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SACRIFICIAL PLATE INSERT FOR RIGID-CORE LAMINATE TOOLING-HOLE DRILLING

Abstract

The present disclosure relates to a rigid-core laminate that includes a core section formed of a first material with a first modulus of at least 50 GPa, a number of sacrificial sockets embedded in the core section through a potting material, a number of top dielectric layers formed over a top surface of the core section and covering a top surface of each sacrificial socket, a number of bottom dielectric layers formed underneath a bottom surface of the core section and covering a bottom surface of each sacrificial socket, and a number of tooling-holes. Herein, each sacrificial socket is formed of a second material with a second modulus that is smaller than the first modulus. Each tooling-hole extends vertically through the top dielectric layers, a corresponding sacrificial socket, and the bottom dielectric layers. No portion of the core section is exposed in any one of the tooling-holes.

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Background/Summary

RELATED APPLICATIONS [0001] This application claims the benefit of provisional patent application Ser. No. 63/551,858, filed Feb. 9, 2024, the disclosure of which is hereby incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to a rigid-core laminate with tooling-holes that are formed by drilling/milling through sacrificial plates embedded in a rigid-core section of the rigid-core laminate.

BACKGROUND

[0003] As microelectronics continue to miniaturize and handle higher powers and frequencies, new package substrates are constantly being introduced to integrated circuit applications. One of the new players in the industry is glass-core laminates. Moving from traditional composite core laminates to the glass-core laminates enables rigid interposers with dimensional stability and finer line/space and offers the ability to embed electronic components within the laminates. Other types of ceramic materials may also be desired materials used for the rigid core portions of laminates.

[0004] However, these ceramic-core laminates are not easy to drill through once they have been manufactured with patterned copper traces. Due to the brittle characteristics of the rigid core materials, drilling can thus be destructive and cause cracks in the core of these laminates. On the other hand, overmolding laminates in packaging processes typically requires the utilization of alignment pins, which need tooling-holes to be held in place. Although other works apply compression molding instead of overmolding to avoid drilling holes, compression molding is costly. In addition, even if tooling-holes may be formed through the rigid-core laminates, the core material (e.g., glass) exposed in the tooling-holes is susceptible to damage by anything that would be inserted into the tooling-holes (e.g., the alignment pins).

[0005] Accordingly, there remains a need for improved laminate designs, which would enable tooling-hole drilling so as to accommodate alignment pins for overmolding. In addition, there is also a desire that the interior of the tooling-hole is soft and firm enough to be capable of handling tensile stresses much better than these rigid core materials.

SUMMARY

[0006] The present disclosure relates to a rigid-core laminate with tooling-holes that are formed by drilling/milling through sacrificial plates embedded in a rigid-core section of the rigid-core laminate. The disclosed rigid-core laminate includes a core section formed of a first material with a first modulus of at least 50 GPa, a number of sacrificial sockets embedded in the core section through a potting material, a number of top dielectric layers formed over a top surface of the core section and covering a top surface of each of the sacrificial sockets, a number of bottom dielectric layers formed underneath a bottom surface of the core section and covering a bottom surface of each of the sacrificial sockets, and a number of tooling-holes. Herein, each sacrificial socket is formed of a second material with a second modulus that is smaller than the first modulus. Each tooling-hole extends vertically through the top dielectric layers, a corresponding sacrificial socket within the core section, and the bottom dielectric layers. No portion of the core section is exposed in any one of the tooling-holes. In one embodiment of the rigid-core laminate, the second modulus is

[0007] no more than 20 GPa.

[0008] In one embodiment of the rigid-core laminate, the first material is a ceramic material.

[0009] In one embodiment of the rigid-core laminate, the second material is a polymer material or a polymer and inorganic composite.

[0010] In one embodiment of the rigid-core laminate, the core section has a height between 10 μm and 2000 μm . Each top dielectric layer has a thickness between 0.2 μm and 60 μm , and each bottom dielectric layer has a thickness between 0.2 μm and 60 μm .

[0011] In one embodiment of the rigid-core laminate, a horizontal shape of each tooling-hole is constant along a vertical direction, which is identical to a shape of an inner perimeter of the corresponding sacrificial socket.

[0012] In one embodiment of the rigid-core laminate, the shape of the inner perimeter of each of the sacrificial sockets is a circle, a square, a rectangle, an oval, or a cushion. The shape of the outer perimeter of each of the sacrificial sockets is a circle, a square, a rectangle, an oval, or a cushion.

[0013] In one embodiment of the rigid-core laminate, a diameter of the inner perimeter of each of the sacrificial sockets is between 1 mm and 5 mm, and a diameter of the outer perimeter of each of the sacrificial sockets is between 1.1 mm and 5 mm.

[0014] According to one embodiment, the rigid-core laminate further includes a number of protective vias. Each sacrificial socket is surrounded by certain ones of the protective vias. Each of the protective vias has a diameter between 100 μm and 150 μm .

[0015] According to one embodiment, the rigid-core laminate further includes a number of top metal layers, and a number of bottom metal layers. Herein, the top dielectric layers and the top metal layers are alternately formed over the top surface of the core section. The bottom dielectric layers and the bottom metal layers are alternately formed underneath the bottom surface of the core section.

[0016] In one embodiment of the rigid-core laminate, the top dielectric layers and the bottom dielectric layers are formed of a dielectric material, which has a modulus of no more than 15 GPa.

[0017] In one embodiment of the rigid-core laminate, the top dielectric layers and the bottom dielectric layers are formed of Ajinomoto build-up film (ABF) epoxy or polyimide.

[0018] In one embodiment of the rigid-core laminate, the potting material is epoxy.

[0019] According to one embodiment, a method of fabricating a package assembly includes forming a rigid-core laminate. Forming the rigid-core laminate starts with providing a core section with a number of cavities. Next, a sacrificial plate is embedded into each cavity. Herein, the core section is formed of a first material with a first modulus of at least 50 GPa, and the sacrificial plate is formed of a second material with a second modulus that is smaller than the first modulus. A potting material is then applied to fill a gap between the sacrificial plate and a corresponding cavity. After the potting material is applied, a number of top dielectric layers are formed over a top surface of the core section and over a top surface of each sacrificial plate, and a number of bottom dielectric layers are formed underneath a bottom surface of the core section and underneath a bottom surface of each sacrificial plate. Lastly, a tooling-hole is formed where a corresponding sacrificial plate is located. Each tooling-hole has a smaller horizontal size than a diameter of the corresponding sacrificial plate, and each sacrificial plate is converted into a corresponding sacrificial socket. Each tooling-hole extends vertically through the top dielectric layers, the corresponding sacrificial socket, and the bottom dielectric layers.

[0020] In one embodiment of the method, the core section further includes a number of hollow protective vias surrounding each cavity.

[0021] In one embodiment of the method, forming the rigid-core laminate further includes applying a metal plating step to the core section before forming the plurality of top dielectric layers and the plurality of bottom dielectric layers. Herein, a first top metal layer is formed with a metal material over the top surface of the core section, a first bottom metal layer is formed with the metal material underneath the bottom surface of the core section, and each hollow protective via is filled with the

metal material.

[0022] In one embodiment of the method, the metal plating step is applied before embedding the sacrificial plate into each of the cavities, such that the metal material extends to cover an interior wall of each of the cavities.

[0023] In one embodiment of the method, forming the rigid-core laminate further includes forming a number of top metal layers and a number of bottom metal layers. Herein, the top metal layers and the top dielectric layers are alternately formed over the top surface of the core section, while the bottom metal layers and the bottom dielectric layers are alternately formed underneath the bottom surface of the core section.

[0024] In one embodiment of the method, the second modulus is no more than 20 GPa.

[0025] In one embodiment of the method, the first material is a ceramic material, and the second material is a polymer material or a polymer and inorganic composite.

[0026] In one embodiment of the method, the tooling-hole is formed by a mechanical drill or laser machining.

[0027] According to one embodiment, the method further includes attaching one or more electrical devices to the rigid-core laminate. In horizontal dimensions, the rigid-core laminate is divided into a border region and an active region, which is surrounded by the border region. The one or more electrical devices are located on a top surface of the rigid-core laminate and within the active region, while each sacrificial socket and the corresponding tooling-hole are located within the border region.

[0028] According to one embodiment, the method further includes inserting one alignment pin into a corresponding tooling-hole and applying a mold compound over the rigid-core laminate. Herein, each alignment pin has a height larger than a height of the rigid-core laminate and protrudes above the top surface of the rigid-core laminate. The mold compound is applied using each alignment pin as a landmark, such that the one or more electrical devices are fully encapsulated by the mold compound.

[0029] In another aspect, any of the foregoing aspects individually or together, and/or various separate aspects and features as described herein, may be combined for additional advantage. Any of the various features and elements as disclosed herein may be combined with one or more other disclosed features and elements unless indicated to the contrary herein.

[0030] Those skilled in the art will appreciate the scope of the present disclosure and realize additional aspects thereof after reading the following detailed description of the preferred embodiments in association with the accompanying drawing figures.

Description

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0031] The accompanying drawing figures incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

[0032] FIGS. 1A-1B show an exemplary rigid-core laminate according to some embodiments of the present disclosure.

[0033] FIGS. 2A-7B show an exemplary fabricating process that illustrates steps to provide the exemplary rigid-core laminate shown in FIGS. 1A-1B.

[0034] FIGS. 8-10B show an exemplary packaging process that illustrates steps to provide a package assembly formed based on the exemplary rigid-core laminate.

[0035] It will be understood that for clear illustrations, FIGS. 1-10B may not be drawn to scale.

DETAILED DESCRIPTION

[0036] The embodiments set forth below represent the necessary information to enable those

skilled in the art to practice the embodiments and illustrate the best mode of practicing the embodiments. Upon reading the following description in light of the accompanying drawing figures, those skilled in the art will understand the concepts of the disclosure and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure and the accompanying claims. [0037] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present disclosure. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0038] It will be understood that when an element such as a layer, region, or substrate is referred to as being “on” or extending “onto” another element, it can be directly on or extend directly onto the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” or extending “directly onto” another element, there are no intervening elements present. Likewise, it will be understood that when an element such as a layer, region, or substrate is referred to as being “over” or extending “over” another element, it can be directly over or extend directly over the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly over” or extending “directly over” another element, there are no intervening elements present. It will also be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, there are no intervening elements present.

[0039] Relative terms such as “below” or “above” or “upper” or “lower” or “horizontal” or “vertical” may be used herein to describe a relationship of one element, layer, or region to another element, layer, or region as illustrated in the Figures. It will be understood that these terms and those discussed above are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures.

[0040] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes,” and/or “including” when used herein specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0041] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0042] Embodiments are described herein with reference to schematic illustrations of embodiments of the disclosure. As such, the actual dimensions of the layers and elements can be different, and variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are expected. For example, a region illustrated or described as square or rectangular can have rounded or curved features, and regions shown as straight lines may have some irregularity. Thus, the regions illustrated in the figures are schematic and their shapes are not intended to illustrate the precise shape of a region of a device and are not intended to limit the scope of the disclosure. Additionally, sizes of structures or regions may be exaggerated relative to

other structures or regions for illustrative purposes and, thus, are provided to illustrate the general structures of the present subject matter and may or may not be drawn to scale. Common elements between figures may be shown herein with common element numbers and may not be subsequently re-described.

[0043] As microelectronics continue to miniaturize and handle higher powers and frequencies, ceramic materials, which enable dimensional stability, finer line/space, and embedded electronic components, attract increasing attention for use in package substrates. FIGS. **1A-1B** show an exemplary rigid-core laminate **10** according to some embodiments of the present disclosure.

[0044] FIG. **1A** illustrates a top view of the rigid-core laminate **10**, while FIG. **1B** illustrates a cross-section view of the rigid-core laminate **10** along a dashed line A-A' in FIG. **1A**. From the top view aspect, the rigid-core laminate **10** can be divided into a border region **12** and an active region **14**, which is surrounded by the border region **12** and includes a number of device-attached segments **16** (for clarity, only one device-attached segment is labeled with a reference number). Each device-attached segment **16** is configured to accommodate one or more electronic components (e.g., dies, surface mounted devices, and/or etc.). Within the border region **12**, on the other hand, there are no electronic functions (e.g., no electronic components or electronic signal routing paths). For the purpose of this illustration, the border region **12** includes six tooling-holes **18** substantially evenly distributed about a periphery of the border region **12**, each of which vertically extends from a top surface of the rigid-core laminate **10** to a bottom surface of the rigid-core laminate **10**. The tooling-holes **18** may be configured to hold alignment pins (not shown in FIGS. **1A-1B**, see FIGS. **9A-9B**) in place to enable a desired overmolding process (more details are described in the following paragraphs). In different applications, the rigid-core laminate **10** may include fewer or more tooling-holes **18** with a different layout in the border region **12**, and/or the rigid-core laminate **10** may include tooling-holes **18** within the active region **14** (e.g., horizontally between the device-attached segments **16** or within certain device-attached segments **16**). The border region **12** may have a width W between 0.2 mm and 50 mm, or between 1.2 mm and 50 mm.

[0045] From the cross-section view aspect, the rigid-core laminate **10** includes a core section **20**, sacrificial sockets **22**, protective vias **24**, top dielectric layers **26**, bottom dielectric layers **28**, top metal layers **30**, bottom metal layers **32**, a top solder-mask **34**, and a bottom solder-mask **36**. In detail, the core section **20** is a rigid section and may be formed of glass, silicon carbide, silicon, aluminum dioxide, aluminum nitride, or other ceramic material, which has a modulus of at least 50 GPa. With the core section **20**, the rigid-core laminate **10** is capable of obtaining dimensional stability and finer line/space and capable of allowing embedded electronic components (not shown). Due to different applications, the core section **20** may also be formed of other rigid materials (other than ceramic materials) with a modulus of at least 50 GPa for desired geometric/electronic/thermal performance. In addition, the core section **20** includes multiple cavities **38**, each of which extends vertically through the core section **20** and is located where a corresponding tooling-hole **18** is formed. As such, when the tooling-holes **18** are located within the border region **12** of the rigid-core laminate **10**, the cavities **38** are also formed around the periphery of the border region **12**. Alternatively, when the tooling-holes **18** are located within the active region **14** the rigid-core laminate **10** and the cavities **38** are formed in the active region **14** accordingly. A border region of the core section **20** and an active region of the core section **20** correspond to (e.g., are aligned with) the border region **12** of the rigid-core laminate **10** and the active region **14** of the rigid-core laminate **10**, respectively. Each cavity **38** may be confined within the border region of the core section **20** and/or within the active region of the core section **20**. The core section **20** may have a height H between 10 μm and 2000 μm , or between 300 μm and 400 μm . Each cavity **38** may have a shape of a circle, a square, a rectangle, an oval, a cushion, or any appropriate shape in a horizontal plane, with a diameter/diagonal D.sub.CA between 0.2 mm and 5 mm or between 1.2 mm and 5 mm.

[0046] Each sacrificial socket **22** is embedded in a corresponding cavity **38** of the core section **20** and attached to the core section **20** via a potting material **40**. The sacrificial sockets **22** may be embedded at the periphery of the border region **12** and/or within the active region **14** due to the locations of the cavities **38**. For the purpose of this illustration, an inner perimeter and an outer perimeter of one sacrificial socket **22** are circles. In different applications, the inner perimeter of one sacrificial socket **22** may also be a square, a rectangle, an oval, a cushion, or any appropriate shape. The outer perimeter of one sacrificial socket **22**, which is required to be smaller than the corresponding cavity **38** (i.e., the diameter/diagonal $D_{sub.CA}$ of one cavity **38** is larger than an outer diameter/diagonal $D_{sub.OUT}$ of the corresponding sacrificial socket **22** and is certainly larger than an inner diameter/diagonal $D_{sub.IN}$) and can fit in the corresponding cavity **38**, may also be a square, a rectangle, an oval, a cushion, or any appropriate shape. Typically, each cavity **38** may have a same horizontal shape as the outer perimeter of the corresponding sacrificial socket **22** with a small horizontal gap (e.g., $20\ \mu\text{m} \sim 150\ \mu\text{m}$) for the potting material **40** therebetween. The inner perimeter of the sacrificial socket **22** and the outer perimeter of the sacrificial socket **22** may have different shapes (e.g., the inner perimeter is a circle, while the outer perimeter is a square). Each sacrificial socket **22** may have a height about the same as the core section **20**. Herein, each sacrificial socket **22** corresponds to one particular tooling-hole **18**, where the inner perimeter of one sacrificial socket **22** defines a horizontal size/shape of the corresponding tooling-hole **18**.

[0047] In some applications, each cavity **38** may have a same or different shape with same or different dimensions. Each sacrificial socket **22** may have a same or different shape of the inner/outer perimeter with same or different dimensions. In addition, each sacrificial socket **22** may be formed from a same or different material. In some embodiments, the diameter/diagonal D_{IN} of the inner perimeter of the sacrificial socket **22** is between 0.1 mm and 5 mm or between 1 mm and 5 mm, the diameter/diagonal $D_{sub.OUT}$ of the outer perimeter of the sacrificial socket **22** is between 0.2 mm and 5 mm or between 1.1 mm and 5 mm, and the height of one sacrificial socket **22** is substantially the same as the height H of the core section **20**. The sacrificial sockets **22** may be formed of polymer, polymer and inorganic composite, or other relatively soft materials that can be readily drilled and serve as a stress buffer between the core section **20** and the alignment pins with a modulus of no more than 20 GPa. Typical materials such as Nylon, polyimide, PEEK are suitable for forming the sacrificial sockets **22**. The potting material **40**, which is configured to bond the sacrificial sockets **22** to the core section **20**, may be an epoxy and fills the gap between each cavity **38** and its corresponding sacrificial socket **22**.

[0048] In addition, each cavity **38**/sacrificial socket **22** may be surrounded by multiple protective vias **24**. Each protective via **24** extends vertically through the core section **20** and has a diameter/diagonal $D_{sub.V}$ between $100\ \mu\text{m}$ and $150\ \mu\text{m}$.

[0049] The protective vias **24** are typically plated with a metal material (e.g., copper) and may be filled with a metal or polymer material. The protective vias **20** are configured to act as crack-stops for the corresponding cavity **38** (more details are described in the following paragraphs).

[0050] The top dielectric layers **26** (e.g., a first top dielectric layer **26-1** over the core section **20** and a second top dielectric layer **26-2** over the first top dielectric layer **26-1**) and the top metal layers **30** (e.g., a first top metal layer **30-1** over the core section **20**, a second top metal layer **30-2** over the first top metal layer **30-1**, and a third top metal layer **30-3** over the second top metal layer **30-2**) are alternately formed over a top surface of the core section **20** (e.g. the first top metal layer **30-1** is formed over the top surface of the core section **20**, the first top dielectric layer **26-1** is formed over the top surface of the core section **20** and encapsulates the first top metal layer **30-1**, the second top metal layer **30-2** is formed over the first top dielectric layer **26-1**, and the second top dielectric layer **26-2** is formed over the first top dielectric layer **26-1** and encapsulates the second top metal layer **30-2**, and the third top metal layer **30-3** is formed over the second top dielectric layer **26-2**). Each top dielectric layer **26** may have a thickness between $0.2\ \mu\text{m}$ and $60\ \mu\text{m}$ or between $20\ \mu\text{m}$ and $30\ \mu\text{m}$, and may be formed of a dielectric material, such as Ajinomoto build-up

film (ABF) epoxy, polyimide, or other dielectric typically used in the microelectronics industry. The top dielectric layers **26** are relatively soft and may have a modulus of no more than 15 GPa. The top metal layers **30** are separated from each other by the top dielectric layers **26**, and may be formed of a conducting material, such as copper or gold. Herein, the top dielectric layers **26** include multiple top holes **42**, each of which extends vertically through all of the top dielectric layers **26** and is vertically aligned with the inner perimeter of a corresponding sacrificial socket **22**. Each top hole **42** may have an identical horizontal shape and size as the inner perimeter of the corresponding sacrificial socket **22**. As such, the top holes **42** may be formed around the periphery of the border region **12** and/or within the active region **14** corresponding to the locations of the sacrificial sockets **22**. Each top metal layer **30** may include multiple discrete metal sections (see FIGS. **4A** and **5A**), is confined within the top dielectric layers **26**, and does not extend across any portion of each top hole **42**.

[0051] Similarly, the bottom dielectric layers **28** (e.g., a first bottom dielectric layer **28-1** underneath the core section **20** and a second bottom dielectric layer **28-2** underneath the first bottom dielectric layer **28-1**) and the bottom metal layers **32** (e.g., a first bottom metal layer **32-1** underneath the core section **20**, a second bottom metal layer **32-2** underneath the first bottom metal layer **32-1**, and a third bottom metal layer **32-3** underneath the second bottom metal layer **32-2**) are alternately formed underneath a bottom surface of the core section **20** (e.g.

[0052] the first bottom metal layer **32-1** is formed underneath the bottom surface of the core section **20**, the first bottom dielectric layer **28-1** is formed underneath the bottom surface of the core section **20** and encapsulates the first bottom metal layer **32-1**, the second bottom metal layer **32-2** is formed underneath the first bottom dielectric layer **28-1**, and the second bottom dielectric layer **28-2** is formed underneath the first bottom dielectric layer **28-1** and encapsulates the second bottom metal layer **32-2**, and the third bottom metal layer **32-3** is formed underneath the second bottom dielectric layer **28-2**). Each bottom dielectric layer **28** may have a thickness between 0.2 μm and 60 μm or between 20 μm and 30 μm , and may be formed of a dielectric material, such as ABF epoxy, polyimide, or other dielectric typically used in the microelectronics industry. The bottom dielectric layers **28** are relatively soft and may have a modulus of no more than 15 GPa. The bottom metal layers **32** are separated from each other by the bottom dielectric layers **28**, and may be formed of a conducting material, such as copper or gold. Herein, the bottom dielectric layers **28** include multiple bottom holes **44**, each of which extends vertically through all of the bottom dielectric layers **28** and is vertically aligned with the inner perimeter of a corresponding sacrificial socket **22**. Each bottom hole **44** may have an identical horizontal shape and size as the inner perimeter of the corresponding sacrificial socket **22**. As such, the bottom holes **44** may be formed around the periphery of the border region **12** and/or within the active region **14** corresponding to the locations of the sacrificial sockets **22**. Each bottom metal layer **32** may include multiple discrete metal sections (see FIG. **4A**), is confined with the bottom dielectric layers **28**, and does not extend across any portion of each bottom hole **44**.

[0053] For the purpose of this illustration, the rigid-core laminate **10** includes two top dielectric layers **26**, three top metal layers **30**, two bottom dielectric layers **28**, and three bottom metal layers **32**. In different applications, the rigid-core laminate **10** may include fewer or more top dielectric layers **26**, fewer or more top metal layers **30**, fewer or more bottom dielectric layers **28**, and fewer or more bottom metal layers **32**. The top dielectric layers **26** may have a total thickness between 0.004 mm and 1 mm, while the bottom dielectric layers **28** may have a total thickness between 0.004 mm and 1 mm.

[0054] The top metal layers **30** and the bottom metal layers **32** are configured to provide signal paths for devices (see FIG. **8**, devices **54**) attached to the active region **14**. In some embodiments, the protective vias **24** may be connected to one top metal layer **30** and/or one bottom metal layer **32**. Regardless of whether the protective vias **24** are connected to the top/bottom metal layers **30/32**, the protective vias **24** are not used to transmit any electrical signals. Furthermore, the top

solder-mask **34** is formed over the top dielectric layers **26** to protect any top metal layer **30** (e.g., the third top metal layer **30-3**) not being encapsulated by the top dielectric layers **26**, while the bottom solder-mask **36** is formed underneath the bottom dielectric layers **28** to protect any bottom metal layer **32** (e.g., the third bottom metal layer **32-3**) not being encapsulated by the bottom dielectric layers **28**. The top solder-mask **34** is confined within the top dielectric layers **26** and does not extend across over any portion of each top hole **42**. The bottom solder-mask **36** is confined within the bottom dielectric layers **28** and does not extend across over any portion of each bottom hole **44**.

[0055] Note that each tooling-hole **18** extends vertically through the top dielectric layers **26**, the core section **20**/the corresponding sacrificial socket **22**, and the bottom dielectric layers **28**, and is a combination of a corresponding top hole **42**, an inner perimeter of a corresponding sacrificial socket **22**, and a corresponding bottom hole **44**. The top dielectric layers **26**, the corresponding sacrificial socket **22**, and the bottom dielectric layers **28** are exposed in each tooling-hole **18**. Since the top dielectric layers **26**, the sacrificial sockets **22**, and the bottom dielectric layers **28** are all relatively soft, there might be no, or negligible cracks introduced during forming the tooling-holes **18** (more details are described in the following paragraphs).

[0056] FIGS. 2A-7B show an exemplary fabricating process that illustrates steps to provide the rigid-core laminate **10** shown in FIGS. 1A-1B. Although the exemplary steps are illustrated in a series, the exemplary steps are not necessarily order dependent. Some steps may be done in a different order than that presented. Further, processes within the scope of this disclosure may include fewer or more steps than those illustrated in FIGS. 2A-7B.

[0057] Initially, the core section **20** with the cavities **38** (only one cavity **38** is shown for simplicity) is provided as illustrated in FIGS. 2A and 2B. FIG. 2A shows a top view of the core section **20** within the partial border region **12**, while FIG. 2B illustrates a cross-section view of the core section **20** along a dashed line A-A' in FIG. 2A. In different applications, the cavities **38** may be formed within the border region of the core section **20**, may be formed within the active region of the core section **20** (e.g., horizontally between the device-attached segments **16** or within certain device-attached segments **16**, not shown), or may be formed in both the border region and the active region of the core section **20** (not shown). Herein, the core section **20** may also include multiple hollow protective vias **24H** surrounding each cavity **38**. Each hollow protective via **24H** extends vertically through the core section **20** and has the diameter/diagonal $D_{sub.V}$ between 100 μm and 150 μm . The hollow protective vias **24H** are configured to prevent cracks due to the formation of the corresponding cavity **38**. Even if cracks occur, they can terminate on the extra surfaces provided by the hollow protective vias **24H** and do not spread to the rest of the core section **20**. Typically, each hollow protective via **24H** and the corresponding cavity **38** have a distance D_1 between 50 μm and 500 μm .

[0058] The core section **20** is a rigid section and may be formed of glass, silicon carbide, silicon, aluminum oxide, aluminum nitride, or other ceramic material, which has a modulus of at least 50 GPa. Due to different applications, the core section **20** may also be formed of other rigid materials (other than ceramic materials) with a modulus of at least 50 GPa for desired geometric/electronic/thermal performance. In addition, the core section **20** may have a height H between 300 μm and 400 μm , and each cavity **38** may have a diameter/diagonal $D_{sub.CA}$ between 0.2 mm and 5 mm or between 1.2 mm and 5 mm.

[0059] Next, a sacrificial plate **46** is embedded into each cavity **38** within the core section **20**, as illustrated in FIGS. 3A and 3B. Typically, the sacrificial plate **46** has a same horizontal shape of a corresponding cavity **38**, such as a circle, a square, a rectangle, an oval, a cushion, or any appropriate shape. The sacrificial plate **46** is embedded into the core section **20** using an existing embedding step for other components (not shown) embedded into the core section **20**. Therefore, the sacrificial plate **46** does not require any additional embedding process. The sacrificial plate **46** has a diameter/diagonal $D_{sub.S}$ slightly smaller than the diameter/diagonal $D_{sub.CA}$ of a

corresponding cavity **38** in order to be accommodated by the corresponding cavity **38**. For a non-limiting example, the diameter/diagonal D.sub.S of the sacrificial plate **46** is smaller than the diameter/diagonal D.sub.CA of the corresponding cavity **38** by about 40 μm~300 μm.

[0060] Once the sacrificial plate **46** is placed in the corresponding cavity **38**, the potting material **40** is applied to fill the gap between the sacrificial plate **46** and its corresponding cavity **38**. The potting material **40** may be an epoxy and may be applied by needle dispense, stencil printing, or three-dimensional (3D) printing. The potting material **40** is configured to bond each sacrificial plate **46** to the core section **20** within the corresponding cavity **38**. After the potting material **40** is applied, a curing step (not shown) may be followed to harden the potting material **40**. A curing temperature may be between 100° C.-300° C. depending on the material used for potting.

[0061] In some applications, each cavity **38** may have a same shape and same dimensions, and each sacrificial plate **46** may have a same shape and same dimensions and may be formed from a same material. In some applications, the cavities **38** may have different shapes and/or different dimensions, and the sacrificial plates **46** may have different shapes and/or different dimensions, and/or may be formed from different materials. The diameter/diagonal D.sub.S of one sacrificial plate **46** may be between 0.2 mm and 5 mm or between 1.1 mm and 5 mm, and the height of one sacrificial plate **46** may be substantially the same as the height H of the core section **20**. The sacrificial plate **46** may be formed of polymer, polymer and inorganic composite, or other relatively soft materials that can be readily drilled or milled and serve as a stress buffer between the core section **20** and subsequently inserted components (e.g., alignment pins) with a modulus of no more than 20 GPa.

[0062] FIGS. 4A and 4B show a metal plating step applied to the core section **20**. Herein, the first top metal layer **30-1** is formed over the top surface of the core section **20**, and the first bottom metal layer **32-1** is formed underneath the bottom surface of the core section **20**. In some embodiments, the first top metal layer **30-1** may not extend over any portion of each cavity **38**, and the first bottom metal layer **32-1** may not extend underneath any portion of each cavity **38**. In some applications, the first top metal layer **30-1**/the first bottom metal layer **32-1** may extend over each cavity **38** (not shown). In addition, by metal plating, each hollow protective via **24H** is lined/plated with a metal material and converted into one protective via **24**. The metal material used to line the hollow protective vias **24H** is the same material used to form the first top metal layer **30-1** and the first bottom metal layer **32-1**, such as copper, and gold.

[0063] In some applications, the metal plating step may be applied before the sacrificial plates **46** are embedded into the cavities **38** (not shown). In such a scenario, the metal material (e.g., the first top metal layer **30-1**/the first bottom metal layer **32-1**) may extend all the way to the edge of each cavity **38** and continuously cover an interior wall of each cavity **38**. After the metal plating step is completed, the sacrificial plates **46** are embedded into the cavities **38** with the potting material **40** (as described above). Herein, the potting material **40** provides adhesion between the sacrificial plates **46** and the metal material. The first top metal layer **30-1** and the first bottom metal layer **32-1** do not extend horizontally over any portion of each sacrificial plate **46**.

[0064] FIGS. 5A and 5B show a building up of the top dielectric layers **26**, the bottom dielectric layers **28**, other top metal layers **30** (e.g., the second and third top metal layers **30-2** and **30-3**), and other bottom metal layers **32** (e.g., the second and third bottom metal layers **32-2** and **32-3**) over or underneath the core section **20**. In detail, the first top dielectric layer **26-1** extends across and is formed over the top surface of the core section **20** to cover each cavity **38** (i.e., cover the sacrificial plate **46** and the potting material **40**) and encapsulate the first top metal layer **30-1**. The first bottom dielectric layer **28-1** extends across and is formed underneath the bottom surface of the core section **20** to cover each cavity **38** (i.e., cover the sacrificial plate **46** and the potting material **40**) and encapsulate the first bottom metal layer **32-1**. The second top metal layer **30-2** is formed over the first top dielectric layer **26-1** and may or may not extend over each cavity **38**. The second top dielectric layer **26-2** is formed over and extends across the first top dielectric layer **26-1**, and

encapsulates the second top metal layer **30-2**. The second bottom metal layer **32-2** is formed underneath the first bottom dielectric layer **28-1** and may or may not extend underneath each cavity **38**. The second bottom dielectric layer **28-2** is formed underneath and extends across the first bottom dielectric layer **28-1**, and encapsulates the second bottom metal layer **32-2**. The third top metal layer **30-3** is formed over the second top dielectric layer **26-2** and may or may not extend over each cavity **38**. The third bottom metal layer **32-3** is formed underneath the second bottom dielectric layer **28-2** and may or may not extend underneath each cavity **38**. For the purpose of this illustration, there are two top dielectric layers **26** and three top metal layers **30** formed over the core section **20**, and two bottom dielectric layers **28** and three bottom metal layers **32** formed underneath the core section **20**. In different applications, there might be fewer or more top dielectric layers **26**, fewer or more top metal layers **30**, fewer or more bottom dielectric layers **28**, and/or fewer or more bottom metal layers **32**.

[0065] Each top dielectric layer **26** may have a thickness between 0.2 μm and 60 μm or between 20 μm and 30 μm , and may be formed of a dielectric material, such as ABF epoxy, polyimide, or other dielectric material typically used in the microelectronics industry. Similarly, each bottom dielectric layer **28** may have a thickness between 0.5 μm and 60 μm or between 20 μm and 30 μm , and may be formed of a dielectric material, such as ABF epoxy, polyimide, or other dielectric material typically used in the microelectronics industry. Both the top dielectric layers **26** and the bottom dielectric layers **28** are relatively soft and may have a modulus of no more than 15 GPa. In addition, the second and third top metal layers **30-2** and **30-3** and the second and third bottom metal layers **32-2** and **32-3** might be formed of copper or gold. Furthermore, during the step of building up the top dielectric layers **26** and the bottom dielectric layers **28**, each protective via **24** might be filled with the dielectric material(s) used to form the top dielectric layers **26** and the bottom dielectric layers **28**.

[0066] Note that in addition to the sacrificial plate **46** needing to be easily and reliably drilled or milled to a stress buffer between the core section **20** and subsequently inserted components, the sacrificial plate **46** also provides mechanical support during the formation of the top and bottom dielectric layers **26** and **28** over the cavities **38**. There will be a manufacturing challenge to add the top and bottom dielectric layers **26** and **28** if there are large unfilled cavities **38** existing in the core section **20**.

[0067] The top solder-mask **34** and the bottom solder-mask **36** are then applied to form a precursor laminate **48**, as illustrated in FIGS. **6A** and **6B**. The top solder-mask **34** is formed over the second top dielectric layer **26-2** to fully cover the third top metal layer **30-3**, while the bottom solder-mask **36** is formed underneath the second bottom dielectric layer **28-2** to fully cover the third bottom metal layer **32-3**. Herein, the top solder-mask **34** includes multiple top mask holes **50** (only one top mask hole **50** is shown for simplicity) vertically aligned with the cavities **38**, respectively, such that portions of the second top dielectric layer **26-2** are exposed through the top solder-mask **34**. A diameter/diagonal $D_{\text{sub.M1}}$ of each top mask hole **50** might be the same, slightly smaller, or slightly larger than the diameter/diagonal $D_{\text{sub.CA}}$ of a corresponding cavity **38**. The bottom solder-mask **36** includes multiple bottom mask holes **52** (only one bottom mask hole **52** is shown for simplicity) vertically aligned with the cavities **38**, respectively, such that portions of the second bottom dielectric layer **28-2** are exposed through the bottom solder-mask **36**. A diameter/diagonal $D_{\text{sub.M2}}$ of each bottom mask hole **52** might be the same, slightly smaller, or slightly larger than the diameter/diagonal $D_{\text{sub.CA}}$ of the corresponding cavity **38**.

[0068] Lastly, the tooling-holes **18** are formed to complete the rigid-core laminate **10**, as shown in FIG. **7A** and **7B**. Each tooling-hole **18** is formed where a corresponding sacrificial plate **46** is originally located and has a smaller horizontal size than the diameter $D_{\text{sub.S}}$ of the corresponding sacrificial plate **46**. The tooling-holes **18** are formed by drilling vertically through the precursor laminate **48** (i.e., drilling vertically through the top dielectric layers **26**, the sacrificial plates **46**, and the bottom dielectric layers **28**, but not touching any portion of the core section **20**) using a

mechanical drill or laser machining. Herein, the top holes **42** are formed vertically through all of the top dielectric layers **26**, the sacrificial plates **46** are converted into the sacrificial sockets **22**, and the bottom holes **44** are formed vertically through all of the bottom dielectric layers **28**. In some embodiments, each tooling-hole **18** has a smaller horizontal size than the diameter $D_{sub.M1}$ of a corresponding top mask hole **50**, and a smaller horizontal size than the diameter $DM2$ of a corresponding bottom mask hole **52**. As such, the drilling operation may not touch the top solder-mask **34** or the bottom solder-mask **36**.

[0069] Since the top dielectric layers **26**, the sacrificial plates **46**, and the bottom dielectric layers **28** are all relatively soft (e.g., with a modulus of no more than 20 GPa), there might be no, or might be only negligible cracks introduced during the drilling step. Each tooling-hole **18** extends vertically through the top dielectric layers **26**, vertically through the corresponding sacrificial socket **22**, and the bottom dielectric layers **28**, and is always confined within the corresponding sacrificial socket **22**. As such, no drilling is performed directly through the core section **20**, and no portion of the core section **20** is exposed in any tooling-hole **18**. Typically, the horizontal size/shape of one tooling-hole **18** is constant along the vertical direction, which is the same as the inner perimeter of the corresponding sacrificial socket **22**. The rigid-core laminate **10** may have a total height between 0.05 mm and 4 mm.

[0070] FIGS. **8-10B** show an exemplary packaging process that illustrates steps to provide a package assembly formed based on the rigid-core laminate **10**. Once the rigid-core laminate **10** is formed, one or more electrical devices **54** are attached to each device-attached segment **16** of the active region **14**, as illustrated in FIG. **8**. In this illustration, the tooling-holes **18** are located in the border region **12**, and no electronic components are formed in the border region **12** or adjacent to the tooling-holes **18**. In different applications, the tooling-holes **18** may be located in the active region **14**, or located in both the border region **12** and the active region **14** (not shown).

[0071] Next, alignment pins **56** are inserted into the tooling-holes **18**, respectively, as shown in FIGS. **9A** and **9B**. Each alignment pin **56** has a height H_p larger than the height of the rigid-core laminate **10**, and has a diameter/diagonal $D_{sub.P}$ slightly smaller than the horizontal size of a corresponding tooling-hole **18** (e.g., the diameter $D_{sub.P}$ is about 80%-97% of the horizontal size of a corresponding tooling-hole **18**). Note that only the top dielectric layers **26**, one sacrificial socket **22**, and the bottom dielectric layers **28**, all of which are relatively soft, are exposed in a corresponding tooling-hole **18**, which allows the tooling-holes **18** to receive the alignment pins **56** or any other kind of tooling without putting excess stress on the core section **20**. In some embodiments, the alignment pins **56** may be formed on a connection tray **58**. The connection tray **58** is placed underneath the rigid-core laminate **10**, and each alignment pin **56** extends from the connection tray **58**, upwards through the corresponding tooling-hole **18**, and is vertically beyond the rigid-core laminate **10**. Accordingly, the rigid-core laminate **10** can be secured to the connection tray **58**, and the assembly or production equipment (e.g., used to form the electronic devices **54** and/or a mold compound **60** shown in FIGS. **10A**, **10B**) can locate the rigid-core laminate **10** more easily. Note that the tooling-holes **18** are only used for alignment/location purposes. None of the tooling-holes are metalized inside for any electronic functionality. The top dielectric layers **26**, the corresponding sacrificial socket **22**, and the bottom dielectric layers **28** are exposed in each tooling-hole **18**. In some applications, the electrical devices **54** may be attached to the active region **14** after the rigid-core laminate **10** is secured to the connection tray **58** by inserting the alignment pins **56** into the tooling-holes **18**.

[0072] After the alignment pins **56** are inserted into the corresponding tooling-holes **18**, a mold compound **60** is formed over the rigid-core laminate **10** to form a package assembly **62**, as illustrated in FIGS. **10A** and **10B**. Herein, the alignment pins **56** serve as “landmarks” for the rigid-core laminate **10** when the mold compound **60** is formed over the rigid-core laminate **10**. In this way, the mold compound **60** can be applied at accurate locations and fully encapsulate each electrical device **54** (not shown) attached to the active region **14**. In some embodiments, the mold

compound **60** is formed by an overmolding step. A singulation step is then followed to separate the package assembly **62** into individual package modules (not shown). If the tooling-holes **18** and the alignment pins **56** are located in the active region **14**, the alignment pins **56** may also serve as “landmarks” during the singulation of the package assembly **62**.

[0073] The border region **12** of the rigid-core laminate **10** with the tooling-holes **18** is not included in the final package modules.

[0074] It is contemplated that any of the foregoing aspects, and/or various separate aspects and features as described herein, may be combined for additional advantage. Any of the various embodiments as disclosed herein may be combined with one or more other disclosed embodiments unless indicated to the contrary herein.

[0075] Those skilled in the art will recognize improvements and modifications to the preferred embodiments of the present disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

Claims

1. A rigid-core laminate comprising: a core section that is formed of a first material with a first modulus of at least 50 GPa; a plurality of sacrificial sockets embedded in the core section through a potting material, wherein the plurality of sacrificial sockets is formed of a second material with a second modulus that is smaller than the first modulus; a plurality of top dielectric layers formed over a top surface of the core section and covering a top surface of each of the plurality of sacrificial sockets; a plurality of bottom dielectric layers formed underneath a bottom surface of the core section and covering a bottom surface of each of the plurality of sacrificial sockets; and a plurality of tooling-holes, each of which extends vertically through the plurality of top dielectric layers, a corresponding one of the plurality of sacrificial sockets within the core section, and the plurality of bottom dielectric layers, wherein no portion of the core section is exposed in any one of the plurality of tooling-holes.
2. The rigid-core laminate of claim 1 wherein the second modulus is no more than 20 GPa.
3. The rigid-core laminate of claim 1 wherein the first material is a ceramic material.
4. The rigid-core laminate of claim 3 wherein the second material is a polymer material or a polymer and inorganic composite.
5. The rigid-core laminate of claim 1 wherein: the core section has a height between 10 μm and 2000 μm ; each of the plurality of top dielectric layers has a thickness between 0.2 μm and 60 μm ; and each of the plurality of bottom dielectric layers has a thickness between 0.2 μm and 60 μm .
6. The rigid-core laminate of claim 1 wherein a horizontal shape of each of the plurality of tooling-holes is constant along a vertical direction, which is identical to a shape of an inner perimeter of the corresponding one of the plurality of sacrificial sockets.
7. The rigid-core laminate of claim 1 wherein: a shape of an inner perimeter of each of the plurality of sacrificial sockets is a circle, a square, a rectangle, an oval, or a cushion; and a shape of an outer perimeter of each of the plurality of sacrificial sockets is a circle, a square, a rectangle, an oval, or a cushion.
8. The rigid-core laminate of claim 7 wherein a diameter of the inner perimeter of each of the plurality of sacrificial sockets is between 1 mm and 5 mm, and a diameter of the outer perimeter of each of the plurality of sacrificial sockets is between 1.1 mm and 5 mm.
9. The rigid-core laminate of claim 1 further includes a plurality of protective vias, wherein: each of the plurality of sacrificial sockets is surrounded by certain ones of the plurality of protective vias; and each of the plurality of protective vias has a diameter between 100 μm and 150 μm .
10. The rigid-core laminate of claim 1 further includes a plurality of top metal layers, and a plurality of bottom metal layers, wherein: the plurality of top dielectric layers and the plurality of top metal layers are alternately formed over the top surface of the core section; and the plurality of

bottom dielectric layers and the plurality of bottom metal layers are alternately formed underneath the bottom surface of the core section.

11. The rigid-core laminate of claim 1 wherein the plurality of top dielectric layers and the plurality of bottom dielectric layers are formed of a dielectric material, which has a modulus of no more than 15 GPa.

12. The rigid-core laminate of claim 11 wherein the plurality of top dielectric layers and the plurality of bottom dielectric layers are formed of Ajinomoto build-up film (ABF) epoxy or polyimide.

13. The rigid-core laminate of claim 1 wherein the potting material is epoxy.

14. A method of fabricating a package assembly comprising forming a rigid-core laminate, wherein forming the rigid-core laminate comprises: providing a core section with a plurality of cavities, wherein the core section is formed of a first material with a first modulus of at least 50 GPa; embedding a sacrificial plate into each of the plurality of cavities, wherein the sacrificial plate is formed of a second material with a second modulus that is smaller than the first modulus; applying a potting material to fill a gap between the sacrificial plate and a corresponding one of the plurality of cavities; forming a plurality of top dielectric layers over a top surface of the core section and a top surface of the sacrificial plate, and forming a plurality of bottom dielectric layers underneath a bottom surface of the core section and a bottom surface of the sacrificial plate; and forming a tooling-hole where a corresponding sacrificial plate is located, wherein: the tooling-hole has a smaller horizontal size than a diameter of the corresponding sacrificial plate, and each sacrificial plate is converted into a corresponding sacrificial socket; and the tooling-hole extends vertically through the plurality of top dielectric layers, the corresponding sacrificial socket, and the plurality of bottom dielectric layers.

15. The method of claim 14 wherein the core section further includes a plurality of hollow protective vias surrounding each of the plurality of cavities.

16. The method of claim 15 wherein forming the rigid-core laminate further comprises applying a metal plating step to the core section before forming the plurality of top dielectric layers and the plurality of bottom dielectric layers, wherein: a first top metal layer is formed with a metal material over the top surface of the core section, a first bottom metal layer is formed with the metal material underneath the bottom surface of the core section; and each of the plurality of hollow protective vias is filled with the metal material.

17. The method of claim 16 wherein the metal plating step is applied before embedding the sacrificial plate into each of the plurality of cavities, such that the metal material extends to cover an interior wall of each of the plurality of cavities.

18. The method of claim 16 wherein forming the rigid-core laminate further comprises forming a plurality of top metal layers and a plurality of bottom metal layers, wherein: the plurality of top metal layers and the plurality of top dielectric layers are alternately formed over the top surface of the core section; and the plurality of bottom metal layers and the plurality of bottom dielectric layers are alternately formed underneath the bottom surface of the core section.

19. The method of claim 14 wherein the second modulus is no more than 20 GPa.

20. The method of claim 14 wherein the first material is a ceramic material.

21. The method of claim 20 wherein the second material is a polymer material or a polymer and inorganic composite.

22. The method of claim 14 wherein the tooling-hole is formed by a mechanical drill or laser machining.

23. The method of claim 14 further comprising attaching one or more electrical devices to the rigid-core laminate, wherein: in horizontal dimensions, the rigid-core laminate is divided into a border region and an active region, which is surrounded by the border region; and the one or more electrical devices are located on a top surface of the rigid-core laminate and within the active region, while each sacrificial socket and the corresponding tooling-hole are located within the

border region.

24. The method of claim 23 further comprising: inserting one alignment pin into a corresponding tooling-hole, wherein each alignment pin has a height larger than a height of the rigid-core laminate and protrudes above the top surface of the rigid-core laminate; and applying a mold compound over the rigid-core laminate using each alignment pin as a landmark, such that the one or more electrical devices are fully encapsulated by the mold compound.
