CLAIMS

1. A multi-mode sensor based on wafer-level packaging, wherein the multi-mode sensor comprises a base, a multi-mode sensor body, a cap layer, and multiple electrodes;

the base comprises: a first substrate, a dielectric layer, a first insulating layer, and multiple TSVs, wherein the dielectric layer covers at least a portion of the first surface of the first substrate; the TSVs penetrate the first substrate and the dielectric layer; the first insulating layer covers the second surface of the first substrate and at least exposes the TSVs, with the first substrate being a silicon substrate;

the electrodes are arranged within the TSV areas and electrically connected to the corresponding TSVs;

the multi-mode sensor body comprises sensing electrodes and a sensing film layer, wherein the sensing electrodes are located above the dielectric layer and connected to the corresponding TSVs; the sensing film layer covers the target area of the sensing electrodes;

the cap layer comprises a second substrate and a bonding ring, wherein the first surface of the second substrate is provided with a cavity, and at least part of the multi-mode sensor body is located within the cavity; the bonding ring is arranged on the first surface of the second substrate and surrounds the cavity in a closed loop, used to fix the base and the cap layer together.

2. The multi-mode sensor according to claim 1, wherein the multi-mode sensor body further comprises: regulating electrodes and a second insulating layer;

the regulating electrodes are located above the dielectric layer and connected to the corresponding TSVs;

the second insulating layer is located above the dielectric layer and at least covers the regulating electrodes, and the second insulating layer is provided with electrode vias that expose the TSVs connected to the sensing electrodes;

wherein the sensing electrodes are located above the second insulating layer, with the target area overlapping the regulating electrodes and connected to the corresponding TSVs through the electrode vias.

3. The multi-mode sensor according to claim 1, wherein the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity, and the bonding ring is fixedly connected to the first surface of the first substrate, so that the base and the cap layer are fixed together, and the multi-mode sensor body and the dielectric layer are located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the bonding ring is fixedly connected to the dielectric layer, so that the base and the cap layer are fixed together, and at least the sensing film layer of the multi-mode sensor body is located within the cavity.

4. The multi-mode sensor according to claim 2, wherein the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity, and the second

insulating layer covers at most the exposed part of the dielectric layer, and the bonding ring is fixedly connected to the first surface of the first substrate, so that the base and the cap layer are fixed together, and the multi-mode sensor body and the dielectric layer are located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the second insulating layer covers at most the exposed part of the dielectric layer corresponding to the cavity, and the bonding ring is fixedly connected to the dielectric layer, so that the base and the cap layer are fixed together, and the multi-mode sensor body is located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the second insulating layer covers the entire exposed part of the dielectric layer, and the bonding ring is fixedly connected to the second insulating layer, so that the base and the cap layer are fixed together, and at least the sensing film layer is located within the cavity.

5. The multi-mode sensor according to claim 2, wherein the shape of the regulating electrodes comprises an extendable shape, wherein the extendable shape is any one of a serpentine shape or an S-shape; and/or

the sensing electrodes comprise interdigitated electrodes and/or intersecting electrodes, and the target area is a periodic pattern area of the sensing electrodes, wherein the size of the extendable shape area of the regulating electrodes matches and overlaps the target area; and/or

the multi-mode sensor body further comprises a sensing structure located above or inside the base, the sensing structure comprising at least one of the following: multiple composite film layers or a geometric structure with a preset three-dimensional (3D) shape.

6. The multi-mode sensor according to claim 2, wherein the multi-mode sensor body detects external gases, and the second surface of the second substrate is further provided with a material exchange via that corresponds to and connects to the target area of the sensor.

7. The multi-mode sensor according to claim 6, wherein the cap layer further comprises:

a breathable membrane layer located above the second surface of the second substrate, covering at least the material exchange via.

8. The multi-mode sensor according to claim 7, wherein the cap layer further comprises:

a dustproof mesh layer, located above the second surface of the second substrate and covering at least the area of the breathable membrane corresponding to the material exchange via, with the dustproof mesh layer being provided with multiple through-vias corresponding to the material exchange via.

9. A manufacturing method for a multi-mode sensor based on wafer-level packaging, wherein it is used to manufacture any one of the multi-mode sensors described in claims 1-8, the method comprising the following steps: base manufacturing step, multi-mode sensor body manufacturing step, cap layer manufacturing step, fixed connection step and electrode manufacturing step.

base manufacturing step: preparing a dielectric layer on the first surface of the first

substrate, etching the first substrate and the dielectric layer, thinning the first substrate to form multiple TSVs, preparing a first insulating layer on the second surface of the first substrate, and etching the first insulating layer to at least expose the through-via areas corresponding to the TSVs, thereby forming the base of the multi-mode sensor;

multi-mode sensor body manufacturing step: manufacturing sensing electrodes on top of the dielectric layer, and forming a sensing film layer above the target area of the sensing electrodes, thereby obtaining the multi-mode sensor body;

cap layer manufacturing step: preparing a bonding ring on the first surface of the second substrate, etching the first surface of the second substrate to form a cavity, thereby forming the cap layer of the multi-mode sensor;

fixed connection step: bonding the bonding ring with the base so that at least part of the multi-mode sensor body is positioned within the cavity;

electrode manufacturing step: bumping in each of the through-via areas to form the electrodes of the multi-mode sensor, completing the preparation of the multi-mode sensor.

10. The method according to claim 9, wherein sensing electrodes are manufactured above the dielectric layer; a sensing film layer is manufactured above the target area of the sensing electrodes, thereby obtaining the multi-mode sensor body, including:

sequentially manufacturing regulating electrodes and a second insulating layer above the dielectric layer, wherein the second insulating layer at least covers the regulating electrodes;

etching the second insulating layer to form electrode vias, exposing the TSVs connected to the sensing electrodes;

manufacturing sensing electrodes on the second insulating layer, wherein the target area overlaps the regulating electrodes, and the sensing electrodes are connected to the corresponding TSVs through the electrode vias;

manufacturing a sensing film layer above the target area, thereby forming the multi-mode sensor body.

11. The method according to claim 9, wherein the bonding ring is fixedly connected to the base by a bonding method, including at least one of the following steps:

if the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity, the bonding ring is fixedly connected to the first surface of the first substrate by a bonding method, thereby fixing the base and the cap layer together, with the multi-mode sensor body and the dielectric layer located within the cavity; or

if the dielectric layer covers the entire area of the first surface of the first substrate, the bonding ring is fixedly connected to the dielectric layer by a bonding method, thereby fixing the base and the cap layer together, with at least the sensing film layer of the multi-mode sensor body located within the cavity.

12. The method according to claim 10, wherein the bonding ring is fixedly connected to the base by a bonding method, including at least one of the following steps:

if the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity and the second insulating layer covers at most the exposed part of the dielectric layer, then the bonding ring is fixedly connected to the first surface of the first substrate by a bonding method, thereby fixing the base and the cap layer together, with the multi-mode sensor body and the dielectric layer located within the cavity;

if the dielectric layer covers the entire area of the first surface of the first substrate, and the second insulating layer covers at most the exposed part of the dielectric layer corresponding to the cavity, then the bonding ring is fixedly connected to the dielectric layer by a bonding method, thereby fixing the base and the cap layer together, with the multi-mode sensor body located within the cavity;

if the dielectric layer covers the entire area of the first surface of the first substrate and the second insulating layer also covers the entire exposed part of the dielectric layer, then the bonding ring is fixedly connected to the second insulating layer by a bonding method, thereby fixing the base and the cap layer together, with at least the sensing film layer located within the cavity.

13. The method according to claim 10, wherein the shape of the regulating electrodes comprises an extendable shape, wherein the extendable shape is any one of a serpentine shape or an S-shape;

the sensing electrodes comprise interdigitated electrodes and/or intersecting electrodes, with the target area being a periodic pattern area of the sensing electrodes, wherein the size of the extendable shape area of the regulating electrodes matches and overlaps the target area; and/or

the multi-mode sensor body further comprises a sensing structure, wherein the sensing structure is located above or inside the base, and the sensing structure comprises at least one of the following: multiple composite film layers or a geometric structure with a preset 3D shape.

14. The method according to claim 10, characterized in that the cap layer manufacturing step further comprises:

etching the second substrate before forming the cavity on the first surface of the second substrate, creating a material exchange via that penetrates through the second substrate and corresponds to the target area, wherein the cavity is connected to the material exchange via.

15. The method according to claim 14, wherein the cap layer manufacturing step further comprises:

adhering a pre-prepared breathable membrane to the second surface of the second substrate, covering at least the material exchange via, thereby forming a breathable membrane layer.

16. The method according to claim 15, wherein the cap layer manufacturing step further comprises:

preparing a dustproof mesh layer above the breathable membrane layer, forming a portion

~~that covers at least the breathable membrane layer and is provided with multiple through-vias.~~

~~17. A multi-mode sensor module based on wafer-level packaging, wherein it comprises:~~

~~multiple multi-mode sensors stacked vertically in succession, wherein the multi-mode sensors are any one of the multi-mode sensors based on wafer-level packaging as described in claims 1-8.~~

1~~8~~. A ~~multi-mode~~ sensor assembly based on wafer-level packaging, wherein it comprises:

a top secondary packaging layer, multiple sensor layers, a secondary packaging via interconnection layer, and a bottom secondary packaging layer,

wherein each of the sensor layers is provided with multiple ~~multi-mode~~ sensors based on wafer-level packaging~~-~~, the sensor comprises a base, a sensor body, a cap layer, and multiple electrodes;

the base comprises: a first substrate, a dielectric layer, a first insulating layer, and multiple TSVs, wherein the dielectric layer covers at least a portion of the first surface of the first substrate; the TSVs penetrate the first substrate and the dielectric layer; the first insulating layer covers the second surface of the first substrate and at least exposes the TSVs, with the first substrate being a silicon substrate;

the electrodes are arranged within the TSV areas and electrically connected to the corresponding TSVs;

the sensor body comprises sensing electrodes and a sensing film layer, wherein the sensing electrodes are located above the dielectric layer and connected to the corresponding TSVs; the sensing film layer covers the target area of the sensing electrodes;

the cap layer comprises a second substrate and a bonding ring, wherein the first surface of the second substrate is provided with a cavity, and at least part of the sensor body is located within the cavity; the bonding ring is arranged on the first surface of the second substrate and surrounds the cavity in a closed loop, used to fix the base and the cap layer together~~as described in claims 1-8~~.

2. The sensor assembly according to claim 1, wherein the sensor body further comprises: regulating electrodes and a second insulating layer;

the regulating electrodes are located above the dielectric layer and connected to the corresponding TSVs;

the second insulating layer is located above the dielectric layer and at least covers the regulating electrodes, and the second insulating layer is provided with electrode vias that expose the TSVs connected to the sensing electrodes;

wherein the sensing electrodes are located above the second insulating layer, with the target area overlapping the regulating electrodes and connected to the corresponding TSVs through the electrode vias.

3. The sensor assembly according to claim 1, wherein the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity, and the bonding ring is fixedly connected to the first surface of the first substrate, so that the base and the cap layer are fixed together, and the sensor body and the dielectric layer are located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the bonding ring is fixedly connected to the dielectric layer, so that the base and the cap layer are fixed together, and at least the sensing film layer of the sensor body is located within the cavity.

4. The sensor assembly according to claim 2, wherein the dielectric layer covers the area of the first surface of the first substrate corresponding to the cavity, and the second insulating layer covers at most the exposed part of the dielectric layer, and the bonding ring is fixedly connected to the first surface of the first substrate, so that the base and the cap layer are fixed together, and the sensor body and the dielectric layer are located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the second insulating layer covers at most the exposed part of the dielectric layer corresponding to the cavity, and the bonding ring is fixedly connected to the dielectric layer, so that the base and the cap layer are fixed together, and the sensor body is located within the cavity; or

the dielectric layer covers the entire area of the first surface of the first substrate, and the second insulating layer covers the entire exposed part of the dielectric layer, and the bonding ring is fixedly connected to the second insulating layer, so that the base and the cap layer are fixed together, and at least the sensing film layer is located within the cavity.

5. The sensor assembly according to claim 2, wherein the shape of the regulating electrodes comprises an extendable shape, wherein the extendable shape is any one of a serpentine shape or an S-shape; and/or

the sensing electrodes comprise interdigitated electrodes and/or intersecting electrodes, and the target area is a periodic pattern area of the sensing electrodes, wherein the size of the extendable shape area of the regulating electrodes matches and overlaps the target area; and/or

the sensor body further comprises a sensing structure located above or inside the base, the sensing structure comprising at least one of the following: multiple composite film layers or a geometric structure with a preset three-dimensional (3D) shape.

6. The sensor assembly according to claim 2, wherein the sensor body detects external gases, and the second surface of the second substrate is further provided with a material exchange via that has position corresponding to the target area of the sensor and connects to the cavity.

7. The sensor assembly according to claim 6, wherein the cap layer further comprises:

a breathable membrane layer located above the second surface of the second substrate, covering at least the material exchange via.

8. The sensor assembly according to claim 7, wherein the cap layer further comprises:

a dustproof mesh layer, located above the second surface of the second substrate and covering at least the area of the breathable membrane corresponding to the material exchange via, with the dustproof mesh layer being provided with multiple through-vias corresponding to the material exchange via.

~~1~~9. A ~~multi-mode~~ sensor assembly based on wafer-level packaging, wherein it comprises:

a top secondary packaging layer, the ~~multi-mode~~ sensor module based on wafer-level packaging, ~~as described in claim 17,~~ a secondary packaging via interconnection layer, and a bottom secondary packaging layer,

wherein the sensor module comprises multiple sensors stacked vertically in succession, wherein the sensor comprises a base, a sensor body, a cap layer, and multiple electrodes;

the base comprises: a first substrate, a dielectric layer, a first insulating layer, and multiple

TSVs, wherein the dielectric layer covers at least a portion of the first surface of the first substrate; the TSVs penetrate the first substrate and the dielectric layer; the first insulating layer covers the second surface of the first substrate and at least exposes the TSVs, with the first substrate being a silicon substrate;

the electrodes are arranged within the TSV areas and electrically connected to the corresponding TSVs;

the sensor body comprises sensing electrodes and a sensing film layer, wherein the sensing electrodes are located above the dielectric layer and connected to the corresponding TSVs; the sensing film layer covers the target area of the sensing electrodes;

the cap layer comprises a second substrate and a bonding ring, wherein the first surface of the second substrate is provided with a cavity, and at least part of the sensor body is located within the cavity; the bonding ring is arranged on the first surface of the second substrate and surrounds the cavity in a closed loop, used to fix the base and the cap layer together.

~~20~~10. A ~~multi-mode~~ sensor assembly based on wafer-level packaging, wherein it comprises:

multiple sensor layers and at least two base sidewalls, wherein each of the sensor layers is provided with multiple ~~multi-mode~~ sensors, the sensor comprises a base, a sensor body, a cap layer, and multiple electrodes;

the base comprises: a first substrate, a dielectric layer, a first insulating layer, and multiple TSVs, wherein the dielectric layer covers at least a portion of the first surface of the first substrate; the TSVs penetrate the first substrate and the dielectric layer; the first insulating layer covers the second surface of the first substrate and at least exposes the TSVs, with the first substrate being a silicon substrate;

the electrodes are arranged within the TSV areas and electrically connected to the corresponding TSVs;

the sensor body comprises sensing electrodes and a sensing film layer, wherein the sensing electrodes are located above the dielectric layer and connected to the corresponding TSVs; the sensing film layer covers the target area of the sensing electrodes;

the cap layer comprises a second substrate and a bonding ring, wherein the first surface of the second substrate is provided with a cavity, and at least part of the sensor body is located within the cavity; the bonding ring is arranged on the first surface of the second substrate and surrounds the cavity in a closed loop, used to fix the base and the cap layer together;~~based on wafer-level packaging as described in claims 1-8;~~

each of the sensor layers is fixedly bonded and connected to the corresponding base sidewalls, and each of the ~~multi-mode~~ sensors is connected laterally to the respective base sidewalls through the TSVs and interconnection lines within their respective bases, achieving electrical connection with the surface lines of the base sidewalls.

~~21~~11. A ~~multi-mode~~ sensor array based on wafer-level packaging, wherein it comprises:

a top secondary packaging cap wafer, a multi-layer sensor layer wafer, a secondary packaging via interconnection wafer, and a bottom secondary packaging layer wafer,

wherein each sensor layer wafer comprises multiple ~~multi-mode~~ sensors~~ based on wafer-level packaging as described in claims 1-8~~, the sensor comprises a base, a sensor body, a

cap layer, and multiple electrodes;

the base comprises: a first substrate, a dielectric layer, a first insulating layer, and multiple TSVs, wherein the dielectric layer covers at least a portion of the first surface of the first substrate; the TSVs penetrate the first substrate and the dielectric layer; the first insulating layer covers the second surface of the first substrate and at least exposes the TSVs, with the first substrate being a silicon substrate;

the electrodes are arranged within the TSV areas and electrically connected to the corresponding TSVs;

the sensor body comprises sensing electrodes and a sensing film layer, wherein the sensing electrodes are located above the dielectric layer and connected to the corresponding TSVs; the sensing film layer covers the target area of the sensing electrodes;

the cap layer comprises a second substrate and a bonding ring, wherein the first surface of the second substrate is provided with a cavity, and at least part of the sensor body is located within the cavity; the bonding ring is arranged on the first surface of the second substrate and surrounds the cavity in a closed loop, used to fix the base and the cap layer together.