A Multiple Internal Seal Ring (MISR) Micro-Electro-Mechanical System (MEMS) vacuum package that hermetically seals MEMS devices using MISR. The method bonds a capping plate having metal seal rings to a base plate having metal seal rings by wafer bonding the capping plate wafer to the base plate wafer. Bulk electrodes may be used to provide conductive paths between the seal rings on the base plate and the capping plate. All seals are made using only metal-to-metal seal rings deposited on the polished surfaces of the base plate and capping plate wafers. However, multiple electrical feed-through metal traces are provided by fabricating via holes through the capping plate for electrical connection from the outside of the package through the via-holes to the inside of the package. Each metal seal ring serves the dual purposes of hermetic sealing and providing the electrical feed-through metal trace.

15 Claims, 10 Drawing Sheets
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FIG. 3

1. ETCH BASE PLATE 300
2. METAL PATTERNING 302
3. ETCH CAPPING PLATE 304
4. METAL PATTERNING 306
5. ALIGN WAFERS 308
6. BOND WAFERS 310
7. ELECTRO-LESS PLATING 312
8. ELECTROPLATING 314
9. MASK AND ETCHING 316
10. DEPOSIT SOLDER BUMPS 318
FIG. 5
MULTIPLE INTERNAL SEAL RING MEMS VACUUM PACKAGE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. Section 119(e) of the following and commonly-assigned U.S. Provisional Application Ser. No. 60/477,463, filed on Jun. 10, 2003, by Ken J. Hayworth, Karl Y. Yee, Kirill V. Shcheglov, Youngsam Bae, Dean V. Wiberg, A. D. Challoner, Chris S. Peay, entitled “MULTIPLE INTERNAL SEAL RING MEMS VACUUM PACKAGE,” which application is incorporated by reference herein.

This application is related to the following co-pending U.S. Utility and Provisional Patent Applications:

U.S. Utility patent application Ser. No. 10/639,134, filed Aug. 12, 2003, by Kirill V. Shcheglov and A. Dorian Challoner, entitled ISOLATED PLANAR GYROSCOPE WITH INTERNAL RADIAL SENSING AND ACTUATION, and


both of which applications claim the benefit under 35 U.S.C. § 119(e) of the following U.S. Provisional Patent Applications:

U.S. Provisional Patent Application Ser. No. 60/402,681, filed Aug. 12, 2002, by Kirill V. Shcheglov and A. Dorian Challoner, and entitled CYLINDER GYROSCOPE WITH INTEGRAL SENSING AND ACTUATION, and

U.S. Provisional Patent Application Ser. No. 60/428,451, filed Nov. 22, 2002, by Kirill V. Shcheglov and A. Dorian Challoner, entitled DESIGN AND FABRICATION PROCESS FOR A NOVEL HIGH PERFORMANCE MESOGYRO, and

all of which applications are incorporated by reference herein.

This application is related to the following co-pending U.S. Utility Patent Applications:


all of which applications and patents are incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the Contractor has elected to retain title.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to vacuum packages, and particularly to multiple internal seal ring (MISR) micro-electro-mechanical (MEMS) vacuum packages.

2. Description of the Related Art

It is well known in the art to fabricate micro-electro-mechanical system (MEMS) devices. MEMS devices typically integrate both electronic and mechanical elements on a semiconductor wafer using semiconductor fabrication techniques. Generally, the electronic and mechanical elements are fabricated using a variety of integrated circuit (IC) processing and micromachining techniques, respectively.

In the fabrication of MEMS devices, it is not unusual to package or “cap” such devices to prevent damage or contamination to the MEMS devices. Often, the cap comprises a captive plate fabricated from a connecting wafer that is bonded to a base plate before the base plate wafer is diced or singulated into individual devices. The captive plate thus hermetically seals the MEMS devices within the base plate.

Even though sealed by the captive plate, the MEMS devices require electrical connection to external circuits. However, the traces used for connection may create gaps where the capturing plate and base plate are bonded. Generally, the surfaces where the capturing plate wafer and the base plate wafer are bonded must be ultra-flat, i.e., polished. This flatness requirement is difficult to meet if additional processing steps are required for bringing electrical feed-through metal traces out through the bonded surfaces. Specifically, bringing electrical wires out through the bonded surfaces requires metal patterning and oxide growth on the wafers’ surfaces. Achieving a bond or seal on top of these uneven surfaces is much more difficult.

Accordingly, what is needed, therefore, is an improved method for sealing and packaging MEMS devices that allows for electrical connection to external circuits.

SUMMARY OF THE INVENTION

To minimize the limitations in the related art described above, and to minimize other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses a Multiple Internal Seal Ring (MISR) Micro-Electro-Mechanical System (MEMS) vacuum package that hermetically seals MEMS devices using MISR. The method bonds a captive plate having metal seal rings to a base plate having metal seal rings by wafer bonding the captive plate wafer to the base plate wafer. Bulk electrodes may be used to provide conductive paths between the seal rings on the base plate and the captive plate. All seals are made using only metal-to-metal seal rings deposited on the polished surfaces of the base plate and captive plate wafers. However, multiple electrical feed-through metal traces are provided by fabricating via holes through the captive plate for electrical connection from the outside of the package through the via-holes to the
inside of the package. Each metal seal ring serves the dual purposes of hermetic sealing and providing the electrical feed-through metal trace.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIGS. 1A, 1B and 1C are perspective views of an embodiment of the present invention, wherein FIG. 1A comprises a base plate, FIG. 1B comprises a capping plate and FIG. 1C shows the final sealed multiple internal seal ring vacuum package;

FIGS. 2A, 2B and 2C are perspective views of the results of wafer scale processing of the vacuum package before singulation, wherein FIG. 2A illustrates bonded wafers containing a plurality of micro-electro-mechanical system devices that are vacuum sealed simultaneously during wafer bonding of a wafer containing the base plates and a wafer containing the capping plates. FIG. 2B is a magnified view of a portion of the bonded wafers, and FIG. 2C is a magnified view of the final sealed multiple internal seal ring vacuum package comprised of the joined base plate and capping plate found in the portion of the bonded wafers.

FIG. 3 is a flowchart that illustrates the steps of a first general micro-electro-mechanical system processing paradigm for a surface processed micro-electro-mechanical system device etched directly from the base plate wafer that is vacuum packaged using the capping plate wafer;

FIGS. 4A-4F illustrate the results of the flowchart of FIG. 3;

FIG. 5 is a flowchart that illustrates the steps of a second general micro-electro-mechanical system processing paradigm for a two-wafer bulk silicon etched micro-electro-mechanical system device etched from a bonded base plate wafer and resonator wafer that is vacuum packaged using the capping plate wafer;

FIGS. 6A-6G illustrate the results of the flowchart of FIG. 5;

FIGS. 7A and 7B illustrate a comparison of the multiple internal seal ring vacuum package design for a two-wafer (surface processed micro-electro-mechanical system device) and three-wafer (bulk processed micro-electro-mechanical system device) designs, wherein FIG. 7A is a partially-cutaway view of the two-wafer multiple internal seal ring vacuum package and FIG. 7B is a partially-cutaway view of the three-wafer multiple internal seal ring vacuum package;

FIG. 8 is a flowchart that illustrates the steps of the three-wafer design packaging a planar gyroscope; and

FIGS. 9A-9I illustrate the results of the flowchart of FIG. 8.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

In the following description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

**Overview**

The present invention discloses a method of vacuum sealing or hermetically sealing Micro-Electro-Mechanical Systems (MEMS) devices using MISR at a wafer level before singulation or dicing. The method bonds a capping plate having metal seal rings to a base plate having metal seal rings by wafer bonding the capping plate wafer to the base plate wafer.Bulk electrodes may be used to provide conductive paths between the seal rings on the base plate and the capping plate. This method works best if the bonding surface of the base plate wafer and the bonding surface of the capping plate wafer are ultra-flat (i.e., polished) before the metal seal rings are deposited on each surface.

This flatness requirement is difficult to meet if additional processing steps are required for bringing electrical feed-through metal traces out underneath the seal rings. Specifically, bringing electrical feed-through metal traces out under the seal rings requires metal patterning and oxide growth on the wafer's surface, which results in an uneven surface. Achieving a metal-to-metal vacuum seal on top of this uneven surface is much more difficult than achieving a metal-to-metal vacuum seal between polished, ultra-flat surfaces.

All seals are made using only metal-to-metal seal rings deposited on the polished surfaces of the base plate wafer and the capping plate wafer. However, the package still enables multiple electrical feed-through metal traces by fabricating multiple via holes through the capping plate for electrical connection from the outside of the vacuum package through the via-holes to the inside of the vacuum package. Each metal seal ring serves the dual purposes of hermetic sealing and providing an electrical feed-through metal trace.

FIGS. 1A, 1B and 1C are perspective views of an embodiment of the present invention, wherein FIG. 1A comprises a base plate 100, FIG. 1B comprises a capping plate 102 and FIG. 1C shows a final, vacuum-sealed, MISR device package 104 comprised of the bonded base plate 100 and capping plate 102, wherein the capping plate 102 is flipped before being bonded to the base plate 100, and the capping plate 102 is shown semi-transparently to better illustrate the components of the package 104. The base plate 100 and the capping plate 102 each include a large periphery seal ring 106 that is used to create one large metal-to-metal seal surrounding the periphery of the package 104 when the base plate 100 and the capping plate 102 are bonded together. In addition, the base plate 100 and the capping plate 102 each include a plurality of small internal seal rings 108. The seal rings 108 of the base plate 100 each provide an independent electrical path from a cavity 110 of the capping plate 102 where the MEMS device (not shown) resides outward towards the periphery of the package 104, but not crossing the seal ring 106. Each of the seal rings 108 of the capping plate 102 surround and electrically connect to one of a plurality of via holes 112 on a bottom surface of the capping plate 102. Each via hole 112 extends through the capping plate 102 to a top surface of the capping plate 102, where the via hole 112 electrically connects to an electrical trace pattern 114 and solder bump 116 on the top surface of the capping plate 102. The package 104 is sealed by compression bonding of the metal-to-metal seal rings 106 and 108, which is followed by singulation to separate the multiple packages 104 on the bonded wafers.

Although FIGS. 1A, 1B and 1C illustrate only a single package 104, the potential benefits (cost savings and simplified, more reliable manufacturing process) of the MISR device package 104 are most dramatic when performed by wafer scale processing. FIGS. 2A, 2B and 2C are perspective views of the results of wafer scale processing of the package 104 before singulation, wherein FIG. 2A illustrates bonded wafers 200 containing a plurality of MEMS devices that are sealed simultaneously during wafer bonding of a
wafer containing the base plates and a wafer containing the capping plates. FIG. 2B is a magnified view of a portion of the bonded wafers, and FIG. 2C is a magnified view of a silicon or other semiconductor material. FIGS. 4A-4E, wherein FIGS. 4A-4E show a base plate with an electro-plating of a thin metal layer and a wafer containing the etching of the electrical trace pattern and a capping plate. FIG. 4B shows the capping plate. FIG. 4C shows the electro-plating of a thicker metal layer on top of the thin metal layer. FIG. 4D shows the patterning of the electrical trace patterns. FIG. 4E shows the masking and etching of the electrical trace patterns. FIG. 4F shows the etching of the via holes. FIG. 4G shows the deposition of the solder bumps. FIG. 4H shows the final processing prior to singulation.

The two-wafer bulk-silicon-etched MEMS device is packaged according to the steps outlined in FIG. 5 and illustrated in FIGS. 6A-7B. FIGS. 6A-6C are cross-sectional views of FIGS. 6A-6C, wherein FIGS. 6A-6C show a base plate with an electro-plating of a thin metal layer and a wafer containing the etching of the electrical trace pattern and a capping plate. FIG. 6D shows the capping plate. FIG. 6E shows the electro-plating of a thicker metal layer on top of the thin metal layer. FIG. 6F shows the patterning of the electrical trace patterns. FIG. 6G shows the masking and etching of the electrical trace patterns. FIG. 6H shows the deposition of the solder bumps. FIG. 6I shows the final processing prior to singulation.

The two-wafer bulk-silicon-etched MEMS device is packaged according to the steps outlined in FIG. 5 and illustrated in FIGS. 6A-7B. FIGS. 6A-6C are cross-sectional views of FIGS. 6A-6C, wherein FIGS. 6A-6C show a base plate with an electro-plating of a thin metal layer and a wafer containing the etching of the electrical trace pattern and a capping plate. FIG. 6D shows the capping plate. FIG. 6E shows the electro-plating of a thicker metal layer on top of the thin metal layer. FIG. 6F shows the patterning of the electrical trace patterns. FIG. 6G shows the masking and etching of the electrical trace patterns. FIG. 6H shows the deposition of the solder bumps. FIG. 6I shows the final processing prior to singulation.
AND ACTUATION, and which application is incorporated by reference herein. However, certain modifications to the package are required.

The planar gyroscope has a large total number of electrodes (48 individual electrode elements). If all of these electrodes were brought out of the package through individual seal rings, the increase in total die area would be prohibitive. This is because a “sealing bulk electrode” must have a large enough diameter to support a good vacuum seal. To avoid having 48 sealing bulk electrodes, electrical connections crisscrossing inside the package are used to connect common sets of electrodes. In the planar gyroscope design, the 48 individual electrodes are reduced to only 12 electrode sets requiring individual package feed-throughs. Thus only 12 sealing bulk electrodes are needed in the final design, and these easily fit into the unused corners of the square planar package.

The internal wire routing (connecting the 48 individual electrodes into 12 sets) requires crossing some wires, and thus requires at least two metal routing layers. The design of the MISR package allows this to be achieved without requiring an extra metalization and oxide growth process (which would interfere with the surface flatness required for good sealing). This crisscrossing of wires is achieved by using small “bridging bulk electrodes” to act as vias between the base plate’s metal patterning and the capping plate’s internal metal pattern. In the current design, 48 of these small bridging bulk electrodes are used (to connect each individual electrode with a circular shorting pattern on the capping plate) and 12 sealing bulk electrodes are used to provide the final package feed-throughs for each electrode set.

As noted above, the processing steps used to create such an MISR package are generally reflected in FIG. 5 and FIGS. 6A-6G. However, some of the steps are further described in FIG. 8 and illustrated as cross-sectional views in FIGS. 9A-9I.

Block 800 represents the etching of the base plate 900, which is illustrated in FIG. 9A.

Block 802 represents the metal patterning of the base plate 900, which is illustrated in FIG. 9B.

Block 804 represents the aligning of the base plate 900 and resonator plate 902, which was processed separately, and which is illustrated in FIG. 9C.

Block 806 represents the bonding of the base plate 900 and resonator plate 902, which is illustrated in FIG. 9D.

Block 808 represents the deep silicon etching of the resonator plate 902, which is illustrated in FIG. 9E.

Block 810 represents the aligning of the base plate 900 and capping plate 904, which was processed separately, and which is illustrated in FIG. 9F.

Block 812 represents the bonding of the base plate 900 and capping plate 904, which is illustrated in FIG. 9G.

Block 814 represents the electro-less plating of the capping plate 904, including its via holes 906, which is illustrated in FIG. 9H.

Block 816 represents the electroplating of the capping plate 904, including its via holes 906, which is also illustrated in FIG. 9I.

Block 818 represents the masking and etching of the electrical trace pattern 908 on the top surface of the capping plate 904, which is illustrated in FIG. 9I.

Block 820 represents the depositing of the solder bumps 910 at one end of the electrical trace pattern 908 etched on the top surface of the capping plate 904, which is also illustrated in FIG. 9I.

This concludes the description of the preferred embodiment of the present invention. The following describes some alternative embodiments for accomplishing the present invention. For example, although specific structures are described in this specification, other structures could be used as well without departing from the scope of the present invention. Variations in the components used in the present invention are possible.

Further, the specific logic or steps performed by the present invention are described for illustration purposes only, and other logic or steps could be used as well. Many variations of the logic and steps performed by the present invention are possible.

What is claimed is:

1. A device package, comprising:
   a capping plate including at least one periphery seal ring and at least one internal seal ring bonded to a base plate including at least one periphery seal ring and at least one internal seal ring;
   wherein the periphery seal rings of the capping plate and base plate create a metal-to-metal seal surrounding the periphery of the package when the capping plate and the base plate are bonded together,
   the internal seal rings of the capping plate electrically connect to a plurality of via holes extending through to an external surface of the capping plate,
   the internal seal rings of the base plate provide an independent electrical path from a cavity in the capping plate outward towards a periphery of the base plate, and
   the internal seal rings of the capping plate and the base plate create a metal-to-metal seal within the periphery of the package when the base plate and the capping plate are bonded together.

2. The device package of claim 1, wherein each seal ring serves the dual purposes of hermetic sealing and providing an electrical feed-through metal trace.

3. The device package of claim 1, wherein the device package is sealed by compression bonding of the seal rings of the capping plate and base plate.

4. The device package of claim 1, wherein the seal rings of the capping plate and the seal rings of the base plate provide a metal-to-metal seal between the base plate and the capping plate, when the base plate and the capping plate are bonded together.

5. The device package of claim 1, wherein the via holes through the capping plate provide electrical connection from outside the device package through the via-holes to inside the device package.

6. The device package of claim 1, wherein each via hole extends through the capping plate from a bottom surface to a top surface of the capping plate.

7. The device package of claim 1, wherein each via hole electrically connects to an electrical trace pattern on the top surface of the capping plate.
8. The device package of claim 1, wherein a plurality of the capping plates are fabricated on a capping plate wafer and a plurality of the base plates are fabricated on a base plate wafer.

9. The device package of claim 1, wherein the capping plate wafer is bonded to the base plate wafer.

10. The device package of claim 1, wherein bulk electrodes provide conductive paths between the seal rings on the base plate and the capping plate.

11. The device package of claim 1, wherein the bulk electrodes are fabricated from a resonator plate wafer bonded to the base plate wafer.

12. A device packaged using a method comprising the steps of:
   (a) metal patterning of at least one seal ring on a base plate;
   (b) etching of via holes in a capping plate;
   (c) metal patterning of at least one seal ring on a bottom surface of the capping plate;
   (d) aligning of the base plate and capping plate;
   (e) bonding of the base plate and capping plate;
   (f) electro-less plating of a thin metal layer on a top surface of the capping plate, including inside the via holes;
   (g) electroplating of a thicker metal layer on top of the thin metal layer;
   (h) masking and etching of electrical trace patterns on the top surface of the capping plate.

13. The device of claim 12, wherein the device comprises a surface-processed micro-electro-mechanical system (MEMS) device etched from the bonded base plate wafer.

14. A device packaged using a method comprising the steps of:
   (a) metal patterning of at least one seal ring on a base plate;
   (b) aligning of the base plate and a resonator plate;
   (c) bonding of the base plate and resonator plate using heat and pressure in an evacuated chamber;
   (d) etching of bulk electrodes on the resonator plate, wherein the doped silicon or a metalization of the resonator plate provides a conductive path for the electrodes;
   (e) etching of at least one via hole in a capping plate;
   (f) metal patterning of at least one seal ring on a bottom surface of the capping plate;
   (g) aligning of the resonator plate and capping plate, and more specifically, the aligning of the bulk electrodes of the resonator plate with the seal rings of the capping plate;
   (h) bonding of the resonator plate and capping plate using heat and pressure in an evacuated chamber;
   (i) electro-less plating of a thin metal layer on a top surface of the capping plate including inside the via holes;
   (j) electroplating of a thicker metal layer on the thin metal layer;
   (k) masking and etching of an electrical trace pattern on the top surface of the capping plate.

15. The device of claim 14, wherein the device comprises a two-wafer bulksilicon-etched micro-electro-mechanical system (MEMS) device etched from the bonded base plate wafer and resonator wafer.