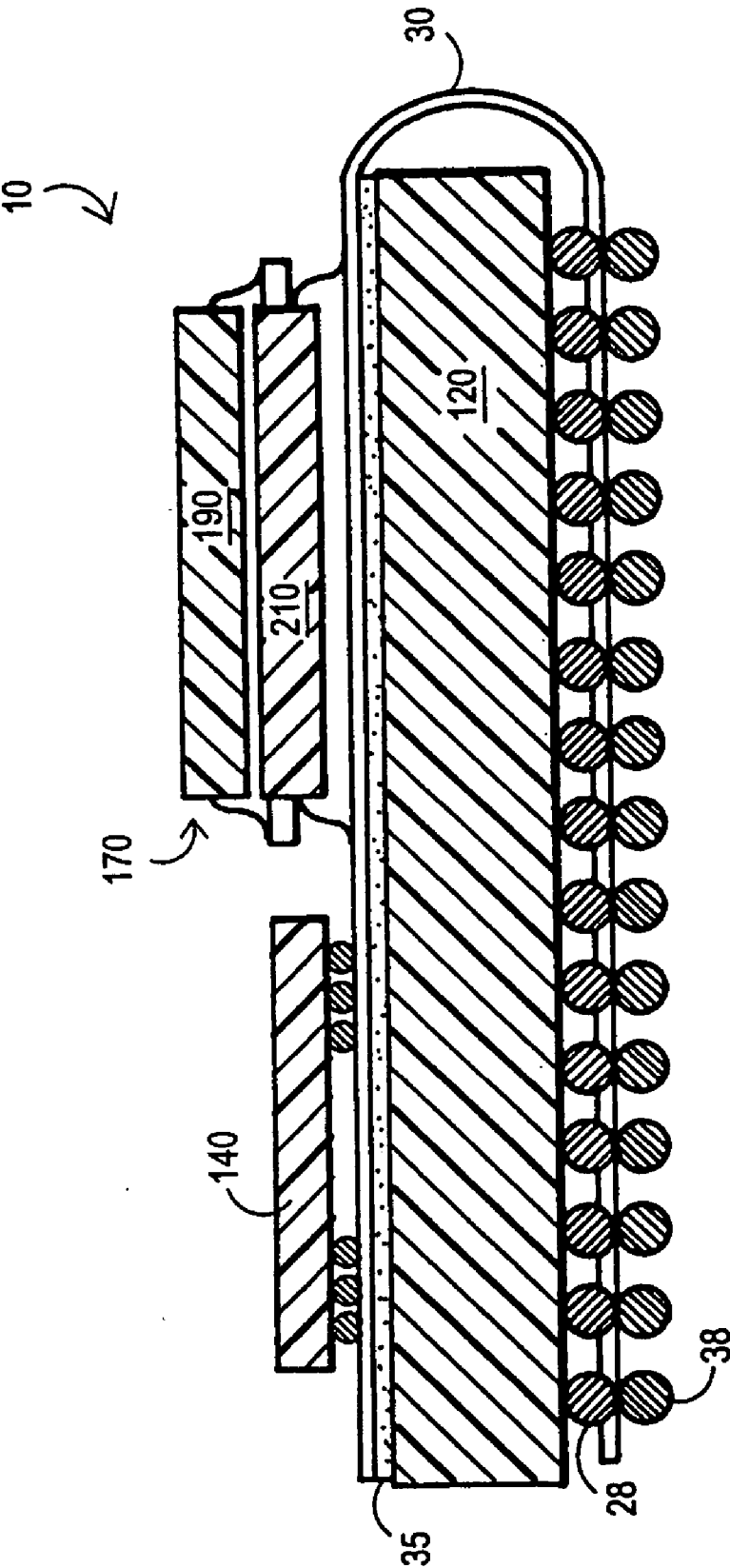


FIG. 12

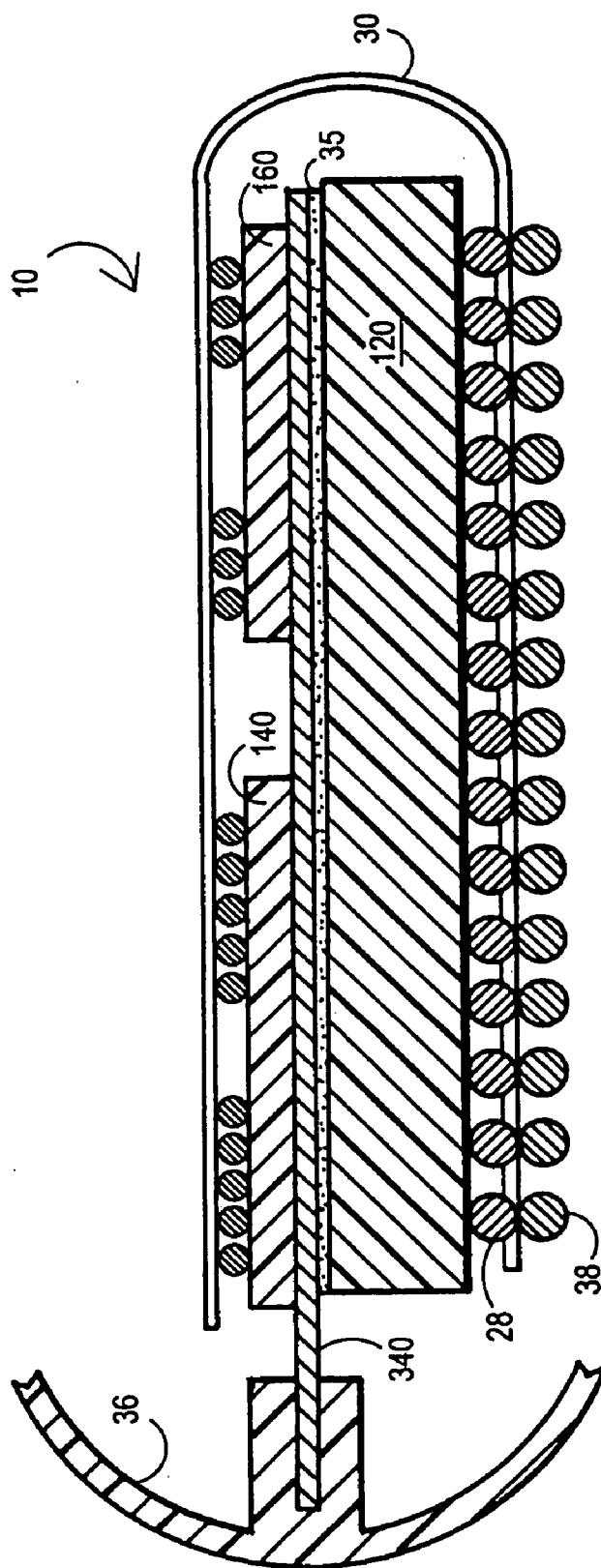


FIG. 13

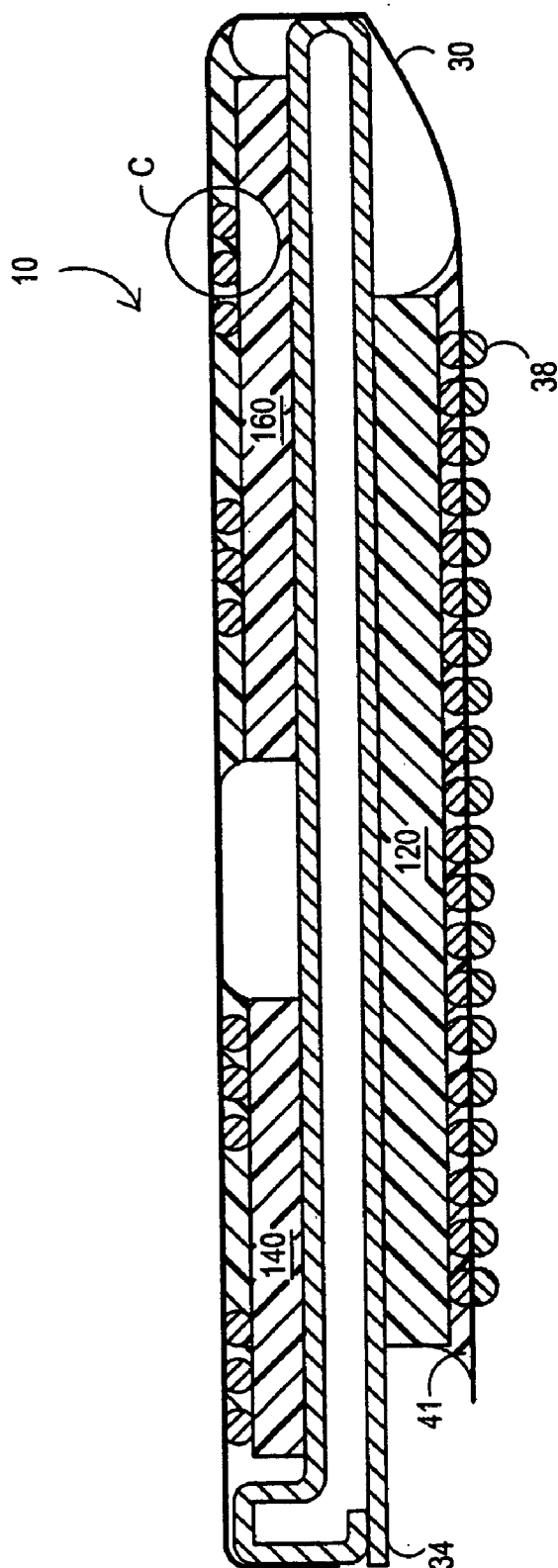


FIG. 14

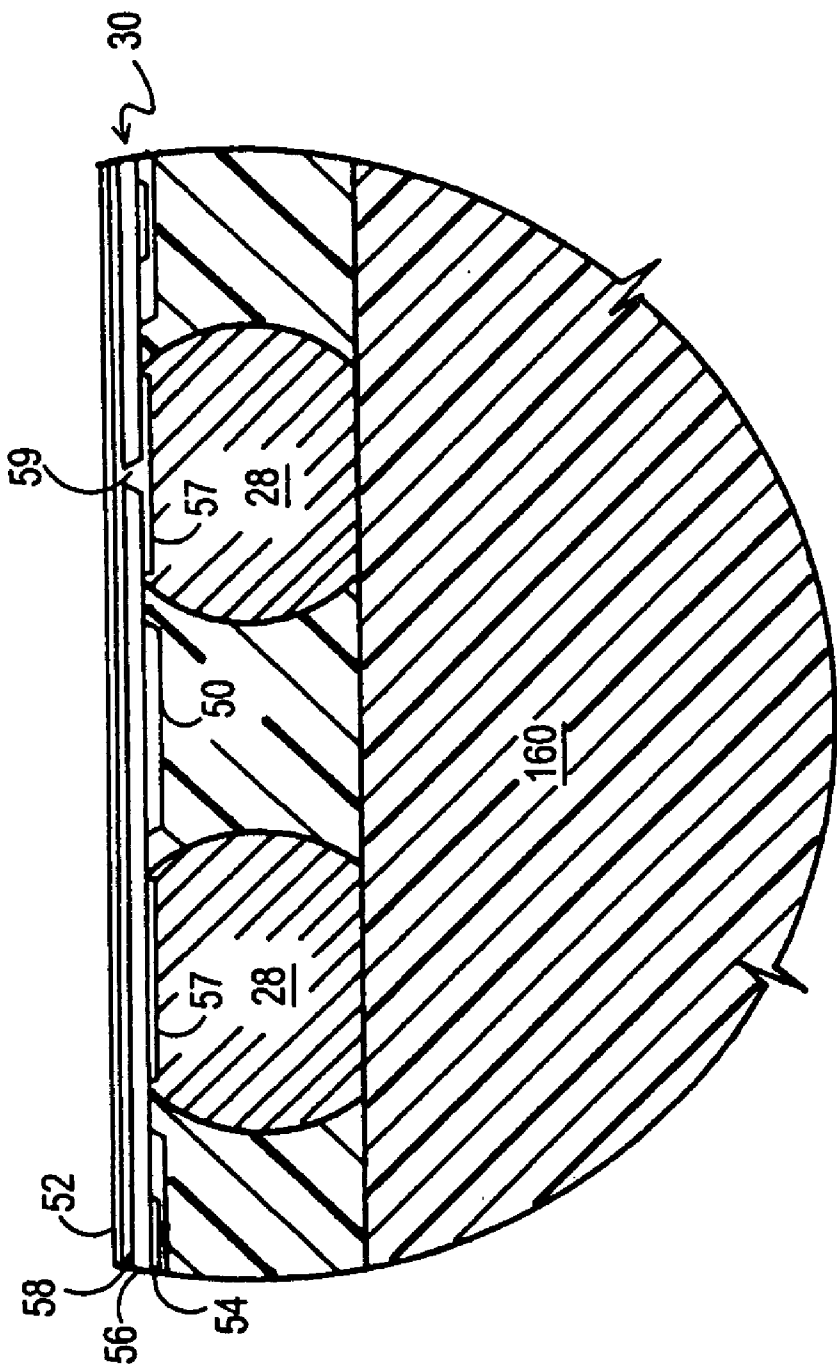


FIG. 15

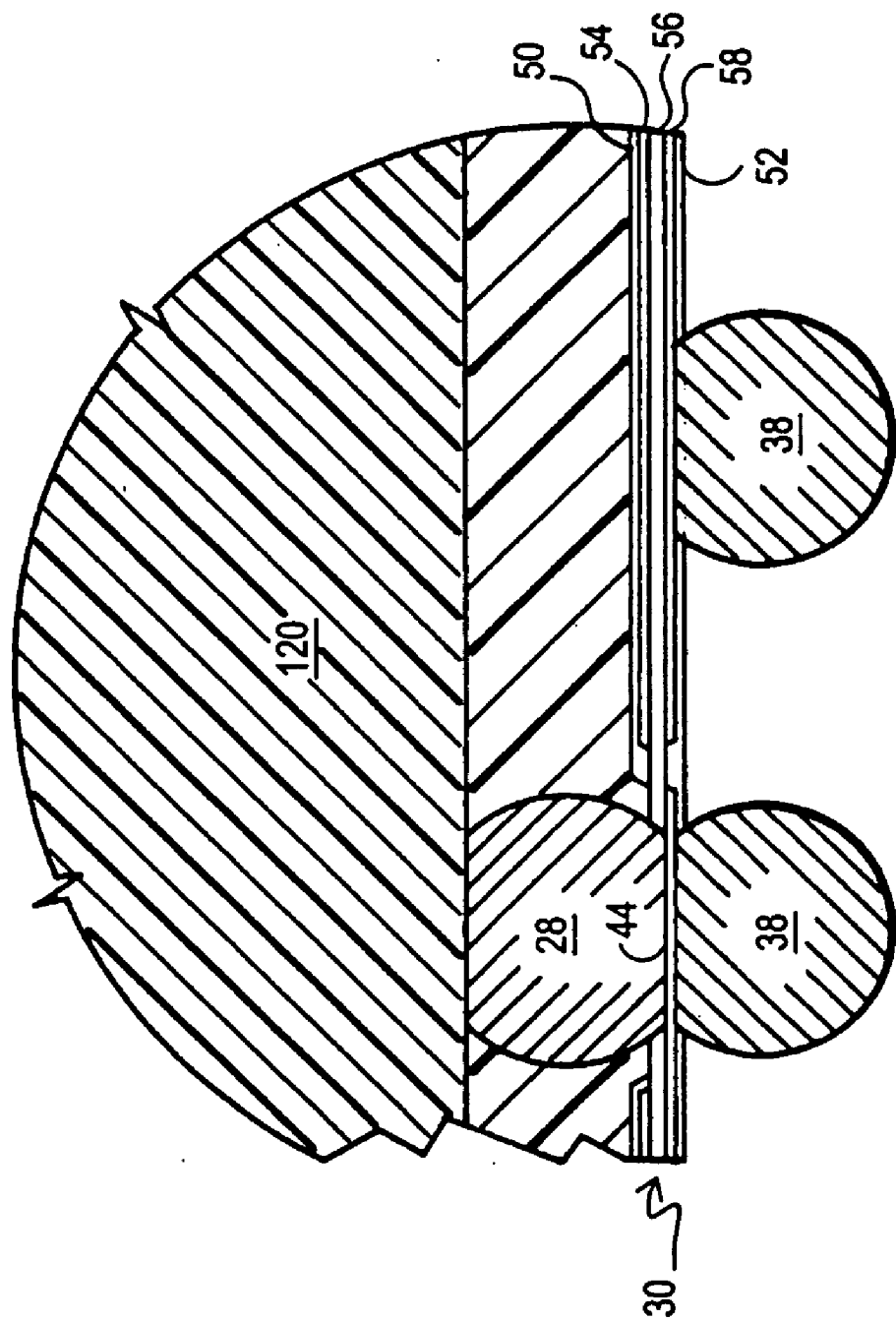


FIG. 16

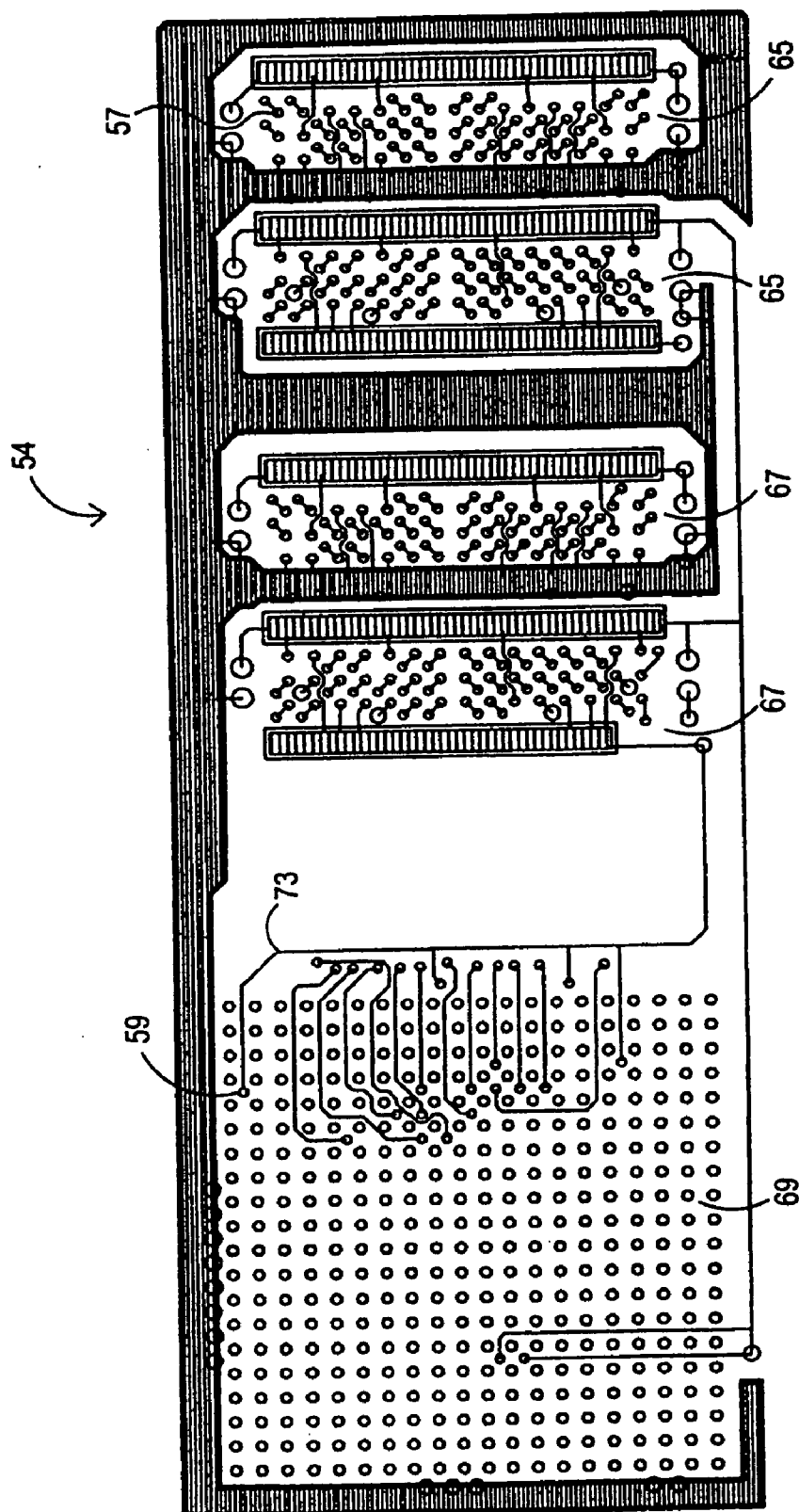


FIG. 17

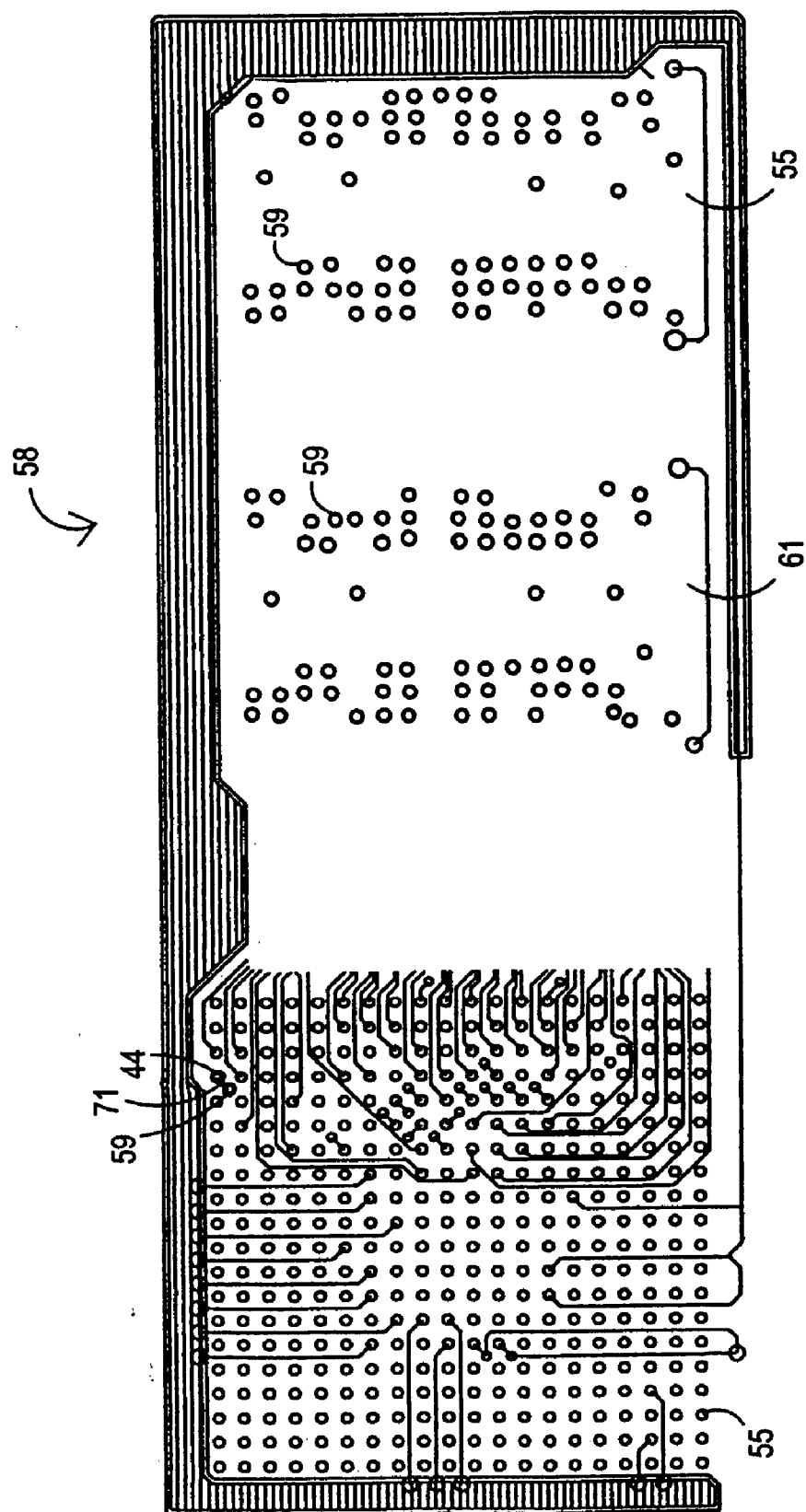


FIG. 18

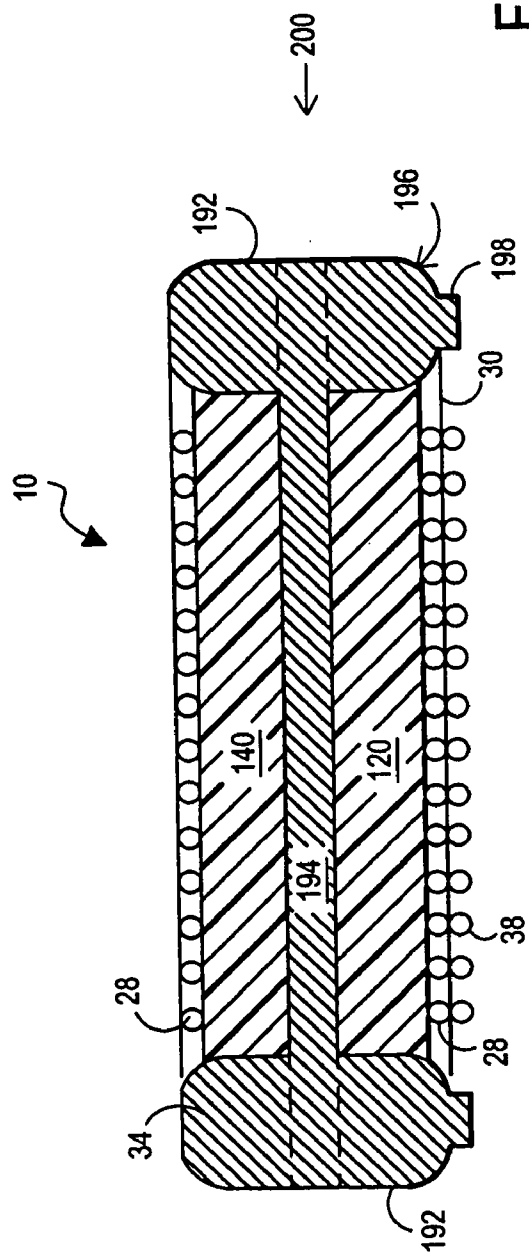


FIG. 19

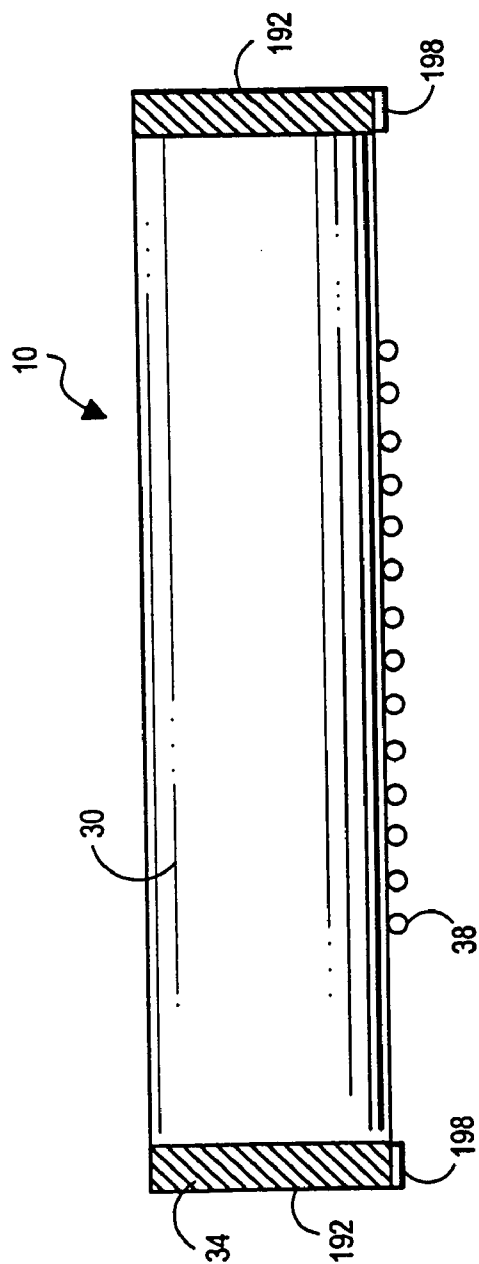


FIG. 20

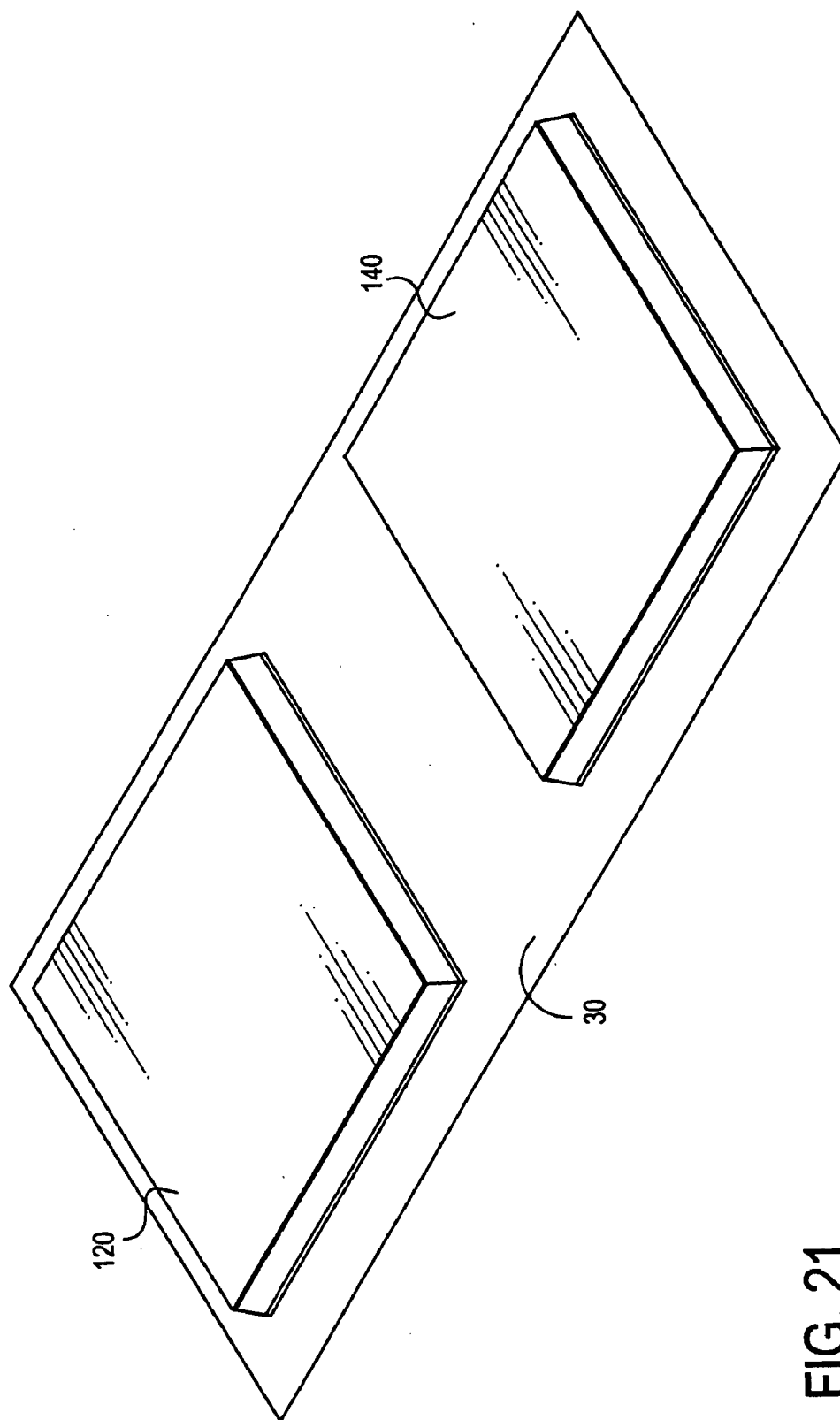


FIG. 21

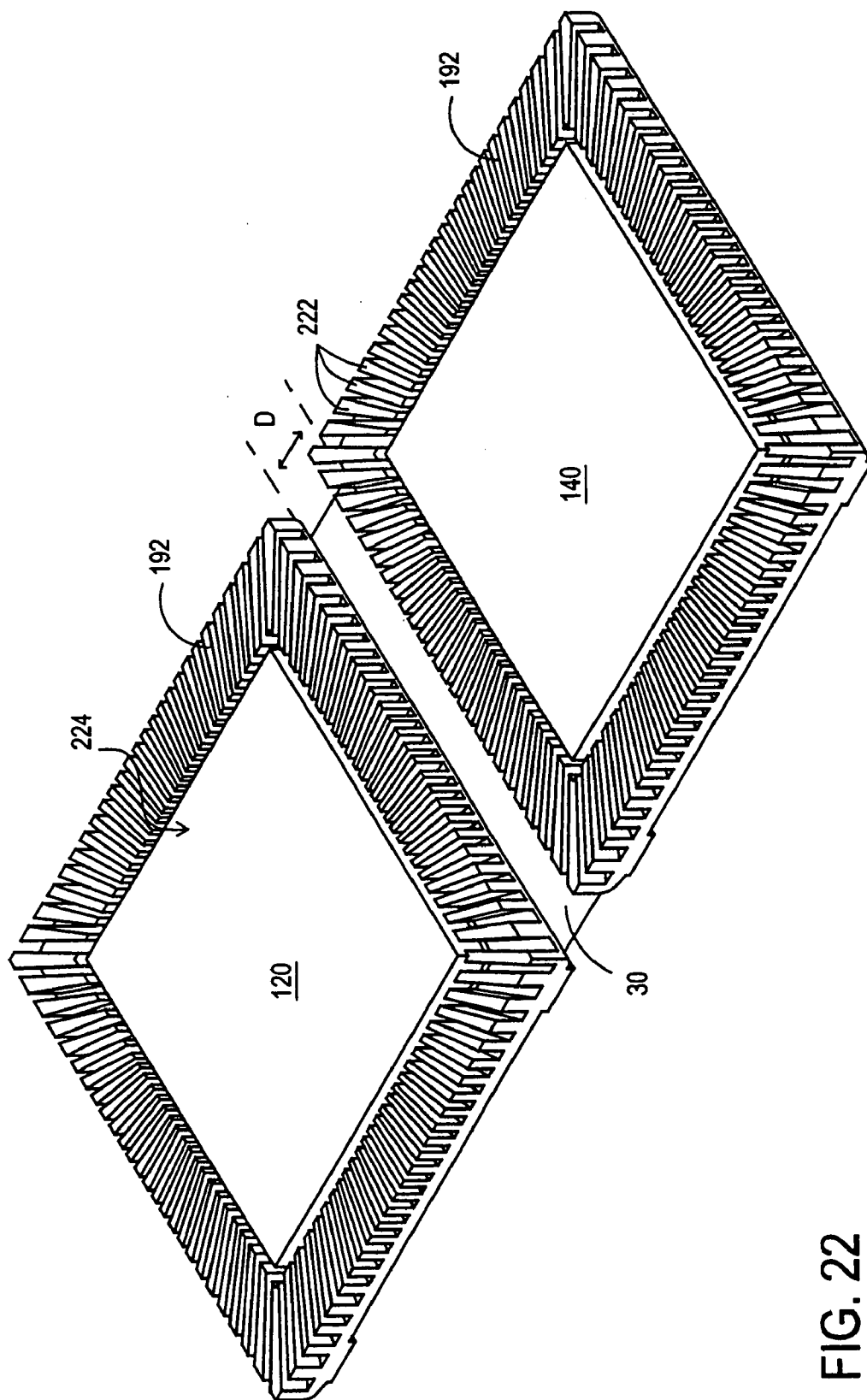


FIG. 22

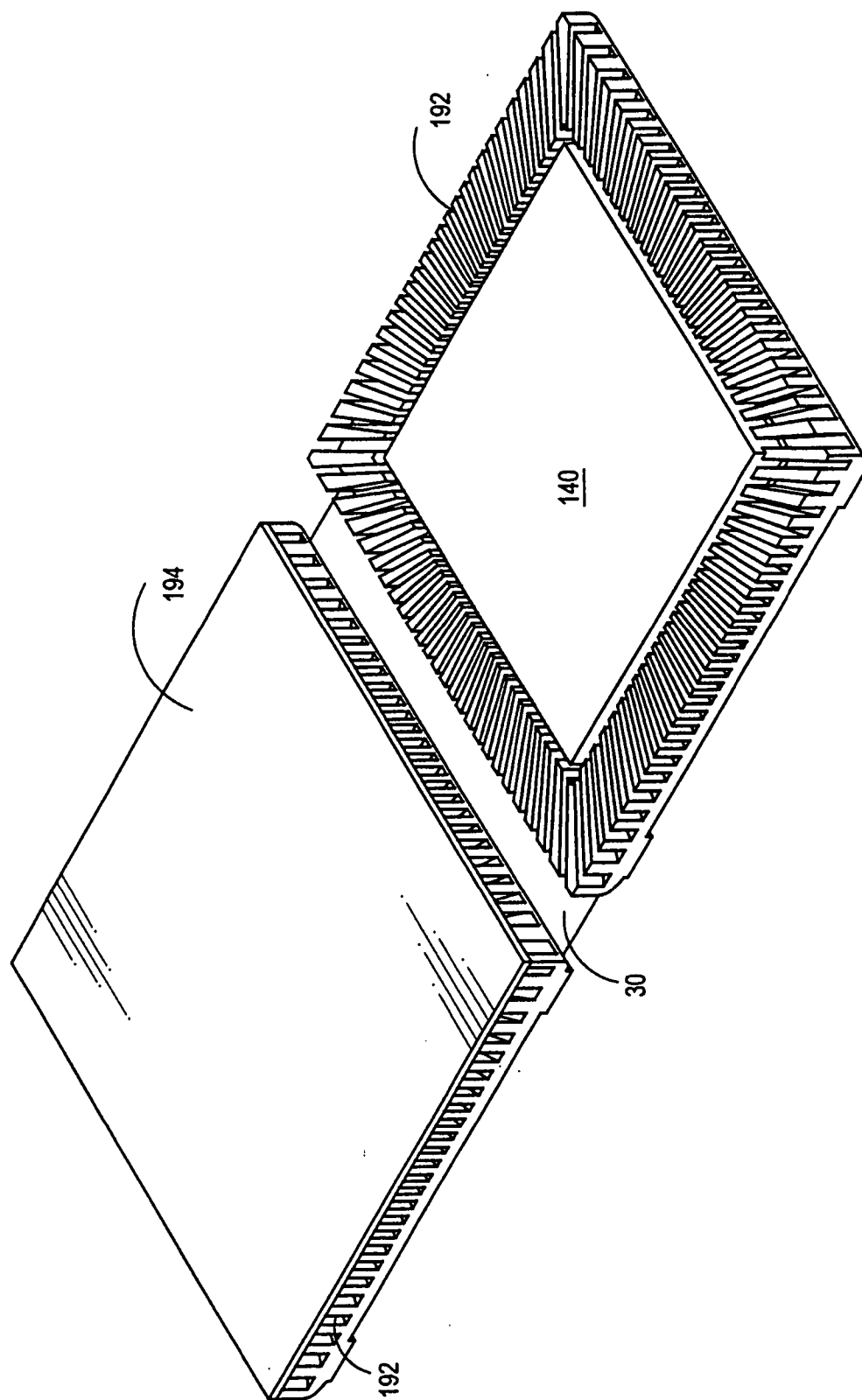


FIG. 23

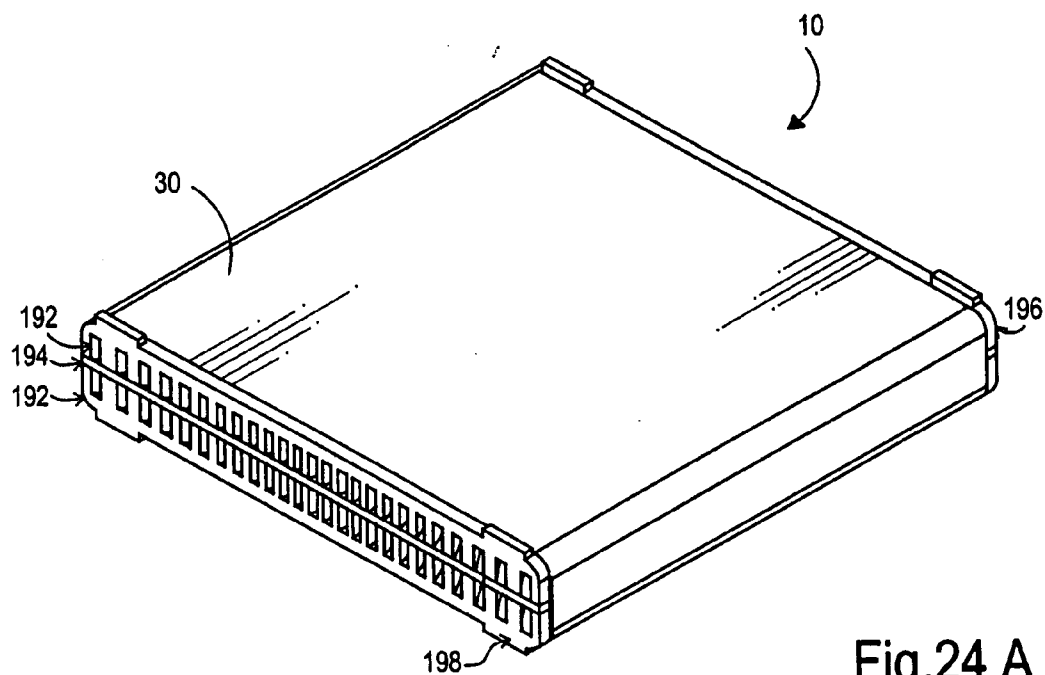


Fig. 24 A

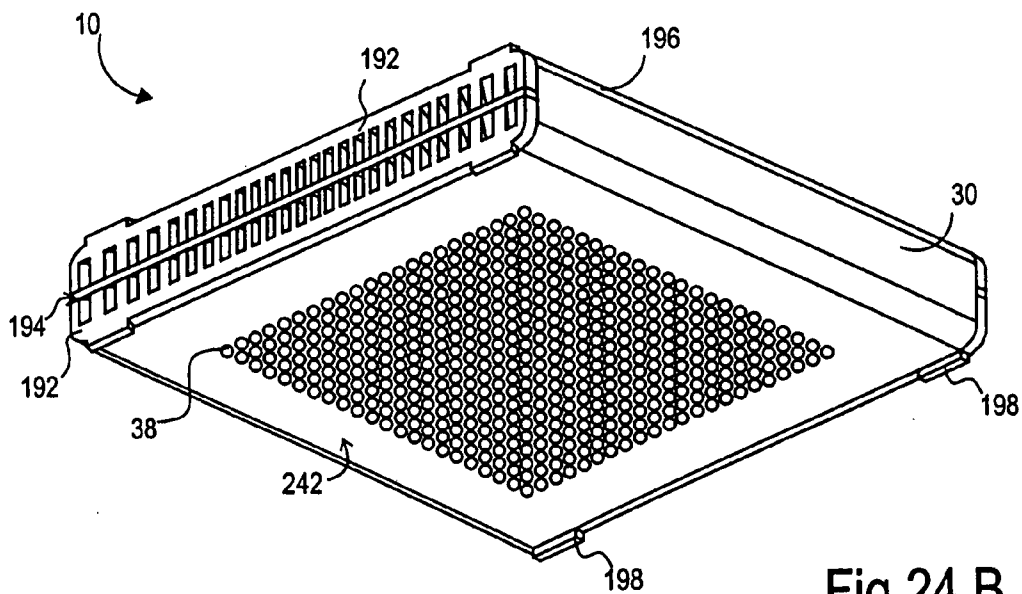


Fig. 24 B

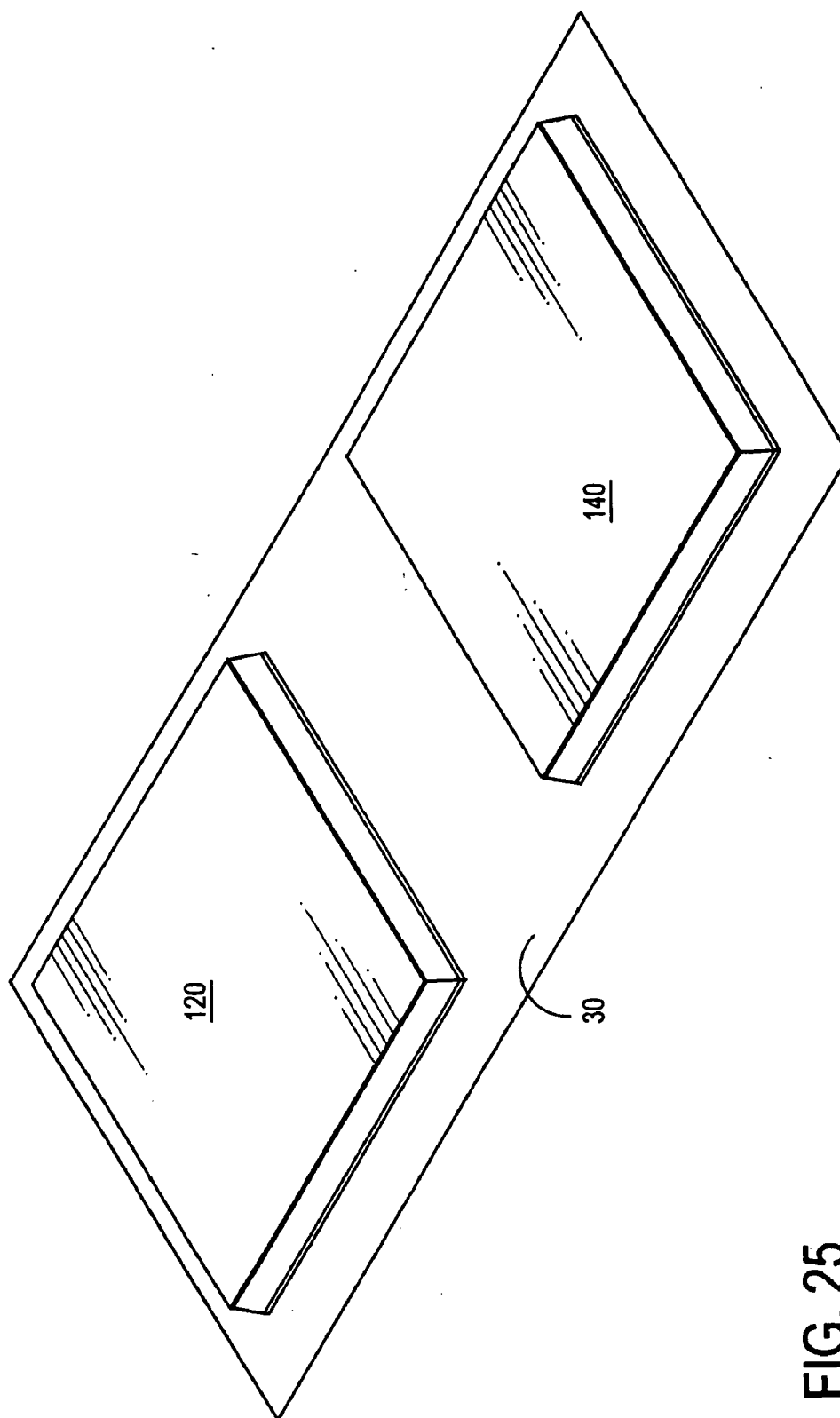
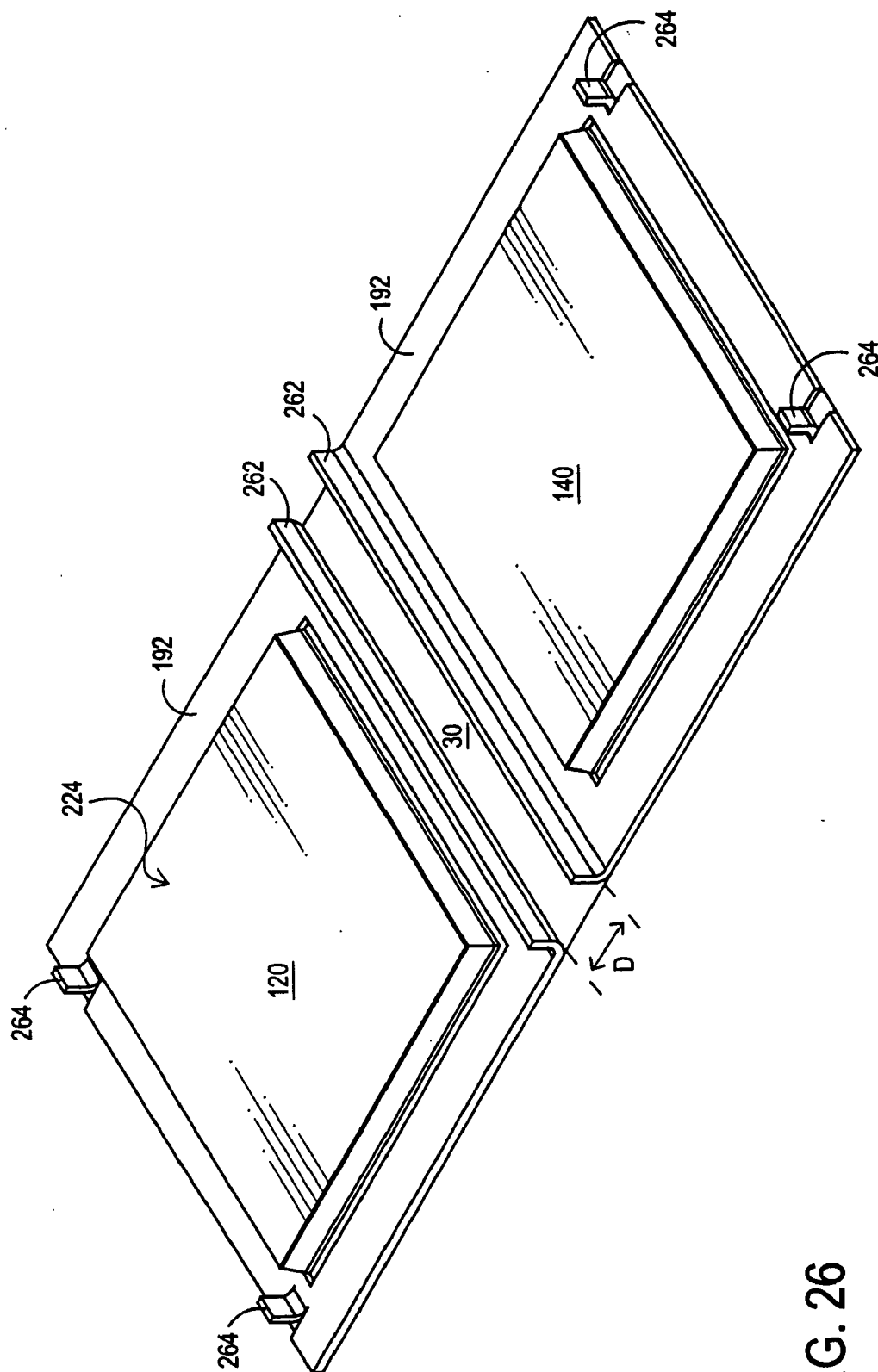


FIG. 25



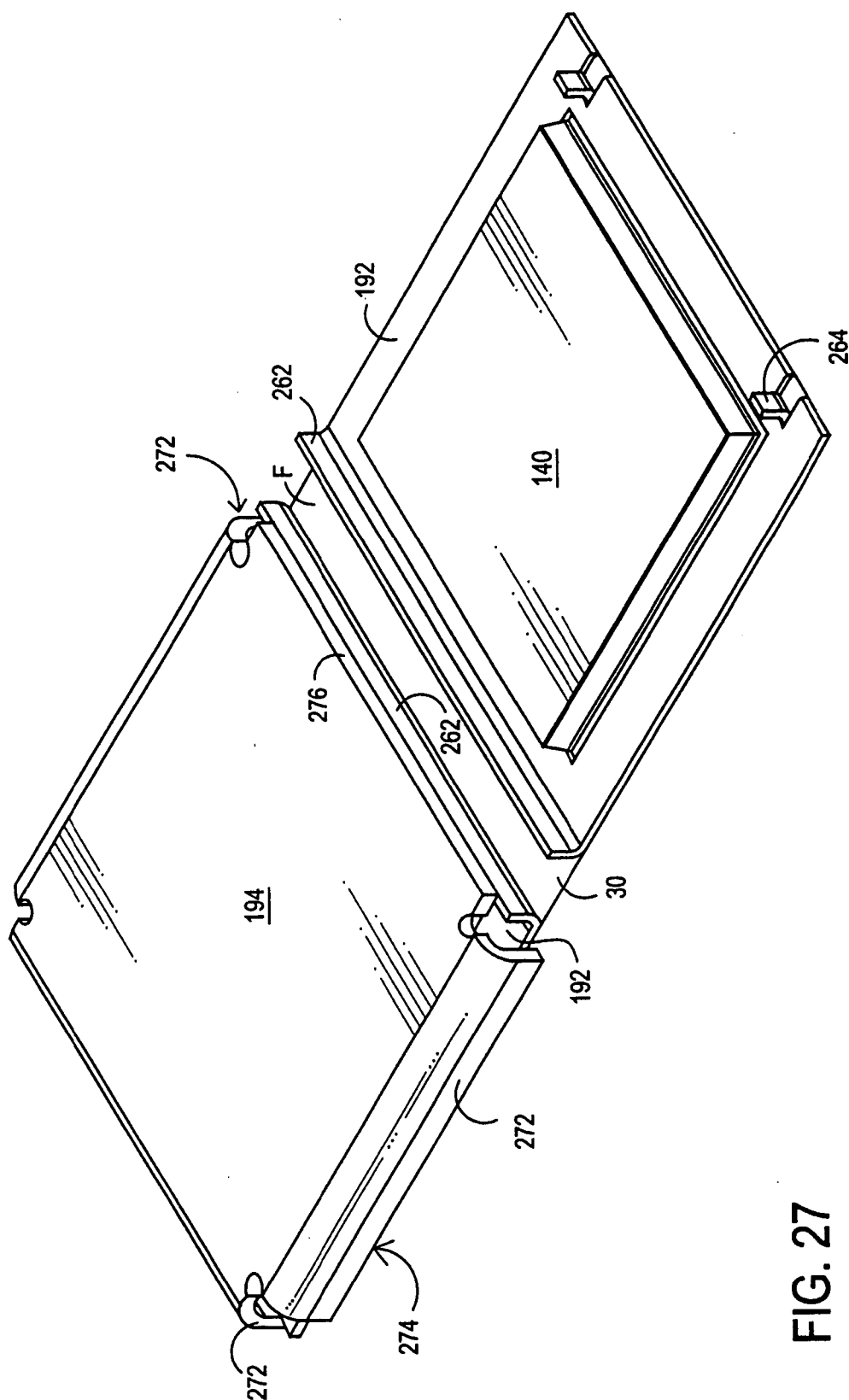


FIG. 27

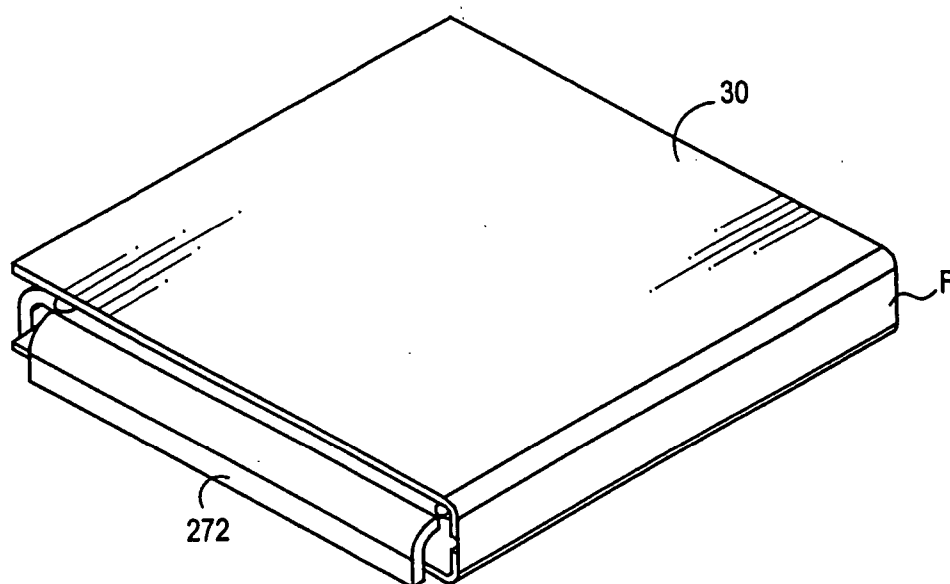


Fig. 28 A

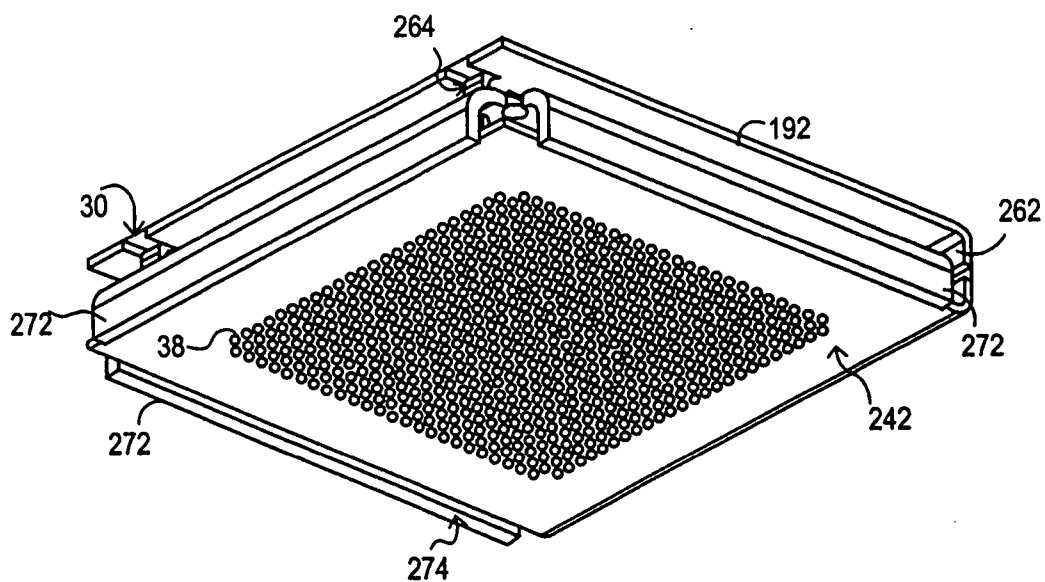


Fig. 28 B

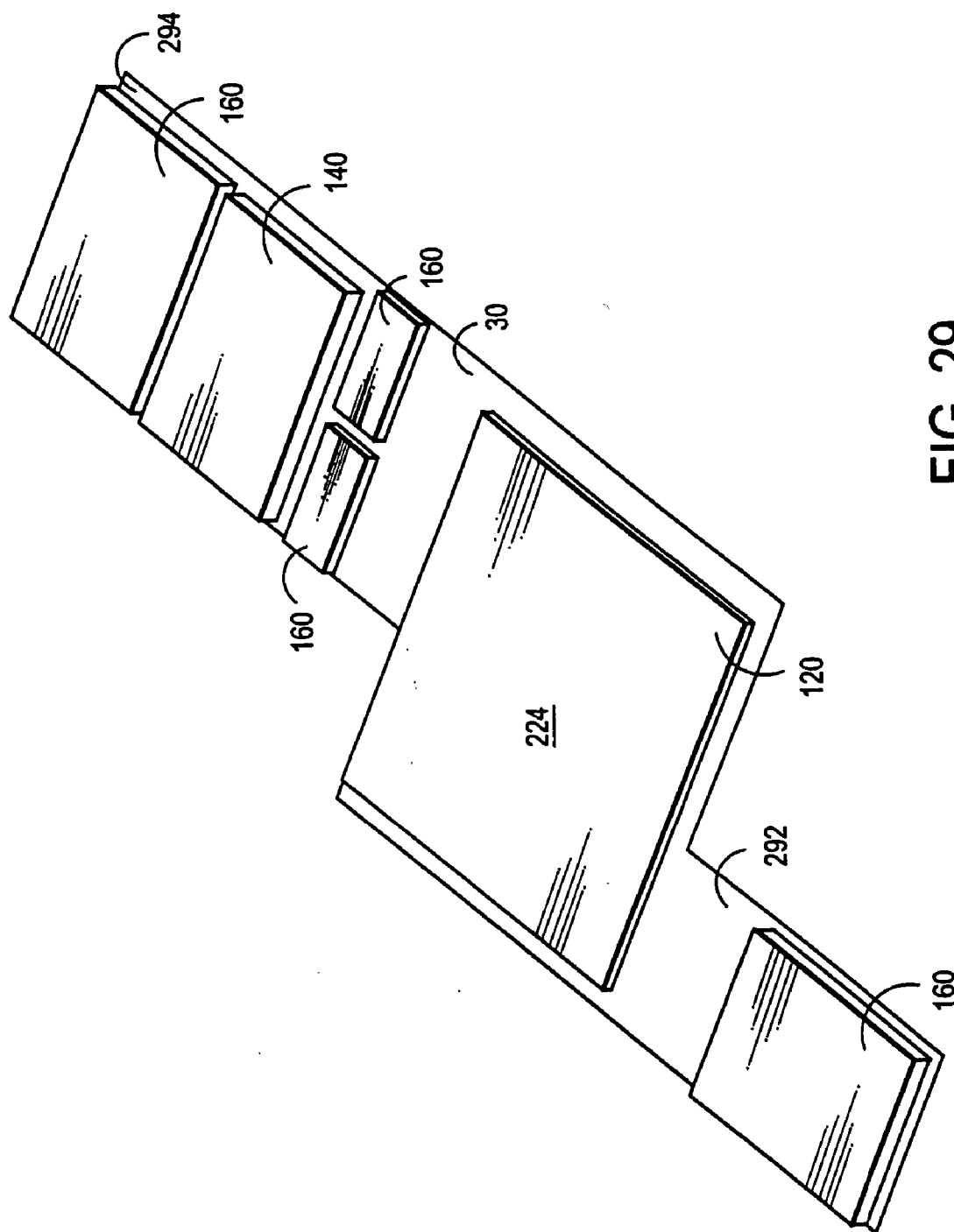
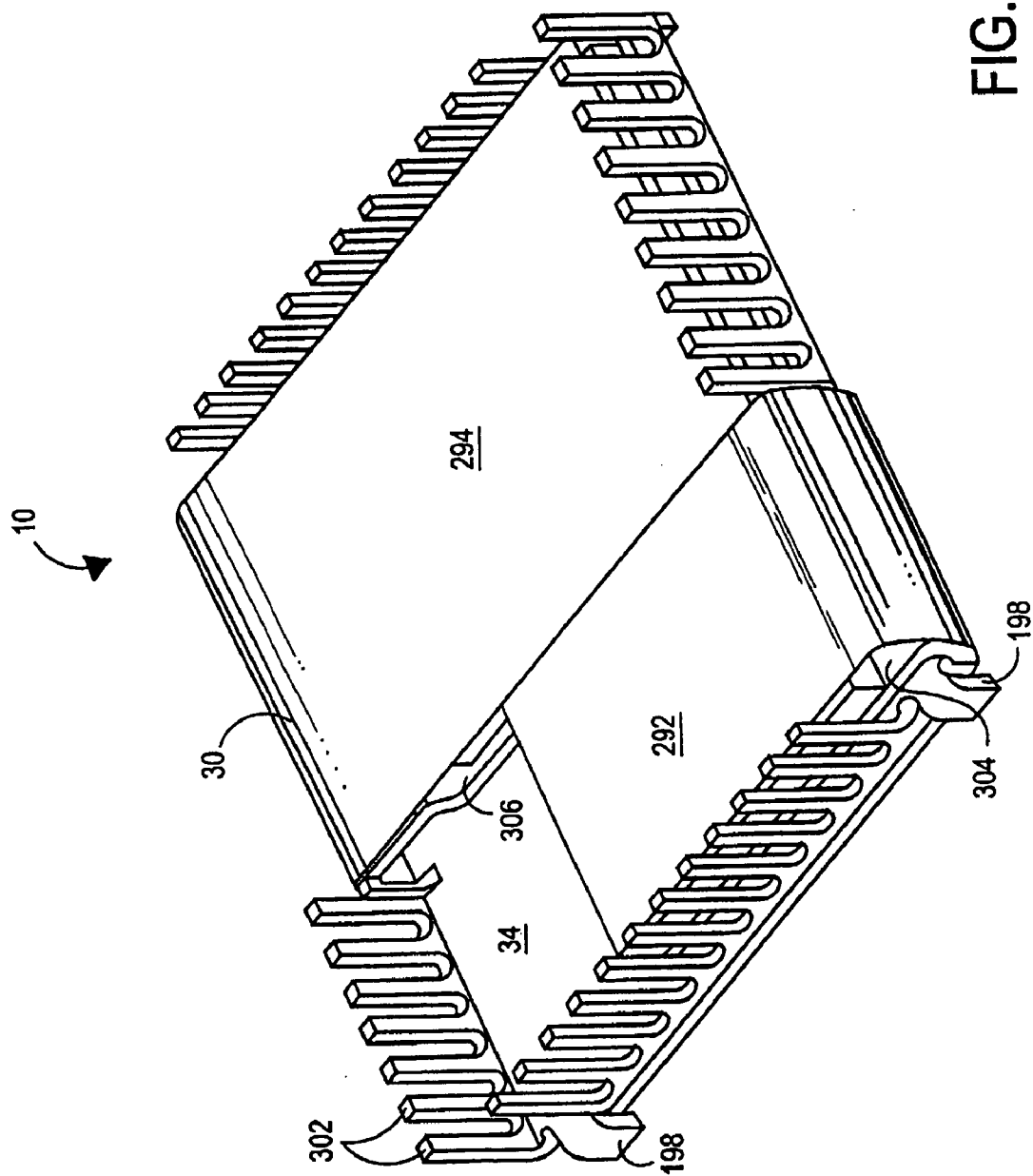


FIG. 29



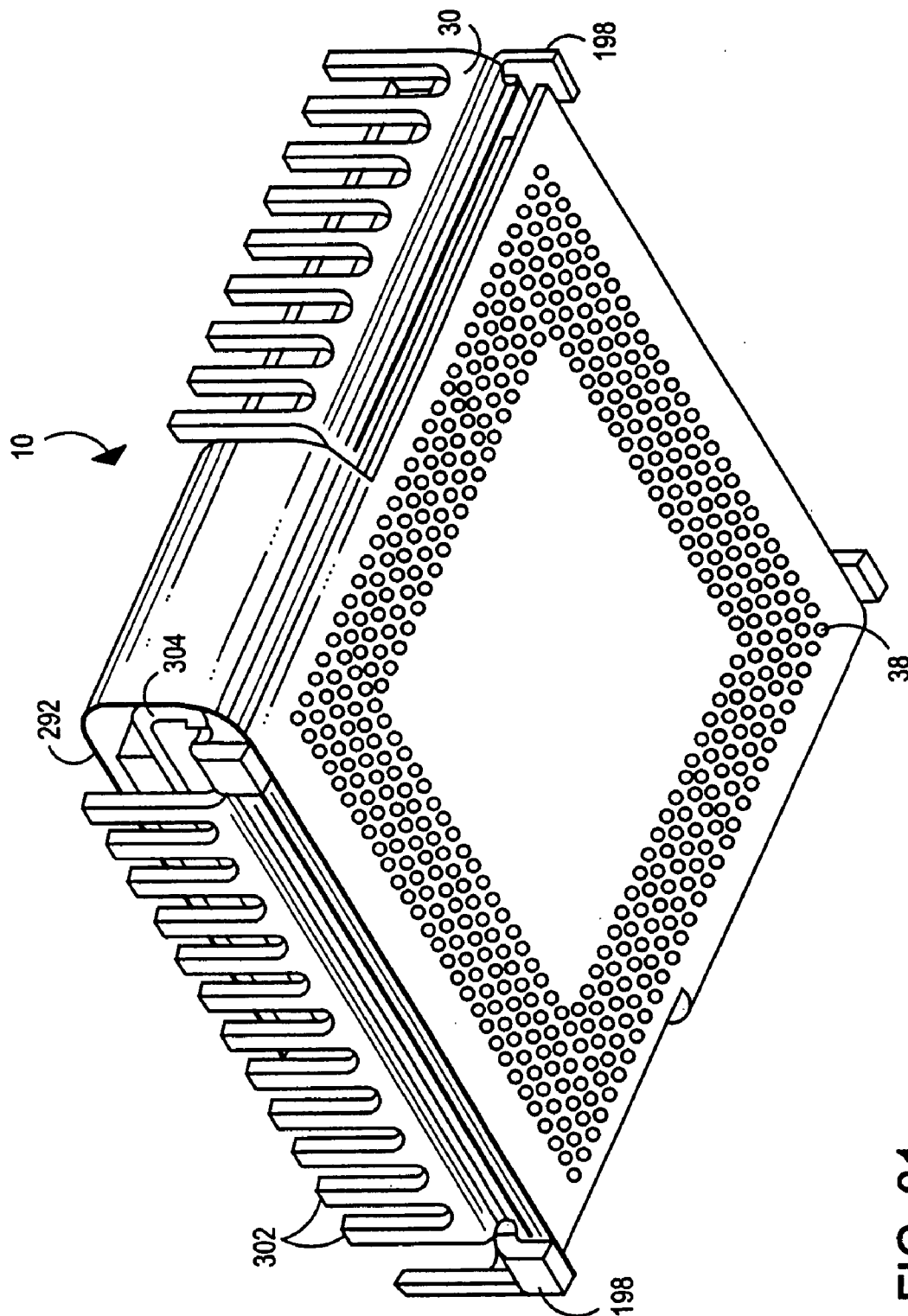


FIG. 31

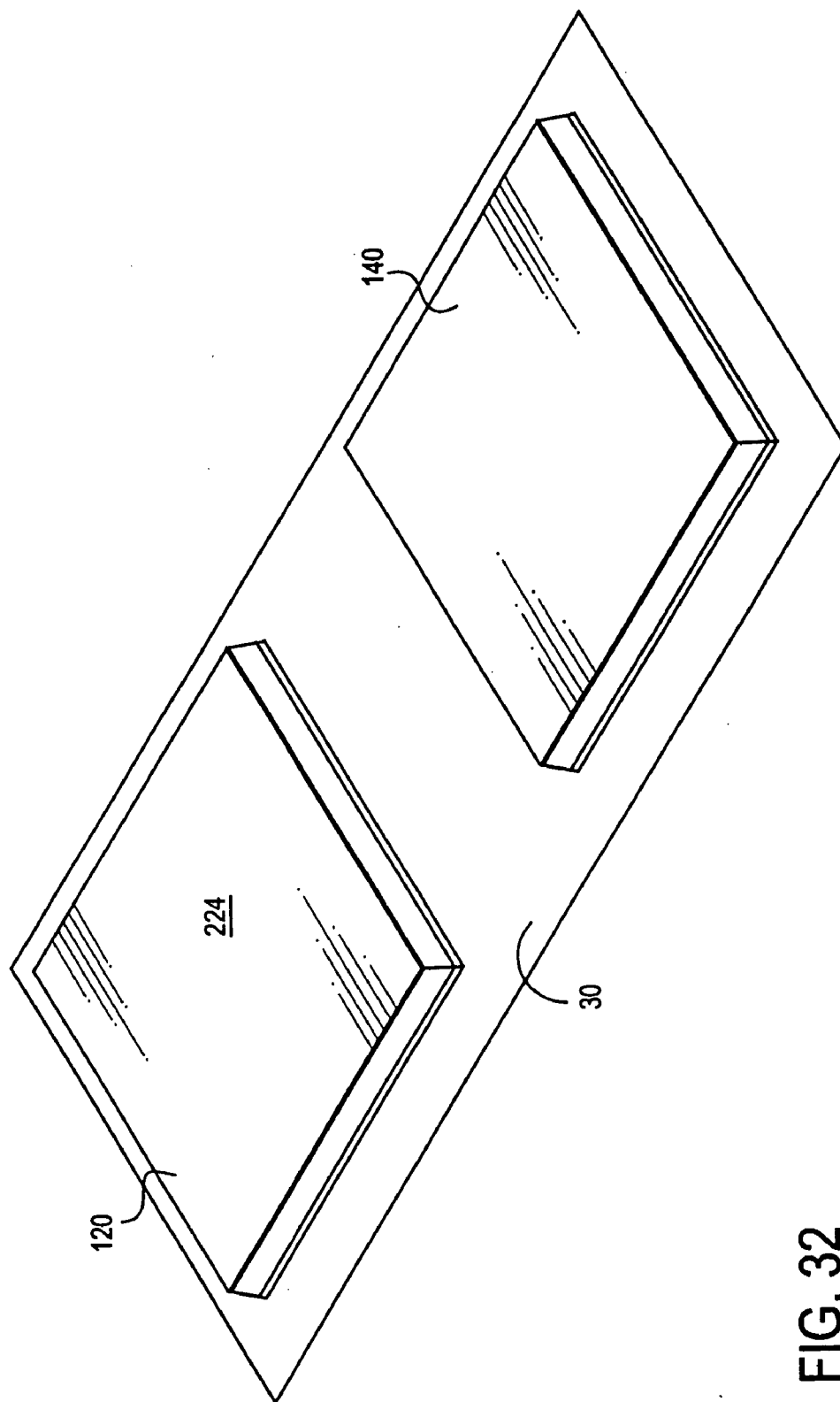


FIG. 32

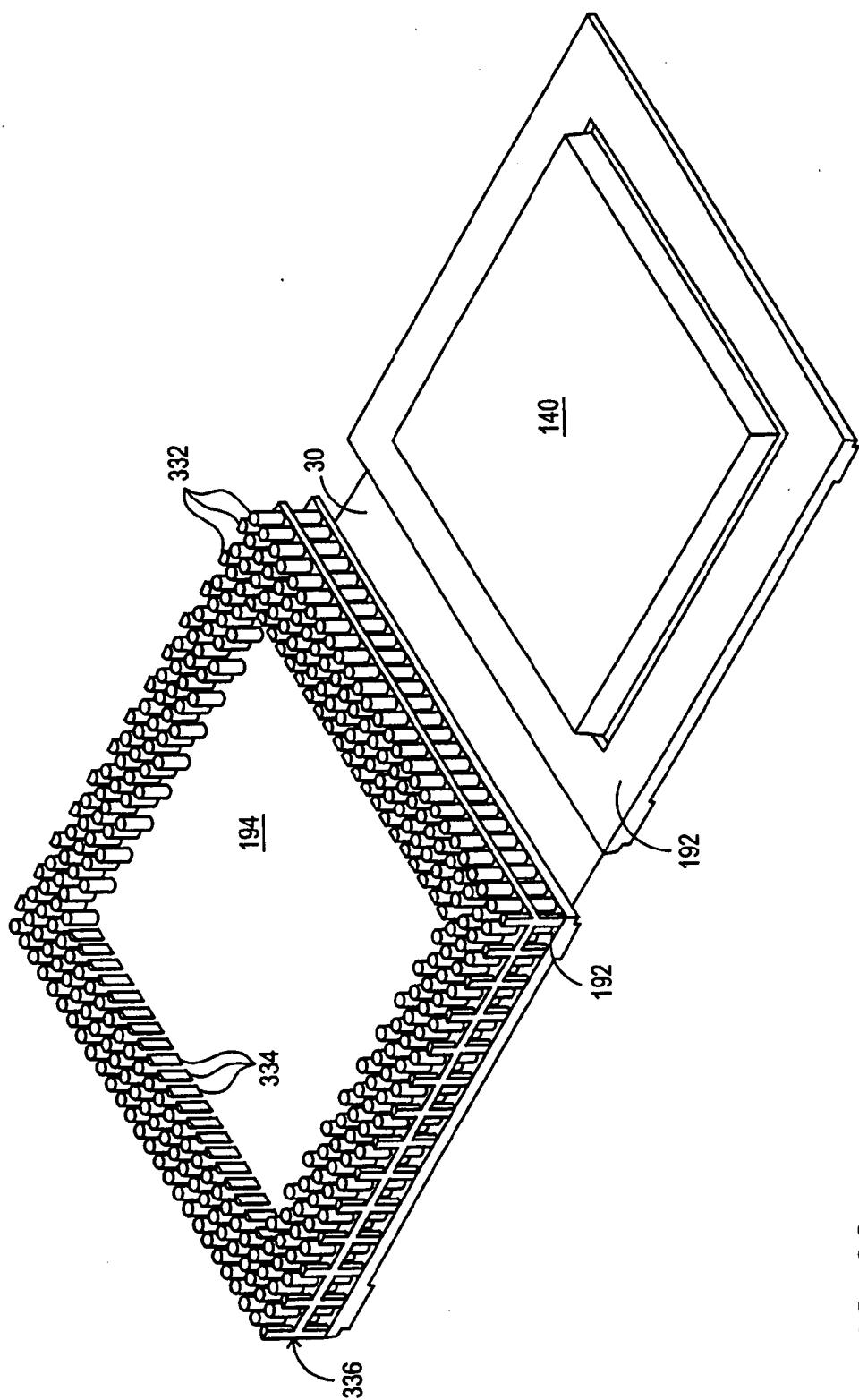


FIG. 33

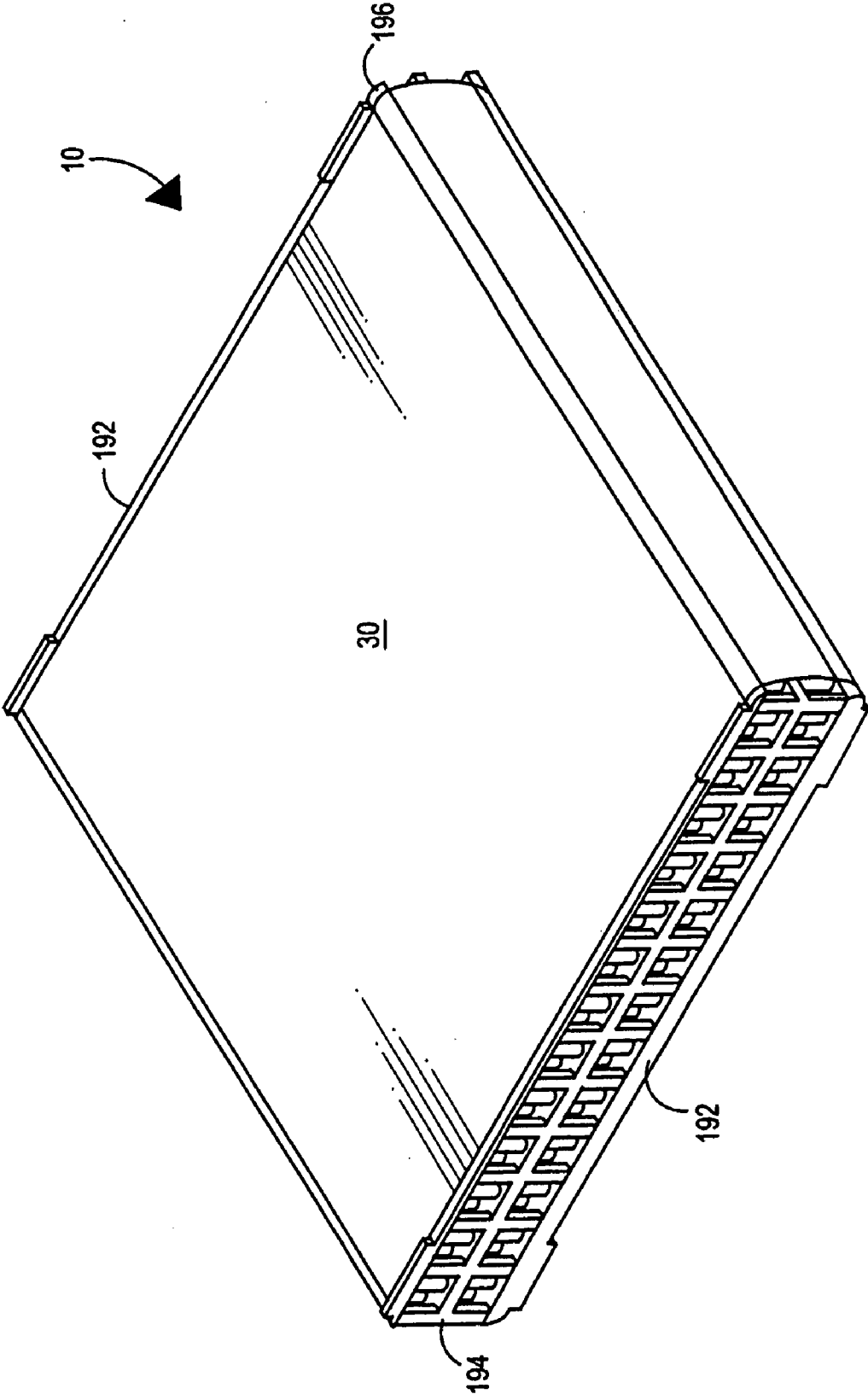


FIG. 34A

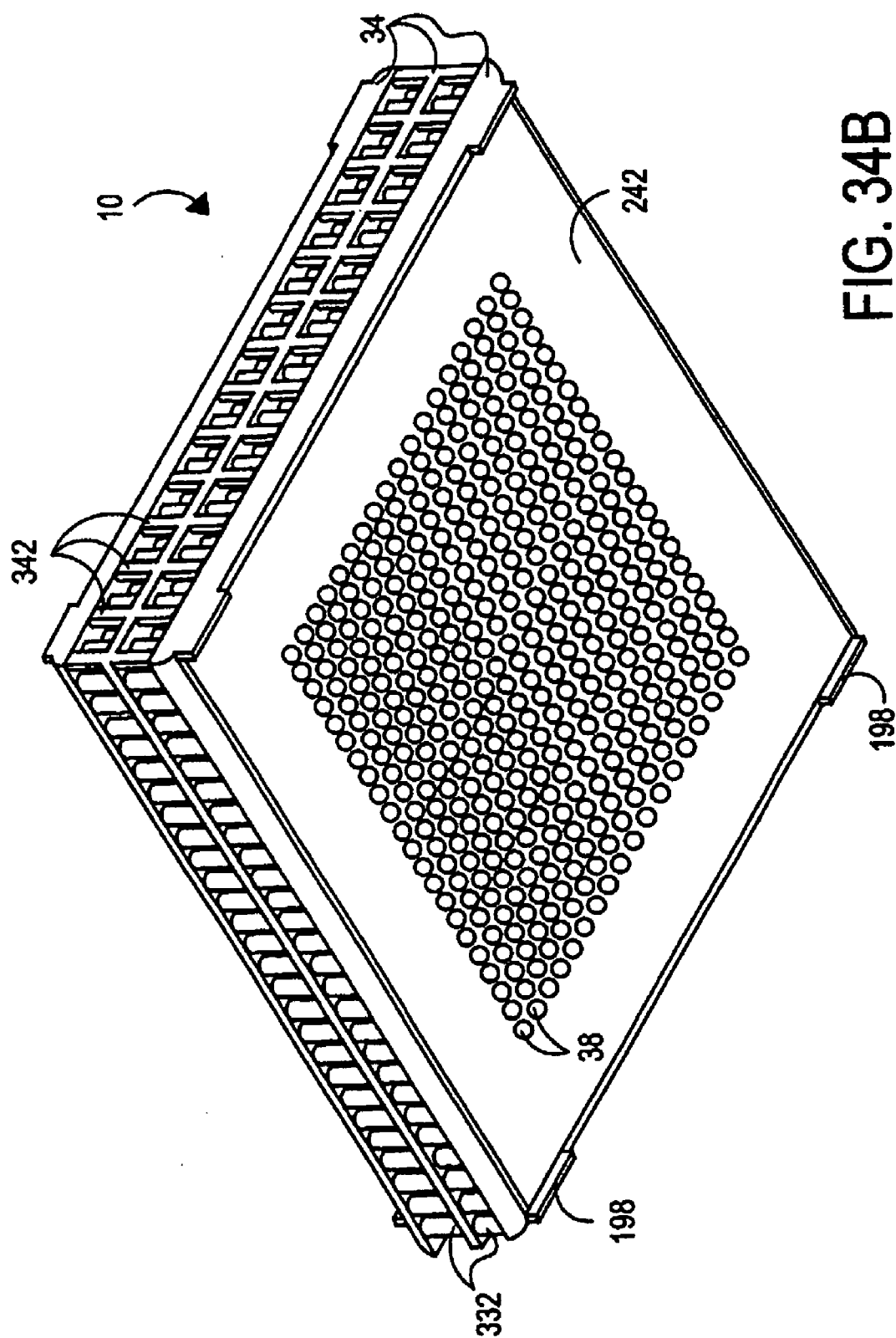


FIG. 34B

INTEGRATED CIRCUIT STACKING SYSTEM AND METHOD

RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 10/814,532, filed Mar. 31, 2004, pending.

[0002] U.S. patent application Ser. No. 10/814,532 is a continuation-in-part of PCT Pat. App. No. PCT/US03/29000, filed Sep. 15, 2003, pending, and a continuation-in-part of U.S. patent application Ser. No. 10/453,398, filed Jun. 3, 2003, pending, which is a continuation-in-part of U.S. patent application Ser. No. 10/005,581, filed Oct. 26, 2001, now U.S. Pat. No. 6,576,992.

TECHNICAL FIELD

[0003] The present invention relates to aggregating integrated circuits and, in particular, to stacking integrated circuits in chip-scale packages and providing such stacked integrated circuits on boards.

BACKGROUND OF THE INVENTION

[0004] A variety of techniques are used to stack packaged integrated circuits. Some methods require special packages, while other techniques stack conventional packages. In some stacks, the leads of the packaged integrated circuits are used to create a stack, while in other systems, added structures such as rails provide all or part of the interconnection between packages. In still other techniques, flexible conductors with certain characteristics are used to selectively interconnect packaged integrated circuits.

[0005] A predominant package configuration employed during the past decade has encapsulated an integrated circuit (IC) in a plastic surround typically having a rectangular configuration. The enveloped integrated circuit is connected to the application environment through leads emergent from the edge periphery of the plastic encapsulation. Such "leaded packages" have been the constituent elements most commonly employed by techniques for stacking packaged integrated circuits.

[0006] Leaded packages play an important role in electronics, but efforts to miniaturize electronic components and assemblies have driven development of technologies that preserve circuit board surface area. Because leaded packages have leads emergent from peripheral sides of the package, leaded packages occupy more than a minimal amount of circuit board surface area. Consequently, alternatives to leaded packages known as chip scale packaging or "CSP" have recently gained market share.

[0007] CSP refers generally to packages that provide connection to an integrated circuit through a set of contacts (often embodied as "bumps" or "balls") arrayed across a major surface of the package. Instead of leads emergent from a peripheral side of the package, contacts are placed on a major surface and typically emerge from the planar bottom surface of the package.

[0008] The goal of CSP is to occupy as little area as possible and, preferably, approximately the area of the encapsulated IC. Therefore, CSP leads or contacts do not typically extend beyond the outline perimeter of the pack-

age. The absence of "leads" on package sides renders most stacking techniques devised for leaded packages inapplicable for CSP stacking.

[0009] There are several known techniques for stacking packages articulated in chip scale technology. The assignee of the present invention has developed previous systems for aggregating FBGA packages in space saving topologies. The assignee of the present invention has systems for stacking BGA packages on a DIMM in a RAMBUS environment.

[0010] In U.S. Pat. No. 6,205,654 B1, owned by the assignee of the present invention, a system for stacking ball grid array packages that employs lead carriers to extend connectable points out from the packages is described. Other known techniques add structures to a stack of BGA-packaged ICs. Still others aggregate CSPs on a DIMM with angular placement of the packages. Such techniques provide alternatives, but require topologies of added cost and complexity.

[0011] Memory expansion is one of the many fields in which stacked module solutions provide advantages. For example, the well-known DIMM board is frequently populated with stacked modules from those such as the assignee of the present invention. This adds capacity to the board without adding sockets.

[0012] A memory expansion board such as a DIMM, for example, provides plural sites for memory IC placement (i.e., sockets) arranged along both major surfaces of a board having an array of contacts dispersed along at least one board edge. Although stacking reduces interconnect length per unit of memory, and thus takes advantage of the general rule that interconnects that are less than half the spatial extent of the leading edge of a signal operate as a lumped element more than a transmission line, it does increase the raw number of devices on a DIMM board. Consequently, despite the reduction in interconnect length per unit of memory, signals accessing data stored in memory circuits physically placed on the DIMM board are typically presented with relatively high impedance as the number of devices on the bus is increased by stacking.

[0013] What is needed are methods and structures for stacking circuits in thermally efficient, reliable structures that perform well at higher frequencies but do not exhibit excessive height yet allow production at reasonable cost with readily understood and managed materials and methods and addressing systems that allow significant reductions in interconnect lengths and/or loading when employed in memory expansion boards and design.

SUMMARY OF THE INVENTION

[0014] The present invention stacks integrated circuits (ICs) into modules that conserve PWB or other board surface area. The present invention can be used to advantage with CSP or leaded packages of a variety of sizes and configurations ranging from larger packaged base elements having many dozens of contacts to smaller packages such as, for example, die-sized packages such as DSBGA.

[0015] Multiple numbers of CSPs may be stacked in accordance with the present invention. A four-high CSP stacked module is preferred for use with the disclosed high performance memory access system while, for many applications, a two-high CSP stack or module devised in accor-

dance with a preferred embodiment of the present invention is preferred. The ICs employed in stacked modules devised in accordance with the present invention are connected with flex circuitry. That flex circuitry may exhibit one or two or more conductive layers with preferred embodiments having two conductive layers.

[0016] A form standard provides a physical form that allows many of the varying package sizes found in the broad family of CSP packages to be used to advantage while employing a standard connective flex circuitry design. In preferred modules, the flex circuitry is partially wrapped about a form standard. The form standard can take many configurations and may be used where flex circuitry is used to connect ICs to one another in stacked modules having two or more constituent ICs. For example, in stacked modules that include four levels of CSPs, three form standards are employed in preferred embodiments, although fewer may be used. In a preferred embodiment, the form standard will be devised of heat transference material, a metal for example, such as copper would be preferred, to improve thermal performance.

[0017] In an alternative preferred embodiment devised in accordance with the present invention, a base element IC and one or more support element ICs are aggregated through a flex circuit having two conductive layers that are patterned to selectively connect the two IC elements. Simpler embodiments may use a one conductive layer flex. A portion of the flex circuit connected to the support element is folded over the base element and about the form standard to dispose the support element(s) above the base element while reducing the overall footprint occupied by the ICs. The flex circuit connects the ICs and provides a thermal and electrical connection path between the module and an application environment such as a printed wiring board (PWB).

[0018] In another aspect, the invention provides a lower capacitance memory expansion addressing system and method and preferably with the CSP stacked modules provided herein. In a preferred embodiment of the present invention, four-high stacked CSP modules are disposed on a memory expansion board(s) in accordance with the memory expansion system and methods of the present invention which may be employed with CSP or other IC stacked modules. A high speed switching system selects a data line associated with each level of a stacked module to reduce the loading effect upon data signals in memory access. This favorably changes the impedance characteristics exhibited by the board loading. The high speed DQ selection switch may be implemented, in a preferred embodiment, for example, with a high speed FET switch. FET multiplexers, for example, under logic control, select particular data lines associated with particular levels of the DIMM-populated stacked modules for connection to a controlling chip set in a memory expansion system in accordance with a preferred embodiment.

SUMMARY OF THE DRAWINGS

[0019] FIG. 1 is an elevation view of a high-density circuit module devised in accordance with a preferred four-high embodiment of the present invention.

[0020] FIG. 2 is an elevation view of a stacked high-density circuit module devised in accordance with a preferred two-high embodiment of the present invention.

[0021] FIG. 3 depicts, in enlarged view, the area marked "A" in FIG. 2.

[0022] FIG. 4 depicts in enlarged view, the area marked "B" in FIG. 2.

[0023] FIG. 5 is an enlarged depiction of an exemplar connection area in a stacked module devised in accordance with a preferred embodiment.

[0024] FIG. 6 depicts a flexible circuit connective set of flex circuits that has a single conductive layer.

[0025] FIG. 7 depicts a four-high stacked module mounted on a memory expansion board in accordance with a preferred embodiment of the present invention.

[0026] FIG. 8 depicts a memory expansion board or DIMM mounted with four-high modules.

[0027] FIG. 9 depicts a memory system devised in accordance with the present invention.

[0028] FIG. 10 is an elevation view of a module illustrating features of an alternative preferred embodiment of the present invention.

[0029] FIG. 11 is an elevation view of a module depicting features of an alternative preferred embodiment of the present invention.

[0030] FIG. 12 is an elevation view of a module depicting features of an alternative preferred embodiment.

[0031] FIG. 13 is another view depicting features of an alternative preferred embodiment of the present invention.

[0032] FIG. 14 is an elevation view of a module that depicts an alternative preferred embodiment of the present invention.

[0033] FIG. 15 depicts, in enlarged view, the area marked "C" in FIG. 14.

[0034] FIG. 16 depicts in enlarged view, an alternative connection strategy between constituent elements of a module and a flex in a preferred embodiment in accordance with the present invention.

[0035] FIG. 17 depicts an exemplar first conductive layer of a flex employed in a preferred embodiment of the invention.

[0036] FIG. 18 depicts an exemplar second conductive layer of a flex employed in a preferred embodiment of the invention.

[0037] FIG. 19 depicts another alternative embodiment of the present invention.

[0038] FIG. 20 is a side view of the embodiment of the invention depicted in FIG. 19 taken along the direction of the arrow marked 200.

[0039] FIG. 21 depicts an early assembly stage of another embodiment of the present invention

[0040] FIG. 22 depicts an assembly stage, later than that depicted in FIG. 21, of another embodiment of the present invention.

[0041] FIG. 23 depicts an assembly stage, later than that depicted in FIG. 22, of another embodiment of the present invention.

[0042] FIG. 24 depicts an assembly stage, later than that depicted in FIG. 23, of another embodiment of the present invention.

[0043] FIG. 25 depicts an early assembly stage of yet another embodiment of the present invention.

[0044] FIG. 26 depicts an assembly stage, later than that depicted in FIG. 25, of another embodiment of the present invention.

[0045] FIG. 27 depicts an assembly stage, later than that depicted in FIG. 26, of another embodiment of the present invention.

[0046] FIG. 28 depicts an assembly stage, later than that depicted in FIG. 27, of another embodiment of the present invention. FIG. 29 depicts an early assembly stage of yet another embodiment of the present invention.

[0047] FIG. 30 depicts an assembly stage, later than that depicted in FIG. 29, of another embodiment of the present invention.

[0048] FIG. 31 depicts the alternative embodiment of the present invention depicted in FIG. 30, from another perspective slightly below module 10.

[0049] FIG. 32 depicts an early assembly stage of another embodiment of the present invention.

[0050] FIG. 33 depicts an assembly stage, later than that depicted in FIG. 32, of another embodiment of the present invention.

[0051] FIG. 34 depicts an assembly stage, later than that depicted in FIG. 33, of another embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0052] FIG. 1 is an elevation view of module 10 devised in accordance with a preferred embodiment of the present invention. Module 10 is comprised of four CSPs: level four CSP 12, level three CSP 14, level two CSP 16, and level one CSP 18. Each of the CSPs has an upper surface 20 and a lower surface 22 and opposite lateral edges 24 and 26 and typically include at least one integrated circuit surrounded by a plastic body 27. The body need not be plastic, but a large majority of packages in CSP technologies are plastic. Those of skill will realize that the present invention may be devised to create modules with different size CSPs and that the constituent CSPs may be of different types within the same module 10. For example, one of the constituent CSPs may be a typical CSP having lateral edges 24 and 26 that have an appreciable height to present a "side" while other constituent CSPs of the same module 10 may be devised in packages that have lateral edges 24 and 26 that are more in the character of an edge rather than a side having appreciable height.

[0053] The invention is used with CSP packages of a variety of types and configurations such as, for example, those that are die-sized, as well those that are near chip-scale as well as the variety of ball grid array packages known in the art. It may also be used with those CSP-like packages that exhibit bare die connectives on one major surface. Thus, the term "CSP" should be broadly considered in the context of this application. Collectively, these will be known herein

as chip scale packaged integrated circuits (CSPs) and some preferred embodiments will be described in terms of CSPs, but the particular configurations used in the explanatory figures are not, however, to be construed as limiting.

[0054] A variety of combinations of packages including leaded and CSP and other configurations of packaged ICs may be employed to advantage by the invention. For example, the elevation views of FIGS. 1 and 2 are depicted with CSPs of a particular profile known to those in the art, but it should be understood that the figures are exemplary only.

[0055] Later figures show embodiments of the invention that employ CSPs of other configurations aggregated with leaded packages as an example of some of the many alternative IC package configurations and combinations with which the invention may be employed. A system of the invention may also be employed with leaded packages while the module itself presents an array of bumps or balls to the application environment.

[0056] Typical CSPs, such as, for example, ball-grid-array ("BGA"), micro-ball-grid array, and fine-pitch ball grid array ("FBGA") packages have an array of connective contacts embodied, for example, as leads, bumps, solder balls, or balls that extend from lower surface 22 of a plastic casing in any of several patterns and pitches. An external portion of the connective contacts is often finished with a ball of solder. Shown in FIG. 1 are contacts 28 along lower surfaces 22 of the illustrated constituent CSPs 12, 14, 16, and 18. Contacts 28 provide connection to the integrated circuit or circuits within the respective packages. In embodiments of the present invention, module 10 may be devised to present a lower profile by stripping from the respective CSPs, the balls depicted in FIG. 1 as contacts 28 and providing a connection facility at contact 28 that results from solder paste that is applied either to the pad contact of the CSP that is typically present under or within the typical ball contacts provided on CSP devices or to the contact sites on the flex circuitry to be connected to contact 28.

[0057] In FIG. 1, iterations of flex circuits ("flex", "flex circuits" or "flexible circuit structures") 30 and 32 are shown connecting various constituent CSPs. Some embodiments may employ more than one flex. The entire flex circuit may be flexible or, as those of skill in the art will recognize, a PCB structure made flexible in certain areas to allow conformability in some areas and rigid in other areas for planarity along contact surfaces may be employed as an alternative flex circuit in the present invention. For example, structures known as rigid-flex may be employed.

[0058] Form standard 34 is shown disposed adjacent to upper surface 20 of each of the CSPs below level four CSP 12. Form standard 34 may be fixed to upper surface 20 of the respective CSP with an adhesive 35 which preferably is thermally conductive. Form standard 34 may also, in alternative embodiments, merely lay on upper surface 20 or be separated from upper surface 20 by an air gap or medium such as a thermal slug or non-thermal layer. In other embodiments, form standard 34 may be inverted relative to the corresponding CSP so that, for example, it would be opened over the upper surface 20 of CSP 18. Further, a form standard may be employed on each CSP in module 10 for heat extraction enhancement. However, where form standard 34 is a thermally conductive material such as the copper

that is employed in a preferred embodiment, layers or gaps interposed between form standard **34** and the respective CSP (other than thermally conductive layers such as adhesive) are not highly preferred.

[0059] Form standard **34** is, in a preferred embodiment, devised from copper to create, as shown in the depicted preferred embodiment of **FIG. 1**, a mandrel that mitigates thermal accumulation while providing a standard sized form about which flex circuitry is disposed. Form standard **34** may take other shapes and forms such as for example, an angular “cap” that rests upon the respective CSP body or as another example, it may be folded to increase its cooling surface area while providing an appropriate axial form for the flex that is wrapped about a part of form standard **34** as shown in later **FIG. 14**. It also need not be thermally enhancing although such attributes are preferable. The form standard **34** allows the invention to be employed with CSPs of varying sizes, while articulating a single set of connective structures useable with the varying sizes of CSPs. Thus, a single set of connective structures such as flex circuits **30** and **32** (or a single flexible circuit in the mode where a single flex is used in place of the flex circuit pair **30** and **32**) may be devised and used with the form standard **34** method and/or systems disclosed herein to create stacked modules with CSPs having different sized packages. This will allow the same flexible circuitry set design to be employed to create iterations of a stacked module **10** from constituent CSPs having a first arbitrary dimension X across attribute Y (where Y may be, for example, package width), as well as modules **10** from constituent CSPs having a second arbitrary dimension X prime across that same attribute Y. Thus, CSPs of different sizes may be stacked into modules **10** with the same set of connective structures (i.e. flex circuitry). Further, as those of skill will recognize, mixed sizes of CSPs may be implemented into the same module **10**, such as would be useful to implement embodiments of a system-on-a-stack an example of which is shown in **FIG. 14**.

[0060] Preferably, portions of flex circuits **30** and **32** are fixed to form standard **34** by adhesive **35** which is preferably a tape adhesive, but may be a liquid adhesive or may be placed in discrete locations across the package. Preferably, adhesive **35** is thermally conductive.

[0061] In a preferred embodiment, flex circuits **30** and **32** are multi-layer flexible circuit structures that have at least two conductive layers. Other embodiments may, however, employ flex circuitry, either as one circuit or two flex circuits, that have only a single conductive layer.

[0062] Preferably, the conductive layers are metal such as alloy **110**. The use of plural conductive layers provides advantages and the creation of a distributed capacitance across module **10** intended to reduce noise or bounce effects that can, particularly at higher frequencies, degrade signal integrity, as those of skill in the art will recognize. Module **10** of **FIG. 1** has plural module contacts **38** collectively identified as module array **40**. Connections between flex circuits are shown as being implemented with inter-flex contacts **43** which are shown as balls but may be low profile contacts constructed with pads and/or rings that are connected with solder paste applications to appropriate connections. Appropriate fills such as those indicated by conformal media reference **41** can provide added structural stability

and coplanarity where desired. Media **41** is shown only as to CSPs **14** and **16** and only on one side to preserve clarity of view.

[0063] **FIG. 2** shows a two-high module **10** devised in accordance with a preferred embodiment of the invention. **FIG. 2** has an area marked “A” that is subsequently shown in enlarged depiction in **FIG. 3** and an area marked “B” that is shown subsequently in enlarged depiction in **FIG. 4**.

[0064] **FIG. 3** depicts in enlarged view, the area marked “A” in **FIG. 2**. **FIG. 3** illustrates in a preferred embodiment, one arrangement of a form standard **34** and its relation to flex circuitry **32** in a two-high module **10**. The internal layer constructions of flex circuitry **32** are not shown in this figure. Also shown are adhesives **35** between flex circuit **32** and form standard **34**. Those of skill will note that adhesive **35** is not required but is preferred and the site of its application may be determined as being best for this embodiment in the area between CSPs with a smaller amount near the terminal point of form standard **34** as shown in **FIG. 3**. Also shown in **FIG. 3** is an application of adhesive **36** between form standard **34** and CSP **18**.

[0065] **FIG. 4** illustrates the connection between example contact **28** and module contact **38** through a lower flex contact **44** to illustrate a preferred solid metal path from level one CSP **18** to module contact **38** and, therefore, to an application PWB or memory expansion board to which the module is connectable. As depicted in **FIG. 4** lower flex contact **44** is preferably comprised from metal at the level of second conductive layer **58** interior to second outer surface **52**. As those of skill in the art will understand, heat transference from module **10** is thereby encouraged.

[0066] Flex circuitry **30** is shown in **FIG. 4** to be comprised of multiple layers. This is merely an exemplar flexible circuitry that may be employed with the present invention. Single conductive layer and other variations on the described flexible circuitry may, as those of skill will recognize, be employed to advantage in the present invention. Flex circuitry **30** has a first outer surface **50** and a second outer surface **52**. Flex circuit **30** has at least two conductive layers interior to first and second outer surfaces **50** and **52**. There may be more than two conductive layers in flex circuitry **30** and flex **32**. In the depicted preferred embodiment, first conductive layer or plane **54** and second conductive layer or plane **58** are interior to first and second outer surfaces **50** and **52**. Intermediate layer **56** lies between first conductive layer **54** and second conductive layer **58**. There may be more than one intermediate layer, but one intermediate layer of polyimide is preferred.

[0067] **FIG. 5** is an enlarged depiction of an exemplar area around a lower flex contact **44** in a preferred embodiment. Windows **60** and **62** are opened in first and second outer surface layers **50** and **52** respectively, to provide access to particular lower flex contacts **44** residing at the level of second conductive layer **58** in the flex. In a two-high embodiment of module **10**, the upper flex contacts **42** are contacted by contacts **28** of second level CSP **16**. In the depicted preferred embodiment, lower flex contacts **44** and upper flex contacts **42** are particular areas of conductive material (preferably metal such as alloy **110**) at the level of second conductive layer **58** in the flex. Upper flex contacts **42** and lower flex contacts **44** are demarked in second conductive layer **58** and may be connected to or isolated

from the conductive plane of second conductive layer 58. Demarking a lower flex contact 44 from second conductive layer 58 is represented in FIG. 5 by demarcation gap 63 shown at second conductive layer 58. Where an upper or lower flex contact 42 or 44 is not completely isolated from second conductive layer 58, demarcation gaps do not extend completely around the flex contact. Contacts 28 of first level CSP 18 pass through a window 60 opened through first outer surface layer 50, first conductive layer 54, and intermediate layer 56, to contact an appropriate lower flex contact 44. Window 62 is opened through second outer surface layer 52 through which module contacts 38 pass to contact the appropriate lower flex contact 44.

[0068] Respective ones of contacts 28 of second level CSP 16 and first level CSP 18 are connected at the second conductive layer 58 level in flex circuits 30 and 32 to interconnect appropriate signal and voltage contacts of the two CSPs. In a preferred embodiment, respective contacts 28 of second level CSP 16 and first level CSP 18 that convey ground (VSS) signals are connected at the first conductive layer 54 level in flex circuits 30 and 32 by vias that pass through intermediate layer 56 to connect the levels as will subsequently be described in further detail. Thereby, CSPs 16 and 18 are connected. Consequently, when flex circuits 30 and 32 are in place about first level CSP 18, respective contacts 28 of each of CSPs 16 and 18 are in contact with upper and lower flex contacts 42 and 44, respectively. Selected ones of upper flex contacts 42 and lower flex contacts 44 are connected. Consequently, by being in contact with lower flex contacts 44, module contacts 38 are in contact with both CSPs 16 and 18.

[0069] In a preferred embodiment, module contacts 38 pass through windows 62 opened in second outer layer 52 to contact lower CSP contacts 44. In some embodiments, as is shown in FIG. 16, module 10 will exhibit a module contact array that has a greater number of contacts than do the constituent CSPs of module 10. In such embodiments, some of module contacts 38 may contact lower flex contacts 44 that do not contact one of the contacts 28 of first level CSP 18 but are connected to contacts 28 of second level CSP 16. This allows module 10 to express a wider datapath than that expressed by the constituent CSPs. A module contact 38 may also be in contact with a lower flex contact 44 to provide a location through which different ICs in the module may be enabled when no unused contacts are available or convenient for that purpose.

[0070] In a preferred embodiment, first conductive layer 54 is employed as a ground plane, while second conductive layer 58 provides the functions of being a signal conduction layer and a voltage conduction layer. Those of skill will note that roles of the first and second conductive layers may be reversed with attendant changes in windowing and use of commensurate interconnections.

[0071] FIG. 6 depicts a flexible circuit connective set of flex circuits 30 and 32 that has a single conductive layer 64. It should be understood with reference to FIG. 6 that flex circuits 30 and 32 extend further than shown and have portions which are, in the construction of module 10 brought about the curvature areas 66 of form standard 34 that mark the lateral extent of this example of a preferred form standard and are then disposed above the body of CSP 18 or the respective CSP of the module and therefore, the form

standard. In this single conductive layer flex embodiment of module 10, there are shown first and second outer layers 50 and 52 and intermediate layer 56. Also shown in FIG. 6 are a set of single layer lower flex contacts 68 demarked at the level of conductive layer 64.

[0072] Form standard 34 is shown attached to the body 27 of first level CSP 18 through an adhesive. In some embodiments, it may also be positioned to directly contact body 27 of the respective CSP. Form standard 34 may take many different configurations to allow a connective flex circuitry to be prepared exhibiting a single set of dimensions which may, when used in conjunction with form standard 34, be employed to create stacked modules 10 from CSPs of a variety of different dimensions. In a preferred embodiment, form standard 34 will present a lateral extent broader than the upper major surface of the CSP over which it is disposed. Thus, the CSPs from one manufacturer may be aggregated into a stacked module 10 with the same flex circuitry used to aggregate CSPs from another manufacturer into a different stacked module 10 despite the CSPs from the two different manufacturers having different dimensions.

[0073] Further, heat transference can be improved with use of a form standard 34 comprised of heat transference material such as a metal or preferably, copper or a copper compound or alloy to provide a significant sink for thermal energy. Such thermal enhancement of module 10 particularly presents opportunities for improvement of thermal performance where larger numbers of CSPs are aggregated in a single stacked module 10.

[0074] FIG. 7 depicts a four-high stacked module 10 mounted on a memory expansion board 70 in accordance with a preferred embodiment of the present invention. As do typical DIMM boards, expansion board 70 shown in FIG. 7 has a set of contacts along one edge that as depicted are set in socket connector 72. Those contacts connect module 10 to a logic system on or connected to board 74 on which expansion board 70 is mounted. It should be understood that in a preferred embodiment of the memory expansion system and method provided herein, expansion board 70 will be populated with nine such modules 10 per side for a total of 72 devices if the stacked modules are each comprised from four devices.

[0075] FIG. 8 depicts memory expansion board 70 mounted with four-high modules 10. As those of skill will recognize, using four-high stacked modules on expansion board 70 reduces the interconnect length for the number of devices accessed but increase the total number of devices and, therefore, the impedance and particularly, the capacitive loading presented by a densely populated DIMM board.

[0076] FIG. 9 depicts a memory system 80 devised in accordance with the present invention. In a preferred mode, system 80 is employed with stacked modules 10 devised in accordance with the present invention. The preferred embodiment is for a DDRII registered DIMM populated with 4 high stacked modules 10 although it may be employed with an equivalent number of DRAMs, i.e., 72 devices of either leaded or CSP packaging aggregated in stacks of any number of levels.

[0077] Chipset 82 depicted in FIG. 9 typically includes a microprocessor or memory controller that controls the memory access with system 80. Clock 84 is provided to

decode logic **86** on each of depicted memory expansion boards **70₍₁₎**, **70₍₂₎**, **70₍₃₎**, and **70₍₄₎**. Those of skill will understand that system **80** and its methods may be employed with one or more DIMMs or other memory expansion boards **70**. It may also be employed off a memory expansion board to access separately, the integrated circuits from which stacked circuit modules are comprised. Decode logic **86** on each of memory expansion boards **70₍₁₎**, **70₍₂₎**, **70₍₃₎**, and **70₍₄₎** provides a decoding of the respective CS signals provided to the respective memory expansion boards **70** as shown in **FIG. 9**. As those of skill will understand, the particular interconnection employed in the system should preferably be devised to minimize and balance power consumption across the circuit modules employed in the system.

[0078] As shown in the example depicted in **FIG. 9**, CS0, CS1, CS2, and CS3 are provided to memory expansion board **70₍₁₎** from chipset **82** while CS4, CS5, CS6, and CS7 are provided to memory expansion board **70₍₂₎** as are CS8, CS9, CS10, and CS11 provided to memory expansion board **70₍₃₎** and CS12, CS13, CS14, and CS15 are provided to memory expansion board **70₍₄₎**.

[0079] In a preferred embodiment, memory expansion boards **70** are populated with nine four high CSP modules **10** per side. The depiction of **FIG. 9** shows, however, only one module **10** per memory expansion board **70** to preserve clarity of the view. The shown module **10** is exploded to depict the four levels of module **10** which, in a preferred construction of module **10** include CSPs **18**, **16**, **14**, and **12** with the form standard **34**.

[0080] Thus, decode logic **86** may, on the appropriate signal from clock **84**, generate a level select signal which, in a preferred embodiment, is a multi-bit signal that controls a multiplexing switch **90** associated with several data lines. Switch **90** is, in a preferred embodiment, a high speed switch and a FET multiplexer would provide a preferred multiplexing switch **90** in the practice of a preferred mode of the invention. The fan-out of multiplexing switch **90** may be any that provides a selection capability to a variety of device data lines from a DQ line from chipset **82**. The DQ lines between chipset **82** and switches **90** are depicted by double-headed arrows **94(1)**, **94(2)**, **94(3)** and **94(4)**. As with the depiction of stacked modules **10**, only one multiplexing switch **90** is shown per memory expansion board **70**, but those of skill will understand that multiple multiplexing switches **90** are employed in practice of the depicted preferred embodiment of the invention. The number of multiplexing switches **90** will depend upon the fan-out ratios. For example, use of nine 8:32 multiplexing switches **90** would be preferred (if available) or 4:8 or 1:4 multiplexing switches **90** will also provide advantages as an example. It should be understood that there are merely examples and that a variety of multiplexing switches and ratios may be employed for multiplexing switches **90**, although the type of switch and the ratios will affect the loading figures. Consequently, a FET mux is preferred for multiplexing switch **90** and a ratio of 1:4 is one of the preferred ratios to employ.

[0081] The depiction in **FIG. 9** is illustrative only and not meant to be limiting. For example, a single DIMM board or expansion board **70** may be employed in a system **80** in accordance with the present invention as well as larger numbers of expansion boards **70**. The number of expansion

boards **70** that may function in system **80** is partially a function of the access speeds required and the signal conformity.

[0082] An exemplar multiplexing switch **90** has multiple inputs **92(a)**, **92(b)**, **92(c)**, and **92(d)** to provide independent data lines for each level of an exemplar module **10** populated upon the respective memory expansion board **70**. Thus, with a 1:4 switch **90**, there will be 18 iterations of multiplexing switch **90**, one for each of the 18 four-high module **10**'s populating memory expansion board **70(1)**. Thus, the system **80** shown in **FIG. 9** presents a total of 288 memory devices. It should be noted that system **80** may be employed with ICs of any package type and need not be limited to DDR or DDRII or even CSP.

[0083] The data line of each level of the constituent CSPs of each module **10** is connected to one input **92** of a corresponding exemplar multiplexing switch **90**. In response to the CS signal **88** from decode logic **86** on a DIMM expansion board **70**, multiplexing switch **90** connects the appropriate one of the DQ signals **94** to one of the four levels of a module **10** on that memory expansion board **70**. This switching of the data bus through multiplexing switch **90** may, in some systems, required further control signal connections as those of skill in the art will recognize to accommodate the data latency of one or more clocks cycles, CAS latency, and burst length, for example. In a preferred mode, expansion board **70** may keep all the constituent devices of the modules **10** as if each constituent device of the modules **10** were the target, instead of having to switch terminations each time a different CS is chosen. In some applications it may be preferred to terminate the end of the data line past the last DIMM expansion board **70**. Other features may enable improvements to the efficiency of system **80** such as creating more CS banks by decoding the chip select lines.

[0084] In the system **80**, the capacitive load presented to chipset **82** would be approximately the combination of the input capacitance of switching multiplexer **90** times the number of DIMM slots plus one DRAM device load plus one times the output capacitance of the multiplexing switch **90**. In large systems, this will reduce capacitive loading by a notable amount, thus allowing more DIMM slots at higher speeds and/or more densely populated DIMMs. Memory access system **80** provides an opportunity to improve high speed memory performance and allows use of memory expansion configurations that might not otherwise be available due to capacitive loading in conventional DIMM systems.

[0085] **FIG. 10** is an elevation view of a module that depicts features of an alternative preferred embodiment of the present invention. The depicted module **10** is comprised of a base element **120** and support elements **140** and **160**. In the depicted embodiment, base element **120** and support elements **140** and **160** are shown as CSP devices, but the invention is not limited to arrangements of CSPs and may be employed to aggregate a variety of package types. Base element **120** and support elements **140** and **160** each have, in the depicted embodiment, upper surfaces **20** and lower surfaces **22** and peripheral or lateral sides or edges **24** and **26** that may be in the character of sides or may, if the CSP is especially thin, be in the character of an edge.

[0086] **FIG. 10** depicts base element **120** and support elements **140** and **160** in a stacked disposition with upper

major surfaces of the constituent elements being proximally located in this back to back configuration. Between upper surfaces 20 of support elements 140 and 160 and upper surface 20 of base element 120 is shown adhesive layer 35 shown in exaggerated scale for clarity of depiction. Contacts 28 are emergent from lower surface 22 of base element 120 and support elements 140 and 160. Module contacts 38 are shown depicted along the bottom of module 10 and provide connection for the module to a PWB or PCB or other mounting site.

[0087] Support elements 140 and 160 are preferably fixed to upper surface 20 of base element 120 by adhesive 35 which is shown as a tape adhesive, but may be a liquid adhesive or may be placed in discrete locations across the package. Preferably, adhesive 35 is thermally conductive. Adhesives that include a flux may be used to advantage in assembly of module 10. Layer 35 may also be a thermally conductive medium to encourage heat flow between the elements of module 10. Alternatively, a mechanical clamp or clamps may be used to hold the base and support elements together. The contacts for the module itself may be closer to either the base element or the support element(s) of the module although more typically and preferably, the module contacts will be closer to the base element. The support elements may also extend over the edges of the base element or may be disposed within the perimeter of the base element. Although not shown in this view, use of a form standard 34 is preferred.

[0088] FIG. 11 illustrates the aggregation of a leaded package device having leads 310 (i.e., as support element 160 in this embodiment) with base element 120 and support element 140. FIG. 11 further depicts the placement of flex circuitry 30 attached to the upper side of base element 120 with the placement of support elements 140 and 160 in a position relatively above flex circuitry 30 rather than below as earlier shown in FIG. 10. Flex circuitry 30 is preferably attached to upper surface 20 of base element 120 with a thermally conductive adhesive depicted by reference 35 in FIG. 11. A conformal media 41 is indicated in FIG. 11 as being placed between contacts 28 to assist in creating conformality of structural areas of module 10. Preferably, conformal media 41 is thermally conductive and is placed along the lower surface 22 of base element 120 although to preserve clarity of the view, its placement between only a few contacts 28 of base element 120 is shown in FIG. 11.

[0089] FIG. 12 depicts another alternative embodiment of the present invention. Shown are base element 120 and support element 140. In the place of previously shown single package support element 160 is leaded stack 170, consisting of upper IC 190 and lower IC 210.

[0090] FIG. 13 depicts a module that employs a CSP base element 120 and CSP support elements 140 and 160 interconnected with flex circuitry 30. Heat sink 340 is disposed between base element 120 and support elements 140 and 160. As shown in FIG. 13, heat sink 340 is in contact with a portion of casing 36 of an application in which module 10 is employed.

[0091] FIG. 14 is an alternative preferred embodiment of the present invention. Depicted in FIG. 14 are base element 120 and support elements 140 and 160 with all of the depicted ICs being packaged in CSP with support elements 140 and 160 extending beyond the physical boundaries of

base element 120. Form standard 34 provides a standard form about which flex circuit 30 arcs. As earlier described, form standards may take a variety of forms and, in this embodiment, form standard 34 is folded to increase cooling surface area while providing an appropriate axial circumference and standard form for flex circuitry 30. Also shown is extensive and preferred use of conformal underfill 41.

[0092] FIG. 15 illustrates in enlarged perspective, detail of the area marked "C" in FIG. 14 and illustrates an exemplar connection between example contacts 28 of a support element and support flex contacts 57 of flex circuitry 30. In this depiction, support flex contacts 57 are shown as being at the level of first conductive layer 54 of flex circuitry 30. FIG. 15 illustrates a via 59 between the support flex contact 57 in contact with the right-most depicted contact 28 and second conductive layer 58. The use of vias between conductive layer levels allows flexibility in strategies employed to connect base element 120 with support elements and allows, for example, the connection of a contact from support elements 140 or 160 to a selected module contact 38. Often, support elements 140 and/or 160 will have signals that are not directly connected to base element 120, but which have functionality relevant to the operation of entire module 10. In such cases, a module contact 38 provides that signal connection to support element 140 or 160 without a corresponding direct connection to base element 120. Such a connection strategy is shown in FIG. 16.

[0093] FIG. 17 illustrates an abstraction of the plot employed for the conductive areas at the level of first conductive plane 54 for a preferred embodiment similar to that depicted in FIG. 14. As those of skill will notice, in the plot shown in FIG. 17, the connective fields identified with references 65 roughly correspond to connective areas for support element 140 while connective fields identified with references 67 roughly correspond to support element 160 as shown in FIG. 14. Connective field 69 provides connections for base element 120. The connective fields 65 and 67 provide support flex contacts 57 as well as traces that, combined with vias 59, provide part of the connective facility for interconnecting support elements 140 and 160 to base element 120. The view is abstracted with many of the actual routing lines removed to assist in the clarity of the view.

[0094] FIG. 18 illustrates an abstraction of the routing plot employed for conductive areas at the level of second conductive surface or plane 58 for a preferred embodiment similar to that depicted in FIG. 14.

[0095] In the area of FIGS. 17 and 18 employed to connect base element 120, there is illustrated an example of using vias 59 to more fully employ the two conductive layers of the preferred embodiments. Connective fields 55 and 61 indicate vias 59 as well as traces (that are not shown in the depiction for clarity of view) that provide part of the connective facility for interconnecting support elements 140 and 160 to base element 120.

[0096] On the depiction of FIG. 18, there is found the identification of a lower flex contact 44 that may be employed by base element 120. With reference to earlier FIGS. 5 and 16, base element 120 has a contact 28 that passes through window 60 and therefore, first conductive layer 54 to contact the identified lower flex contact 44 at the

level of the second conductive layer as shown in **FIG. 18**. It should be understood that this is a heuristic explanation and meant to be merely an example illustrating a feature found in some preferred embodiments of the invention.

[0097] The identified lower flex contact **54** at the level of second conductive layer **58** is connected to a via **59** by a trace **71**. Via **59** passes in a relatively upward direction toward the body of base element **120**. As via **59** passes upwardly through flex circuitry **30**, it contacts a conductive area at the level of first conductive layer **54** as shown in **FIG. 17** by the identification of via **59** in the field **69**. The identified via **59** is then connected to trace **73** that provides a connection network to a variety of other contacts in the depicted embodiment. Thus, the use of two conductive layers is given an added flexibility by the illustrated use of vias through an intermediate layer.

[0098] Vias that route through intermediate layer **56** to interconnect traces or flex contacts or conductive areas at different conductive layers may be “on-pad” or coincident with the support or base flex contact to which they are connected. Such vias may also be “off-pad” and located near windows associated with the flex contacts from which signals are to be conveyed to another conductive layer. This provides added flexibility to connection schemes and layout routing.

[0099] **FIG. 19** depicts another alternative embodiment of the present invention. Depicted in **FIG. 19** are base element **120** with support element **140** in an inverted position with respect to base element **120**. Form standard **34** is shown positioned between base element **120** and support element **140** (referred to together, with reference to this embodiment, “the depicted CSPs”), with radiating form portions **192** extending upwards and downwards in an area outside the lateral extent of base element **120**. In various embodiments, radiating form portions **192** may take various shapes and forms. For example, radiating form portions **192** extend partially around the circumference of the depicted CSPs, base element **120** and support element **140**, or may be disposed only on one or more lateral sides of the depicted CSPs or may extend fully around the circumference of the depicted CSPs. As an additional exemplar, radiating form portions **192** may have voids or fins or other non-contiguous features devised to increase their surface area.

[0100] In this embodiment, heat spreader portion **194** is a central portion of form standard **34**, which is disposed between the depicted CSPs and may extend past the lateral extent of one or both of the designated ICs, as shown by the dotted lines. Heat spreader portion **194** and radiating form portions **192** may be composed of similar materials or they may be composed of a different suitable heat-conducting materials. Further heat spreader portion **194** and radiating form portions **192** may be made in a variety of ways. For example, the depicted IC’s may first be attached to flex circuitry **30** in a flat configuration with a radiating form portion **192** placed about each depicted IC, then heat spreader portion **194** placed atop base element **120** and the selected radiating form portion **192**, and affixed with adhesive or other suitable attachment methods such as, for example, tape adhesive, liquid adhesive, soldering, welding, or clamping. Subsequently, flex circuitry **30** may be folded to produce the relative positions shown in **FIG. 19**. Adhesive or other suitable attachment methods may be used to

secure radiating form portion **192** associated with support element **140** to heat spreader portion **194**. As those of skill in the art will understand, after appreciating this specification, radiating form portions **192** and heat spreader portion **194** may be separate pieces that are placed adjacent to each other in a manner devised to achieve a form standard **34**. Further, as those of skill will understand, in an alternative embodiment, radiating form portions **192** may be disposed around one or both of the depicted CSPs without the presence of heat spreader **194** between the depicted CSPs.

[0101] In this embodiment, flex circuitry **30** is connected to base element **120** through contacts **28** and wrapped around one side of form standard **34** to connect to contacts **28** of support element **140**. In this embodiment, radiating form portions **192** of form standard **34** have curved edges **196** devised to provide an appropriate axial form for the flex circuitry **30** that is wrapped about a part of form standard **34**. Further, in this embodiment, form standard **34** is provided with mounting feet **198** which are disposed on radiating form portions **192** outside of the lateral extent of flex circuitry **30**. The use of conformal underfill is not shown to simplify the depiction, however some embodiments may use conformal underfill as described with reference to **FIG. 14**.

[0102] **FIG. 20** is a side view of the embodiment of the invention depicted in **FIG. 19** taken along the direction of the arrow marked **200**. Flex circuitry **30** is shown wrapped around the curved edges **196** of form standard **34**. Module contacts **38** are provided on flex circuitry **30** for connection of module **10** to its operating environment. In a preferred embodiment, flex circuitry **30** is a multi-layer flexible circuit structures that has at least two conductive layers. Other embodiments may, however, employ flex circuitry, either as one circuit or two flex circuits, that have only a single conductive layer. Mounting feet **198** extend outside of the lateral extent of flex circuitry **30** in a manner devised to provide stability and mechanical connectivity of module **10** to its operating environment.

[0103] **FIGS. 21-24** depict another embodiment of the present invention in the process of assembly.

[0104] **FIG. 21** depicts an early assembly stage of another embodiment of the present invention. Base element **120** and support element **140** are preferably CSPs. Flex circuit **30** is shown with base element **120** and support element **140** connected. In this embodiment, the connection is achieved by a variety of means be achieved by other means such as, for example, soldering, solder paste with later reflow, adhesives, laminate adhesives, and/or combinations of these and other known connection schemes. Further, base element **120** and support element **140** may, in other embodiments, be attached at a later stage and may at this stage be held in place with other schemes such as, for example, adhesive or pastes.

[0105] **FIG. 22** depicts an assembly stage, later than that depicted in **FIG. 21**, of another embodiment of the present invention. While a preferred scheme of assembling an exemplar embodiment of the invention is depicted by this and related Figures, the order is not limiting and, as those of skill will realize after appreciating this specification, various embodiments of the present invention may be assembled in various orders. Base element **120** has upper surface **224**. Radiating form portions **192** are shown disposed around base element **120** and support element **140** (“the depicted CSPs”). In this embodiment, radiating form portions **192**

have heat radiating fins 222 formed therein. Preferably, there is thermal conduction between radiating form portions 192 and the depicted CSPs. In various embodiments, radiating form portions 192 may be placed adjacent to or in contact with the depicted CSPs, or may be attached by adhesive, or interference fit, or may be attached to flex circuitry 30. In other embodiments, radiating form portions 192 may be near but not touch the depicted CSPs. A distance 'D' separates the proximal edges of radiating form portions 192. Distance D is devised to facilitate folding of flex at a later stage of assembly of module 10. In certain embodiments, distance D may be devised by finding the added height of form portions 192 or of the depicted CSPs, whichever is greater. This summed height may be increased by the height of heat spreader portion 194, if the particular embodiment contains a heat spreader portion 194. Further, distance D may be increased by factors such as the additional distance needed to wrap about curved edges 196 (an example of which is described with reference to FIG. 24), or 'slack' needed for folding and assembly, if any, or desired 'slack' after assembly, if any.

[0106] FIG. 23 depicts an assembly stage, later than that depicted in FIG. 22, of another embodiment of the present invention. In this embodiment, heat spreader portion 194 is shown placed on upper surface 224 of base element IC 120. In other embodiments, however, form standard 34 may be assembled in a different order, such as, for example, placing heat spreader portion 194 of form standard 34 on either of the depicted CSPs or, as another alternative exemplar assembly order, placing two or more pieces on top of either or both of the depicted CSPs. Heat spreader portion 194 of form standard 34 may be fixed to upper surface 224 of the respective CSP with an adhesive which preferably is thermally conductive. Heat spreader portion 194 may also, in alternative embodiments, merely lay on upper surface 224 or be separated from upper surface 224 by an air gap or medium such as a thermal slug or non-thermal layer. The lateral extent of heat spreader portion 194 is preferably greater than the lateral extent of one or both of the depicted CSPs, and preferably, in this embodiment, equal to the largest lateral extent of radiating form portions 192 in each lateral direction. However, in other embodiments, the lateral extent of heat spreader portion 194 may be greater than that of radiating form portions 192 in either direction or less than that of the depicted CSPs in either direction.

[0107] FIG. 24 depicts an assembly stage, later than that depicted in FIG. 23, of another embodiment of the present invention. The depiction in FIG. 24(a) is from a perspective slightly above module 10, viewed after flex circuitry 30 has been folded to place support element 140 in a stacked, inverted position over base element 120. In this embodiment, flex circuitry 30 is depicted with a portion in a curved disposition over curved edges 196 of radiating form portions 192. Module 10 may be secured in this configuration by a number of schemes such as, for example, adhesive, laminate adhesive, and soldering. The depiction in FIG. 24(b) is from a perspective slightly below module 10. Mounting feet 198 are depicted extending from radiating form portions 192. Module contacts 38 are present on the bottom surface 242 of module 10 for connection of module 10 to its operating environment. Preferably, mounting feet 198 are sized such that they extend the same distance as module contacts 38 in a perpendicular direction from bottom surface 242. In other

embodiments, however, mounting feet may extend less or more than module contacts 38.

[0108] FIGS. 25-28 depict another embodiment of the present invention in various stages of assembly.

[0109] FIG. 25 depicts an early assembly stage of yet another embodiment of the present invention. This stage is similar to that described with regard to FIG. 21, with base element 120 and support element 140 attached to flex circuitry 30.

[0110] FIG. 26 depicts an assembly stage, later than that depicted in FIG. 25, of another embodiment of the present invention. While a preferred scheme of assembling an exemplar embodiment of the invention is depicted by this and related Figures, the order is not limiting and, as those of skill will realize after appreciating this specification, various embodiments of the present invention may be assembled in various orders. Base element 120 has upper surface 224. Radiating form portions 192 are shown disposed around base element 120 and support element 140 ("the depicted CSPs"). The separation distance D and the connection of radiating form portions 192 to flex circuitry 30 and may follow the description made with regard to FIG. 22. In this embodiment, radiating form portions 192 of form standard 34 are metal pieces with form curves 262 and form tabs 264, which will be further described with reference to FIG. 27. In other embodiments, radiating form portions 192 may be made of suitably rigid and heat conducting materials such as, for example, various metals, alloys, and composites.

[0111] FIG. 27 depicts an assembly stage, later than that depicted in FIG. 25, of another embodiment of the present invention. In a preferred embodiment, heat spreader portion 194 is made of copper and has a thickness of approximately 1 mm. The depiction in FIG. 27 has the same orientation as that in FIG. 26. In this embodiment, heat spreader portion 194 is shown placed on upper surface 224 of base element IC 120. Heat spreader portion 194 of form standard 34 may be fixed to upper surface 224 of the respective CSP with an adhesive which preferably is thermally conductive. Heat spreader portion 194 may also, in alternative embodiments, merely lay on upper surface 224 or be separated from upper surface 224 by an air gap or medium such as a thermal slug or non-thermal layer. The lateral extent of heat spreader portion 194 is preferably greater than the lateral extent of one or both of the depicted CSPs, and preferably, in this embodiment, greater than the largest lateral extent of radiating form portions 192 in each of the three lateral directions shown in which heat spreader portion 194 has a mount 272. Preferably, mount 272 has thermally conductive properties. In this embodiment, heat spreader portion 194 has mounts 272 extending from three of its four sides. The fourth side, in this embodiment, has no mount 272 and instead presents a side edge 276 that is preferably flush with the outside edge presented by the adjacent form curve 262. Preferably, heat spreader 194 touches form curve 262 in a manner devised to promote thermal conduction. Mounts 272 preferably extend in a downward direction with respect to upper surface 224 of base element 120 (FIG. 26), and preferably extend past the radiating form portions 192. Flex circuitry 30 has portion 'F' that is folded in a later stage of assembly from that depicted in FIG. 27. Form tabs 264 of the radiating form portion 192 that is underneath heat spreader 194 are preferably in contact with the lower surface of heat spreader 194

(not visible in this depiction) in a manner devised to provide mechanical support and heat conductivity.

[0112] **FIG. 28** depicts an assembly stage, later than that depicted in **FIG. 27**, of another embodiment of the present invention. The depiction in **FIG. 28(a)** is from a perspective slightly above module **10**, viewed after flex circuitry **30** has been folded at portion **F** to place support element **140** in a stacked, inverted position over base element **120**. In this embodiment, flex circuitry **30** is depicted with a portion in a curved disposition over form curves **262** of radiating form portions **192**. Module **10** may be secured in this configuration by a number of schemes such as, for example, adhesive, laminate adhesive, welding, clamping, and soldering. The depiction in **FIG. 28(b)** is from a perspective slightly below module **10**. Mounts **272** are depicted extending from radiating form portions **192**. Module contacts **38** are present on the bottom surface **242** of module **10** for connection of module **10** to its operating environment. Preferably, mounts **272** extend the same distance as module contacts **38** downward in a direction perpendicular to bottom surface **242**, but preferably outside the lateral extent of base element **120**. In other embodiments, however, mounts **272** may extend less or more than module contacts **38** depending on the packaging scheme and operating environment. Bottom mounting surfaces **274** of mounts **272** are preferably soldered to a ground plane of the circuit board used in module **10**'s operating environment. In other embodiments, however, mounts **272** have different shapes that extend in different directions and mounts **272** may be welded or soldered or rest on a variety of surfaces in module **10**'s operating environment, such as, for example, circuit boards, mounts formed on circuit boards, chassis, walls or other interior surfaces of hermetic packaging containers, etc. Those of skill in the art will understand, after appreciating this specification, that module **10** may be packaged in various forms of sealed electronic packages devised to provide high-reliability under severe operating conditions.

[0113] **FIGS. 29-31** depict another embodiment of the present invention in various stages of assembly.

[0114] **FIG. 29** depicts an early assembly stage of yet another embodiment of the present invention. In this embodiment, flex circuitry **30** has flex extensions **292** and **294**. Support elements **140** and **160** are disposed on flex extension **292** and **294**, and may, at the depicted stage of assembly, be attached by various ways such as, for example, soldering, solder paste, adhesives, and laminate adhesives.

[0115] **FIG. 30** depicts an assembly stage, later than that depicted in **FIG. 29**, of another embodiment of the present invention. While a preferred scheme of assembling an exemplar embodiment of the invention is depicted by this and related Figures, the order is not limiting and, as those of skill will realize after appreciating this specification, various embodiments of the present invention may be assembled in various orders. In this embodiment, flex extensions **292** and **294** are depicted wrapped about form standard **34**. Base element **120**, not visible in this depiction, is underneath form standard **34** with its upper surface **224** adjacent to form standard **34**. In this embodiment, form standard **34** has folded portions **304** and **306**, devised to present support and heat absorption surfaces on which support elements **140** and **160** rest. In this depiction, support elements **140** and **160** are inverted with respect to their depiction in **FIG. 29**, due to the

folding of flex extensions **292** and **294**. While in this embodiment, flex circuitry **30** is shown with two flex extensions, this is not limiting and other embodiments may contain one or two or three or more flex extensions which may be devised to provide flexible circuit connectivity to each other and/or base element **120** and/or the operating environment of module **10**. Further, while in this embodiment form standard **34** has two folded portions **304** and **306**, other embodiments may have one or two or three or more folded portions, and such portions may be devised to provide support and/or heat absorption for support elements **140** and **160**, and may be devised to present surfaces for attachment and/or support and/or heat absorption for support elements **140** and/or **160** that may be horizontal or vertical or disposed at other angles with respect to base element **120**. While folded portions **304** and **306** are shown in this embodiment, form standard **34** may be made in a folded configuration or be made of solid material or material shaped with voids of various shapes devised to provide heat radiation and/or ease of manufacturing. In this embodiment, folded portion **306** is shaped with a contour to provide for support elements **140** and **160** that may have different heights. Form standard **34** has radiating portions **302** disposed partially around its outside edges.

[0116] **FIG. 31** depicts the alternative embodiment of the present invention depicted in **FIG. 30**, from another perspective slightly below module **10**.

[0117] **FIGS. 32-34** depict another embodiment of the present invention in the process of assembly.

[0118] **FIG. 32** depicts an early assembly stage of another embodiment of the present invention. Flex circuit **30** is shown with base element **120** and support element **140** connected.

[0119] **FIG. 33** depicts an assembly stage, later than that depicted in **FIG. 32**, of another embodiment of the present invention. While a preferred scheme of assembling an exemplar embodiment of the invention is depicted by this and related Figures, the order is not limiting and, as those of skill will realize after appreciating this specification, various embodiments of the present invention may be assembled in various orders. Radiating form portions **192** are shown disposed around base element **120** and support element **140** ("the depicted CSPs"). In this embodiment, heat spreader portion **194** is shown placed on upper surface **224** of base element **IC 120** and atop of the respective radiating form portion **192**. In this embodiment, heat spreader portion **194** is provided with radiating pins **332**, devised to present increased surface area for heat radiation and to provide mechanical support for form standard **34** and the assembled module **10**. In this embodiment, those radiating pins **332** disposed about the interior portion of heat spreader **194** are provided with flat internal edges **334** to provide a flush surface for placement in contact with or near support element **140** when flex circuitry **30** is folded (at a later stage of assembly) to place module **10** in its completed configuration. More radiating pins **332** are provided underneath central surface **336** of heat spreading portion **194**. In this embodiment, radiating pins **332** are depicted as having uniform size and spacing, however, this is not limiting and radiating pins **332** may have different sizes and spacing, and may extend in different directions.

[0120] **FIG. 34** depicts an assembly stage, later than that depicted in **FIG. 33**, of another embodiment of the present

invention. The depiction in **FIG. 34(a)** is from a perspective slightly above module **10**, viewed after flex circuitry **30** has been folded to place support element **140** in a stacked, inverted position over base element **120**. In this embodiment, flex circuitry **30** is depicted with a portion in a curved disposition over curved edges **196** of radiating form portions **192**. The depiction in **FIG. 34(b)** is from a perspective slightly below module **10**. Mounting feet **198** are depicted extending from radiating form portions **192**. Module contacts **38** are present on the bottom surface **242** of module **10** for connection of module **10** to its operating environment. In this embodiment, radiating pins **332** have flat edges **342** devised to present a flat profile at the lateral extent of module **10**. Such a flat profile may enhance heat transfer characteristics when module **10** is placed in abutment to a wall of a packaging unit or other surface that may be present in the operating environment of module **10**. Although the present invention has been described in detail, it will be apparent to those skilled in the art that the invention may be embodied in a variety of specific forms and that various changes, substitutions and alterations can be made without departing from the spirit and scope of the invention. The described embodiments are only illustrative and not restrictive and the scope of the invention is, therefore, indicated by the following claims.

1. A method of making a high-density circuit module comprising the steps of:

- (a) providing a form standard having a first radiating form portion, a second radiating form portion, and a heat spreader form portion;
- (b) providing a flex circuit having first and second sets of flex contacts;
- (c) providing a first CSP and a second CSP each having a top surface;
- (d) connecting the first CSP and second CSP to the first and second sets of flex contacts, respectively;
- (e) attaching the first radiating form portion of the form standard to the flex circuit, the first radiating form portion extending at least partially around the first CSP;
- (f) attaching the second radiating form portion of the form standard to the flex circuit, the second radiating form portion extending at least partially around the second CSP;
- (g) attaching the heat spreader form portion of the form standard to the top surface of the first CSP such that at least one thermal mount of the heat spreader form portion reaches downward, relative to the top surface of the first CSP, outside of a lateral extent of the first CSP;
- (h) folding the flex circuit at an area between the first and second CSPs such that the flex circuit is folded around form curves on the first and second radiating form portions, and such that the second CSP is placed in an inverted, stacked position above the first CSP and thereby contacts the heat spreader form portion on a side of the heat spreader form portion opposite from a side adjacent to the first CSP.

2. The method of claim 1 in which the at least one thermal mount extends downward, relative to the top surface of the first CSP, to a level beside a plurality of module contacts on a side of the flex circuit opposite the first CSP.

3. The method of claim 1 further including the steps of:

- (a) packaging the high-density circuit module in a hermetically sealed container;
- (b) soldering the high-density circuit module to a circuit board;
- (c) bonding the at least one thermal mount to the circuit board with a thermally conductive bonding means.

4. The method of claim 1 further including the steps of:

- (a) soldering the high density circuit module onto a circuit board;
- (b) bonding the at least one thermal mount to the circuit board with a thermally conductive bonding means.

5. A method of assembling a high-density circuit module comprising the steps of:

- (a) providing a flex circuit having first and second flex extensions and a central portion with a plurality of flex contacts arranged as a first set and a second set;
- (b) providing first, second, and third CSPs;
- (c) providing a form standard;
- (c) connecting the first CSP to the first set flex contacts on the central portion of the flex circuit;
- (d) placing the second CSP on the first flex extension;
- (e) placing the third CSP on the second flex extension;
- (f) folding the first and second flex extensions over first and second folded portions of the form standard.

6. The method of claim 5 further including the step of bonding the flex circuit to the form standard.

7. The method of claim 5 in which the step of providing a form standard includes assembling the form standard from at least two pieces.

8. The method of claim 5 in which the form standard has a means for radiating heat.

9. The method of claim 5 in which the form standard comprises fins.

10. The method of claim 5 in which the form standard comprises pins formed near at least one lateral edge of the form standard.

11. The method of claim 5 in which the form standard has heat conductive mounting feet.

12. The method of claim 5 in which the form standard has heat conductive thermal mounts.

13. The method of claim 5 in which the form standard has heat extensions for thermal connection of the high-density circuit element to its operating environment.

14. The method of claim 5 in which the form standard has mounting extensions for mechanically stabilizing the high-density circuit element in its operating environment.

15. The method of claim 14 in which the operating environment comprises a hermetically sealed package.

16. A method of assembling a high-density circuit module comprising the steps of:

- (a) providing a flex circuit having a plurality of flex contacts, the flex contacts being arranged into first and second sets;
- (b) providing a form standard element;

- (c) providing a first CSP and a second CSP each having a first and a second lateral edge delineating a lateral extent;
 - (d) connecting the first and second CSPs to the first and second sets of flex contacts, respectively;
 - (e) fitting the form standard element on the first CSP, the form standard element covering a portion of the first CSP and extending partially beyond the lateral extent of the first CSP;
 - (f) folding the flex circuit around a curved edge of the form standard element such that the second CSP is in contact with the form standard element on a side of the form standard element opposite from a side contacting the first CSP.
- 17.** The method of claim 16 further including the steps of securing the form standard to the first CSP with an adhesive.
- 18.** The method of claim 16 in which the form standard element is assembled from multiple pieces.
- 19.** The method of claim 16 in which the form standard element has a means for radiating heat.
- 20.** The method of claim 16 in which the form standard comprises fins.
- 21.** The method of claim 16 in which the form standard comprises pins formed in a hollowed interior portion of the form standard element.
- 22.** The method of claim 16 in which the form standard element has heat conductive mounting feet.
- 23.** The method of claim 16 in which the form standard element has heat extensions for thermal connection of the high-density circuit element to its operating environment.
- 24.** The method of claim 16 in which the form standard element has mounting extensions for fixing the high-density circuit element to an operating environment.
- 25.** The method of claim 24 in which the operating environment comprises a hermetically sealed package.
- 26.** The method of claim 16 further including the step of fixing the form standard element to a top major surface of the second CSP after the step of folding the flex circuit.

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