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LAMINATE SUBSTRATE-BASED DIFFERENTIAL PRESSURE SENSOR PACKAGE COMBINING AIR CAVITY CHANNEL SUBSTRATE, OVERMOLD, AND LID WITH TWO CHIMNEYS

Abstract

The sensor device includes a substrate having upper and lower surfaces with a channel formed therebetween. First and second port holes are formed through the upper surface to the channel. The sensor device also includes an application-specific integrated circuit (ASIC) die mounted on the upper surface so as not to cover the first and second port holes. The sensor device further includes an overmolding formed on the upper surface that is molded over the ASIC die and forms first and second cavities surrounding the first and second port holes, respectively. The sensor device also includes a transducer electrically connected with the ASIC die and mounted within the first cavity on the upper surface so as to cover the first port hole. The sensor device further includes a lid attached to the overmolding having first and second chimneys.

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Background/Summary

BACKGROUND OF THE SPECIFICATION
[0001] The present disclosure relates to differential pressure sensors (DPS).
[0002] DPS are a type of pressure sensor device that measures differences in pressure between two points in a system. This allows for more accurate readings of fluid (liquid or gas) systems, where changes in pressure can be critical. By measuring pressures at different locations, these sensors enable the detection of flow rates, filter conditions, and other variables that influence system performance. Packaging of DPS can be very important. For example, overall sizes of DPS and implementations (e.g., accessing both sides of a membrane) can be difficult in small applications.
SUMMARY
[0003] A sensor device is described herein. The sensor device includes a substrate having a substrate upper surface and a substrate lower surface opposite the substrate upper surface. The substrate forms a channel between the substrate upper surface and the substrate lower surface and forms first and second port holes through the substrate upper surface to the channel. The sensor device also includes an application-specific integrated circuit (ASIC) die mounted on the substrate upper surface so as not to cover the first port hole and the second port hole. The sensor device further includes an overmolding formed on the substrate upper surface that is molded over the ASIC die and forms first and second cavities surrounding the first and second port holes, respectively. The sensor device also includes a transducer electrically connected with the ASIC die and mounted within the first cavity on the substate upper surface so as to cover the first port hole. The sensor device further includes a lid attached to the overmolding and having first and second chimneys.
[0004] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description. In the drawings, like reference numbers indicate identical or functionally similar elements.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0005] FIG. **1** illustrates an example of a laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0006] FIG. **2** illustrates an exploded view of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0007] FIG. **3** illustrates a top plan view of a substrate of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two

chimneys.
[0008] FIG. **4** illustrates a section view through a channel of the substrate of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0009] FIG. **5** illustrates a bottom plan view of the substrate of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0010] FIGS. **6-10** illustrate top plan views of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys as various manufacturing steps are applied.
[0011] FIG. **11** illustrates a section view through chimneys of a lid of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0012] FIG. **12** illustrates a bottom plan view of the lid of the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.
[0013] FIG. **13** illustrates an example method of manufacturing the laminate substrate-based differential pressure sensor package combining an air cavity channel substrate, an overmold, and a lid with two chimneys.

DETAILED DESCRIPTION

[0014] FIG. **1** illustrates an example of a differential pressure sensor **100**. The differential pressure sensor **100** contains a substrate **102**, an overmolding **104**, and a lid **106**. The lid **106** contains a first port **108** and a second port **110**. The first port **108** and the second port **110** may be configured to accept tubing, piping, or directly connect to an area of interest. The differential pressure sensor **100** is configured to measure a pressure differential between the first port **108** and the second port **110**. The differential pressure sensor **100** may have a rectangular footprint and have a size on the order of 7 mm long by 7 mm wide by 5 mm tall. The differential pressure sensor **100** may be configured to be disposed in a variety of environments ranging from −40C to 85C. Furthermore, the differential pressure sensor **100** may be configured to withstand at least 5 bar of differential pressure.
[0015] FIG. **2** illustrates an exploded view of the differential pressure sensor **100**. The substrate **102** contains a substrate upper surface **200**. Formed between the substrate upper surface **200** and a substrate lower surface (not shown), is a channel **202**. Formed through the substrate upper surface **200** to the channel **202** is a first port hole (not shown) and a second port hole **204**. The first port hole and the second port hole **204** are formed on opposite ends of the channel **202**. The substrate **102** may be a four-layer structure (as discussed further below) with an overall thickness around 600 μm. The channel **202** may have a depth around 360 μm.
[0016] The channel **202** may be straight along a longitudinal axis with a rectangular cross section. A length of the channel **202** may be configured to mitigate condensation forming within the channel **202**. Furthermore, the longitudinal axis of the channel **202** may be non-parallel to sides of the differential pressure sensor **100**. In other words, as illustrated, the channel **202** may traverse diagonally across the substrate **102**.
[0017] Attached to the substrate upper surface **200** are an ASIC die **206** and a transducer **208**. The ASIC die **206** may be a semiconductor device and/or comprise a complementary metal oxide semiconductor (CMOS). The ASIC die **206** is configured to receive a voltage (or other electrical property) from the transducer **208** and communicate the voltage (or other electrical property) or a differential pressure to an external device.
[0018] The transducer **208** is communicatively coupled with the ASIC die **206**. The transducer **208** may be a micro-electromechanical system (MEMS) with a membrane configured to affect a capacitance of the transducer **208** in response to a difference in pressure between the sides of the

membrane. Other differential pressure sensing devices may be used without departing from the scope of this disclosure. For example, the transducer **208** may be piezoresistive, optical fiber, resonant, or piezoelectric. Regardless of how it is configured, the transducer **208** is configured to output an electrical property (e.g., voltage) that varies according to the differential pressure.

[0019] The transducer **208** is disposed on top of the first port hole in the substrate. Doing so allows a pressure from within the channel **202** to be communicated to one side of the transducer **208**. Accordingly, a pressure reaching the second port hole **204** is communicated via the channel **202** to the first port hole and, thus, one side of the transducer **208**.

[0020] Formed on top of the substrate **102** (e.g., on the substrate upper surface **200**) is the overmolding **104** having an overmolding upper surface **210**. The overmolding **104** is configured to encapsulate the ASIC die **206** while forming a first cavity **212** around the transducer **208** and a second cavity **214** around the second port hole **204**. The first cavity **212** and the second cavity **214** are formed through the overmolding **104** (e.g., from the overmolding upper surface **210** to an overmolding lower surface (not shown)). The first cavity **212** may be formed such that, when the lid **106** is installed, the first port **108** is not directly above the transducer **208**. In other words, the first port **108** may be offset from a top of the transducer **208**. Doing so may help with environmental impact on the transducer **208** (e.g., anything falling through the port **108** will not land on the transducer **208**). The shapes, sizes, and/or locations of the first cavity **212** and the second cavity **214** may vary without departing from the scope of this disclosure.

[0021] Attached to the overmolding upper surface **210** is the lid **106**. The lid **106** may be formed of a plastic (e.g., a liquid-crystal polymer). The lid **106** has a lid upper surface **216** that is opposite a lid lower surface (not shown) that is attached to the overmolding upper surface **210**. Protruding from the lid upper surface **216** is a first chimney **218** and a second chimney **220**. The first chimney **218** and the second chimney **220** may be generally cylindrical and coaxial with the first port **108** and the second port **110**, respectively. It should be noted that the first port **108** is aligned with the first cavity **212** and the second port **110** is aligned with the second cavity **214**. Accordingly, the first port **108** communicates a first pressure to a top side of the transducer **208** and the second port **110** communicates a second pressure to a bottom side of the transducer via the second port hole **204**, the channel **202**, and the first port hole.

[0022] FIG. **3** illustrates a top plan view of the substrate **102** prior to having the ASIC die **206** or the transducer **208** installed thereon. As discussed above, the substrate **102** contains the channel **202**, the second port hole **204**, and the first port hole **300**. Disposed on the substrate upper surface **200** are one or more transducer bond pads **302** and one or more ASIC die bond pads **304**. The transducer bond pads **302** are configured to communicatively couple the transducer **208** to the ASIC die **206**. The ASIC die bond pads **304** are configured to communicatively couple the ASIC die **206** to the transducer **208** and to couple the ASIC die **206** to one or more substrate bond pads on the substrate lower surface. The bond pads may be coupled to each other via metal layers in the substrate, vias, or any other number of electrical connections.

[0023] FIG. **4** illustrates a section view of the substrate **102** through the channel **202**. The substrate **102** will be described from the bottom up. On a bottom of the substrate **102** is the substrate lower surface **400**. The substrate lower surface **400** may be formed as part of a lower solder mask layer **402**. Above the lower solder mask layer **402** is a first of a plurality of metal layers **404**. The metal layers **404** may be disposed as shown, including lining a top and bottom of the channel **202**. The metal layers **404** around the channel **202** may form structural components to stiffen the substrate **102**. The other metal layers **404** may be used for electrical connections. The metal layers **404** may comprise one or more materials. Above the lower-most metal layer **404** is a first of a plurality of core layers **406**. The core layers **406** may be non-conductive. Above the upper-most metal layer **404** (e.g., a signal layer), is an upper solder mask layer **408** that forms the substrate upper surface **200**.

[0024] The transducer bond pads **302** and the ASIC die bond pads **304** may be portions of the upper-most metal layer **404** exposed via the upper solder mask layer **408**. The substrate bond pads may be portions of the lower-most metal layer **404** exposed via the lower solder mask layer **402** Various vias, plugs, drills, pads, wires, and other structures through or on the substrate **102** may exist to facilitate signals/communications between the ASIC die **206** and the transducer **208** and/or between the ASIC die **206** and an external device.

[0025] FIG. **5** illustrates a bottom plan view of the substrate **102**. The substrate **102** has a substrate lower surface **500** and substrate pins **502** that form a land grid array (LGA). The substrate pins **502** may be exposed portions of the lower-most metal layer **404** through the lower solder mask layer **402**. The substrate pins **502** may enable communication between the ASIC die **206** and an external device and/or provide structural bonding between the substrate **102** (and thus, the differential pressure sensor **100**) and the external device. The configuration of the substrate pins **502** may vary without departing from the scope of this disclosure. For example, there may be any number of substrate pins **502** and each substrate pin **502** may have any shape, size, and orientation.

[0026] FIG. **6** illustrates a top plan view of the differential pressure sensor **100** after the overmolding **104** has been applied to the substrate upper surface **200**. After the overmolding **104** has been applied/formed, the differential pressure sensor **100** has the overmolding upper surface **210** with the first cavity **212** and the second cavity **214** formed within the overmolding **104** and exposing portions of the substrate upper surface **200**. As discussed above, the first cavity **212** exposes the first port hole **300** and the transducer bond pads **302**. The second cavity **214** exposes the second port hole **204**. The overmolding **104** also encapsulates/covers the ASIC die **206**.

[0027] FIG. **7** illustrates a top plan view of the differential pressure sensor **100** after an adhesive layer **700** has been applied to the substrate **102**. The adhesive layer **700** is configured to provide for pressure transfer between the channel **202** and an underside of the transducer **208** (e.g., a membrane of the transducer **208**), form a seal between the substrate upper surface and the underside of the transducer **208**, and also to provide stress decoupling (e.g., due to differences in thermal expansions) between the transducer **208** and the substrate **102**. The adhesive layer **700** surrounds the first port hole **300** and has a shape that corresponds to a perimeter of the transducer **208**. The adhesive layer **700** may be a low-modulus epoxy (e.g., 0.5 MPa at 100% elongation) and have a bond line thickness (BLT) of around 40 μm.

[0028] FIG. **8** illustrates a top plan view of the differential pressure sensor **100** after the transducer **208** is affixed to the substrate **102** via the adhesive layer **700**. The transducer **208** is affixed such that it covers the first port hole **300**. The transducer **208** includes transducer connection pads **800** that are configured to connect with the transducer bond pads **302**. In some implementations, the transducer **208** may be directly bonded to the transducer bond pads **302** and sealed using the adhesive layer **700**.

[0029] FIG. **9** illustrates a top plan view of the differential pressure sensor **100** after the transducer connection pads **800** are connected with the transducer bond pads **302**. The transducer connection pads **800** may be connected with the transducer bond pads **302** using wires **900**. Other ways of connecting the transducer connection pads **800** to the transducer bond pads **302** may be used without departing from the scope of this disclosure. For example, the transducer connection pads **800** may be connected with the transducer bond pads **302** as part of installing the transducer **208**. There may also be a connector to which the transducer **208** may be connected. Regardless, the connection of the transducer **208** ensures that the transducer **208** is in electrical connection with the ASIC die **206**.

[0030] FIG. **10** illustrates a top plan view of the differential pressure sensor **100** after the transducer **208** and associated connections have been covered with a protection layer **1000**. The protection layer **1000** is disposed within the first cavity **212** and configured to cover the transducer **208** and associated connections (e.g., the transducer connection pads **800**, the transducer bond pads **302**, the wires **900**). The protection layer **1000** is configured to adequately protect the components without affecting performance of the transducer **208**. For example, the protection layer **1000** may comprise

a 100 μm thickness of a perfluoropolyether material (1-part or 2-part).
[0031] FIG. **11** illustrates a section view of the lid **106** through the first chimney **218** and the second chimney **220**. As discussed above, the lid **106** has a lid upper surface **216** and a lid lower surface **1100**. The first chimney **218** and the second chimney **220** extend from the lid upper surface **216** in a generally cylindrical manner. The first port **108** and the second port **110** are formed within the first chimney **218** and the second chimney **220**, respectively. Protruding from the lid lower surface **1100** are standoffs **1102**. The standoffs **1102** are configured to maintain a separation distance between the lid **106** and the overmolding **104** when the lid **106** is attached to the overmolding **104** (e.g., to ensure a proper adhesive thickness). For example, the standoffs **1102** may be around 25 μm in height.
[0032] FIG. **12** illustrates a bottom plan view of the lid **106**. The first port **108** and the second port **110** run through the lid **106** to the lid lower surface **1100**. The standoffs **1102** may be placed in corners of the lid lower surface **1100** as shown. A number and/or configuration of the standoffs **1102** may vary without departing from the scope of this disclosure. Furthermore, in some implementations, standoffs **1102** may not be used.
[0033] FIG. **13** illustrates an example method **1300** of manufacturing the differential pressure sensor **100**. Example method **1300** can include one or more operations, actions, or functions as illustrated by one or more of blocks **1302** to **1312**. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, eliminated, performed in different order, or performed in parallel, depending on the desired implementation.
[0034] At **1302**, a substrate is provided. For example, the substrate **102** may be provided.
[0035] At **1304**, an ASIC die is mounted on the substrate. For example, the ASIC die **206** may be mounted on the substrate upper surface **200**. In some implementations, the ASIC die **206** may already be installed on the substrate **102** when it is provided, thus, rendering step **1304** moot.
[0036] At **1306**, an overmolding is formed on the substrate. For example, the overmolding **104** may be formed or molded on top of the substrate upper surface **200** forming the first cavity **212** and the second cavity **214**.
[0037] At **1308**, a transducer is mounted on the substrate. For example, the transducer **208** may be adhered to the substrate upper surface **200** via the adhesive layer **700**. The mounting may involve electrically connecting the transducer **208** to the substrate **102** (e.g., via wires **900**).
[0038] At **1310**, the transducer is sealed. For example, the protection layer **1000** may be applied within the first cavity **212**. The protection layer **1000** may cover the transducer **208** and associated wiring/connection points (e.g., the transducer connection pads **800**, the transducer bond pads **302**, and the wires **900**).
[0039] At **1312**, a lid is mounted on the overmolding. For example, the lid **106** may be attached to the overmolding upper surface **210**. The lid **106** may be attached using any mechanical or chemical means (e.g., a non-conductive epoxy) and may utilize standoffs **1102** to maintain a separation distance between the overmolding upper surface **210** and the lid lower surface **1100**.
[0040] The flowchart and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be implemented substantially concurrently, or the blocks may sometimes be implemented in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer

instructions.
[0041] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. 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” and/or “comprising,” when used in this specification, 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.
[0042] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements, if any, in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The disclosed embodiments of the present invention have been presented for purposes of illustration and description but are not intended to be exhaustive or limited to the invention in the forms disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiments were chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A sensor device comprising: a substrate: comprising a substrate upper surface; comprising a substrate lower surface opposite the substrate upper surface; forming a channel between the substrate upper surface and the substrate lower surface; forming a first port hole through the substrate upper surface to the channel; and forming a second port hole through the substrate upper surface to the channel; an application-specific integrated circuit (ASIC) die mounted on the substrate upper surface so as not to cover the first port hole and the second port hole; an overmolding: formed on the substrate upper surface; molded over the ASIC die; forming a first cavity surrounding the first port hole; forming a second cavity surrounding the second port hole; and comprising an overmolding upper surface; a transducer: mounted on the substrate upper surface so as to cover the first port hole; placed within the first cavity; and electrically connected with the ASIC die; and a lid: attached to the overmolding upper surface; comprising a lid upper surface; comprising a first chimney protruding from the lid upper surface and aligned with the first cavity; and comprising a second chimney protruding from the lid upper surface and aligned with the second cavity.
2. The sensor device of claim 1, wherein the sensor device is a differential pressure sensor.
3. The sensor device of claim 1, wherein the substrate further comprises a plurality of pins disposed on the substrate lower surface that are electrically connected with the ASIC die.
4. The sensor device of claim 1, wherein the channel has a rectangular cross section.
5. The sensor device of claim 1, wherein the channel is straight.
6. The sensor device of claim 1, wherein the channel has at least one dimension configured to mitigate condensation in the channel.
7. The sensor device of claim 1, wherein the ASIC die comprises a complementary metal oxide semiconductor (CMOS).
8. The sensor device of claim 1, wherein the transducer is a micro-electromechanical system (MEMS).
9. The sensor device of claim 1, wherein the transducer comprises a membrane.
10. The sensor device of claim 1, wherein the first chimney and the second chimney are configured to connect with tubing.
11. The sensor device of claim 1, wherein the first chimney and the second chimney are

substantially cylindrical.

12. The sensor device of claim 1, wherein: the lid further comprises a lid lower surface opposite the lid upper surface; and the lid lower surface is attached to the overmolding upper surface.

13. The sensor device of claim 12, wherein the lid further comprises one or more standoffs configured to maintain a minimum adhesive thickness between the overmolding upper surface and the lid lower surface.

14. The sensor device of claim 1, wherein the lid is formed of a liquid-crystal polymer.

15. The sensor device of claim 1, wherein the sensor device further comprises a protection layer formed over the transducer.

16. The sensor device of claim 15, wherein the protection layer is configured to not affect performance of the transducer.

17. The sensor device of claim 1, wherein: the sensor device has a rectangular footprint; and the channel is formed diagonally across the rectangular footprint.

18. The sensor device of claim 1, wherein: the sensor device further comprises an adhesive layer disposed between the transducer and the substrate upper surface; and the adhesive layer is configured to: allow for pressure transfer between the channel and an underside of the transducer; form a seal between the substrate upper surface and the underside of the transducer; and provide stress decoupling between the substrate upper surface and the transducer.

19. The sensor device of claim 1, wherein the substrate further comprises a plurality of pins disposed on the substrate lower surface that form a land grid array (LGA).
