

APPARATUS AND METHOD FOR COOLING A SEMICONDUCTOR DEVICE

5 FIELD OF INVENTION

The present invention relates broadly to an apparatus and method for cooling a semiconductor device.

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BACKGROUND

During electrical testing of a semiconductor device, an electric current may be supplied to relevant components of the semiconductor device under test. With increasing metal layers and flip chip bonding, analysis of the integrated circuits (IC) on the semiconductor device can typically only be done from the backside of the chip through the silicon substrate using infrared imaging. It has been noted that the semiconductor device may heat up during such testing due to power dissipation and may need to be cooled.

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In one existing cooling method, a cooled diamond window is used to press on the backside of the semiconductor device. This method allows air-gap lens operation. The diamond window allows the system to perform the analysis through the silicon substrate while testing. The diamond conducts heat from the semiconductor device to an attached copper heat exchanger block. Typically, the heat exchanger uses a cooled liquid or super cooled air. Another version of this method involves having a small opening on the diamond window to allow a Solid Immersion Lens (SIL), which can enhance the imaging resolution, to land on the device.

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However, in the above method, the thermal resistance is high between the cold contact (diamond window) and the semiconductor device, and between the cold contact and the heat exchanger block, making it difficult for the user to operate the device at a higher power. In addition, in the above method, device planarity requirements are

typically stringent and passive components protruding from the device may have to be removed.

5 In another existing cooling method, a liquid jet is used to spray a cooled liquid onto the silicon substrate of the semiconductor device. The sprayed liquid is then collected back to the heat exchanger. However, this method typically can only be used on an SIL which has sealed optics. Also, this method can only cool the device to temperatures above 10 degrees Celsius (°C).

10 A need therefore exists to provide an apparatus and method for cooling a semiconductor device that seek to address at least some of the above problems.

SUMMARY

15 In accordance with a first aspect of the present invention, there is provided an apparatus for cooling a semiconductor device, comprising:

a chamber configured for receiving a cooling fluid; and

20 a plurality of contact elements comprising respective first ends disposed within the chamber;

wherein, during operation, respective second ends of contact elements contact a silicon substrate of the semiconductor device for transferring heat generated in the semiconductor device to the cooling fluid.

25 The contact elements may be independently adjustable.

The contact elements may be mounted to the chamber in a spring-loaded type configuration.

30 Each of the contact elements may be anchored on a respective elastic O-ring.

The contact elements may be fabricated from a heat conducting material.

The contact elements each may comprise a first bulk material coated, at a contact area of the contact element, with a second material.

5 The first bulk material may comprise copper and the second material may comprise gold.

The chamber may further comprise an inlet and an outlet for forming a continuous flow of the cooling fluid.

10 The first ends of the contact elements may be formed integrally with or be attached to respective cooling fins.

The chamber may be configured to allow inspection of the silicon substrate by at least one of a solid immersion lens (SIL) and an air gap lens.

15 In accordance with a second aspect of the present invention, there is provided a system for inspecting and testing of integrated circuits on a semiconductor device, the system comprising the cooling apparatus as defined in the first aspect.

20 In accordance with a third aspect of the present invention, there is provided a method for cooling a semiconductor device, the method comprising the steps of:

providing a cooling fluid in a chamber;
providing a plurality of contact elements comprising respective first ends
25 disposed within the chamber; and

coupling respective second ends of the contact elements to a silicon substrate of the semiconductor device for transferring heat generated in the semiconductor device to the cooling fluid.

30 The cooling fluid may comprise a cooling gas or a cooling liquid.

The cooling gas may comprise super-cooled air.

The cooling liquid may comprise water or diluted glycol.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

10 Figure 1(a) shows a perspective view of a cooling apparatus according to an example embodiment.

 Figure 1(b) shows an alternative perspective view of the cooling apparatus of Figure 1(a).

15 Figure 1(c) shows a side view of the cooling apparatus of Figure 1(a).

 Figure 1(d) shows a cross-sectional view of the cooling apparatus about a line A-A in Figure 1(c) according to an example embodiment.

20 Figure 2(a) shows an enlarged view of detail B in Figure 1(d).

 Figure 2(b) shows an enlarged view of detail C in Figure 1(d).

25 Figure 3 shows an exploded perspective view of a system for inspecting a semiconductor device according to an example embodiment.

 Figure 4 shows a design drawing showing an exploded side view of an SIL optics assembly suitable for use in the system of Figure 3 according to an example embodiment.

30 Figure 5 shows a flow chart 500 illustrating a method for cooling a semiconductor device according to an example embodiment.

DETAILED DESCRIPTION

Figure 1(a) shows a perspective view of a cooling apparatus 100 according to an example embodiment. Figure 1(b) shows an alternative perspective view of the cooling apparatus 100 of Figure 1(a). Figure 1(c) shows a side view of the cooling apparatus 100 of Figure 1(a). Figure 1(d) shows a cross-sectional view of the cooling apparatus 100 about a line A-A in Figure 1(c) according to an example embodiment.

In the example embodiment, the cooling apparatus 100 is in the form of a circular disc comprising an upper face 110 and a lower face 120. The upper face 110 of the cooling apparatus 100 is configured to receive a Solid Immersion Lens (SIL) (not shown). For example, as can be seen from Figure 1(a), a recess 102 comprising a substantially conical aperture 104 is formed on the upper face 110 such that, during testing operation, the conical aperture 104 accommodates a corresponding conical portion of the SIL. In an alternate embodiment using an air-gap lens, the air-gap lens may also be positioned directly above the conical aperture 104.

As can be seen from Figure 1(d), the upper face 110, the lower face 120 and a rim 130 of the cooling apparatus 100 together define a hollow chamber 140 capable of containing a cooling fluid (gas or liquid). In the example embodiment, an inlet 106 is provided on the top face 110 for injecting the cooling fluid (gas or liquid), e.g. super-cooled air, water or diluted glycol, into the chamber 140, and an outlet 108 is provided on the top face 110 diagonally opposite the inlet 106 for removing said fluid from the chamber 140 during the cooling process, which will be described in detail below. The inlet 106 and outlet 108 thus enable a continuous flow of cooling fluid in the example embodiment.

In addition, as can be seen from Figure 1(b), an array of contact elements 112 (herein interchangeably referred to as contacts 112) are mounted adjacent the lower face 120. In the example embodiment, the contact elements 112 are adjustable independently of one another, thus enabling a better surface contact with the target silicon substrate without requiring a high degree of planarity. Preferably,

the contact elements 112 are fabricated using a heat conducting material. In Figure 1(b) the contact area of some of the contact elements 112 are shown as hexagons. However, it should be appreciated that other shapes, e.g. triangle, square or polygon, may be used in alternate embodiments.

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Also, can be seen in Figures 1(b) and 1(d), the contacts 112 in the central region of the lower face 120 have respective contact areas configured for maximizing contact with the semiconductor device without covering the aperture 104 where the SIL lands, and for accommodating the limited mounting space adjacent to the conical aperture 104 in the chamber 140. In the example embodiment, this is achieved by using central contacts 112 with petal-shaped contact areas as shown in Figure 1(b) and by positioning a mounting point of each central contact 112 nearer to the respective outer end where more space is available (as illustrated in detail in Figure 2(a)). Preferably, this arrangement helps to achieve weigh balance as the outer end is typically larger than the inner end.

Figure 2(a) shows an enlarged view of detail B in Figure 1(d). Figure 2(b) shows an enlarged view of detail C in Figure 1(d). In Figures 2(a)-(b), the same reference numerals are used to identify the same parts compared to Figures 1(a)-(d).

The contact elements 112a, 112b are preferably mounted in a spring-loaded type configuration. In the example embodiment, the spring-loaded type configuration comprises anchoring the contact elements 112a, 112b on respective O-rings 202a, 202b disposed between the lower face 120 and respective bottom portions 203a, 203b.. In the example embodiment, the O-rings 202a, 202b are fabricated from an elastic material such as rubber or silicone to provide spring loading for the contact elements 112a, 112b respectively. Thus, the array of contact elements 112a, 112b can advantageously conform to and maintain good contact even with a surface of a non-flat silicon substrate. Also, the contact elements 112a, 112b, which are typically fabricated from a thermally conductive material such as copper, are coated with a relatively softer material such as gold at least on the contact areas of the respective bottom portions 203a, 203b in the example embodiment, for further enhancing the thermal contact with the silicon substrate of the semiconductor device.

Also, in the example embodiment, top portions 205a, 205b of the contact elements 112a, 112b are disposed within the chamber 140 such that, during operation, heat is conducted from the silicon substrate to the contact elements 112a, 112b and is removed by direct contact with the cooling fluid, e.g. super-cooled air, water or diluted glycol, present in the chamber 140. The contact elements 112a, 112b thus increase an effective cooling surface of the silicon substrate during operation. In a preferred embodiment, the top portions 205a, 205b of the contact elements 112a, 112b are formed integrally with or are secured to respective cooling fins 204a, 204b, which are also made of a heat conducting material, to enhance the heat exchange with the cooling fluid in the chamber 140.

Figure 3 shows an exploded perspective view of a system 300 for inspecting a semiconductor device 302 according to an example embodiment. The semiconductor device 302 is typically formed on a silicon substrate together with passive components 304, as will be appreciated by a person skilled in the art. The semiconductor device 302, the passive components 304 and the silicon substrate together may be referred to as a chip 310, which is usually mounted on a holder (not shown) during testing. The cooling apparatus 100 is disposed between a solid immersion lens (SIL) 320 and the chip 310 such that the upper face of the cooling apparatus 100 is adjacent the SIL while the lower face of the cooling apparatus 100 is adjacent the backside of the chip 310 in the example embodiment. Thus, the cooling apparatus 100 advantageously allows inspection and analysis of the chip 310 while removing heat generated away from the chip 310.

As described above, the cooling apparatus in the example embodiments has advantageously provides improved thermal contact and conductivity such that the thermal resistance is advantageously reduced, thereby allowing the user to operate the semiconductor device at a higher power. Preferably, the cooling apparatus in the example embodiments can cool the semiconductor device to temperatures below 0°C and does not require the silicon substrate to have high planarity. Furthermore, the passive components on the chip do not need to be removed in the example embodiments. Also, as the cooling fluid is contained within the cooling apparatus

rather than being sprayed onto the silicon substrate, the SIL does not need to have sealed optics in the example embodiments.

Figure 4 shows a design drawing showing an exploded side view of an SIL optics assembly 400 suitable for use in the system of Figure 3 according to an example embodiment. The SIL optics assembly 400 comprises an objective lens 402, received within a lens adaptor 404. The lens adapter 404 is adapted for threaded engagement with a spring tube 408. A spacer ring 406 is provided for the SIL optics assembly length adjustment. It will be appreciated that the spacer ring 406 is optional and can be of different height, depending on a desired configuration of the SIL optics assembly 400 for different SIL diameters, and centric and aplanatic imaging applications.

An SIL holder 410 is provided for threaded engagement with the spring tube 408. The SIL holder 410 comprises a raised conical portion 412 for attachment of a solid immersion lens (SIL) 414. The SIL 414 is attached to the SIL holder 410 using epoxy in this example embodiment, but it will be appreciated that other attachment means may be used in different embodiments.

In the example embodiment, relative movement required during focusing of the SIL holder 410 with respect to the objective lens 402 is provided by way of the spring tube 408, which includes an integrated radial spring section 416 forming a hollow cylindrical support for the SIL holder 410 in the example embodiment. The adjustment set screws 411 on the lens adaptor 404 allow pre-alignment of the SIL 414 optical axis to the objective optical axis. The hollow cylindrical support preferably maintains the alignment during relative axial movement when focusing.

The compression of the spring tube 408 at and near focus provides a force to eliminate the minute air gap between the SIL 414 and a device under test (DUT) surface, reducing reflection losses and total internal reflection at the interface, thus preferably avoiding numerical aperture (NA) reduction. It will be appreciated that the spring tube 408 advantageously provides a biased support for the SIL holder 410 in a manner such that shadowing of the SIL 414 by the biasing member can be eliminated.

It will be appreciated that the lens adapter 404 allows exchange of objective lenses 402 of different magnifications and NA to match the type of SIL 414 used. Spring tubes 408 of different spring stiffness can also be used. Increasing the stiffness and thus axial stability of the spring can advantageously improve repeatable SIL placement for imaging and probing. Also, while the radial spring can be formed as a single start helix spring as described in the example embodiment, double or more start helix springs can be implemented in different embodiments to increase axial stability for improving repeatable SIL placement, and to reduce side loading.

The SIL holder 410 can be custom made to hold SILs 414 of different diameters and thickness to cater for DUTs of different substrate thickness. Spacer rings 406 of different heights can be used to adjust the initial offset of the SIL 414 from the par focus of the lens assembly; and thus the compression and force of the spring tube 408 at focus. Furthermore, the spring tube 408 can preferably accommodate a small angular displacement of the SIL holder 410 relative to a central axis 418 of the SIL optics assembly 400 without or with a reduced risk of the SIL holder 410 being "stuck" relative to the objective lens 402. Alternatively or additionally, the DUT may be levelled during operation to achieve better image quality.

In the example embodiment, the lens adapter 404, spacer ring 406 and spring tube 408 are fabricated from aluminium. The SIL holder 410 is fabricated from stainless steel. The SIL holder can be made from copper or brass if thermal dissipation through the SIL 414 is required. The spring tube 408 can be made from stainless steel to vary the spring rate and thermal conductivity depending on application.

The SIL 414 material can be gallium arsenide (GaAs) or silicon (Si) in example embodiments. The choice of material typically depends on the wavelength. For example, GaAs is typically used for 1000-1200nm wavelength and Si for 1200nm onwards. The SIL 414 can be hemispheres, used for imaging at the centric point or hyper-hemispheres, used for imaging at the aplanatic point. The plano surface of the SIL 414 can also be made convex for better conformance to the device surface.

The lens adapter 404, spacer ring 406 and spring tube 408 are fabricated by turning, and the SIL holder 410 is fabricated by turning and computer numerical control (CNC) in the example embodiment.

5 It will be appreciated by a person skilled in the art that other suitable materials and other fabrication techniques may be used indifferent embodiments for the respective parts without departing from the spirit or scope of the invention.

10 Figure 5 shows a flow chart 500 illustrating a method for cooling a semiconductor device according to an example embodiment. At step 502, a cooling fluid is provided in a chamber. At step 504, a plurality of contact elements comprising respective first ends disposed within the chamber are provided. At step 506, respective second ends of the contact elements are coupled to a silicon substrate of the semiconductor device for transferring heat generated in the
15 semiconductor device to the cooling fluid.

 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly
20 described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. An apparatus for cooling a semiconductor device, comprising:
a chamber configured for receiving a cooling fluid; and
5 a plurality of contact elements comprising respective first ends disposed within the chamber;

wherein, during operation, respective second ends of contact elements contact a silicon substrate of the semiconductor device for transferring heat generated in the semiconductor device to the cooling fluid.

2. The apparatus as claimed in claim 1, wherein the contact elements are independently adjustable.

3. The apparatus as claimed in claim 2, wherein the contact elements are mounted to the chamber in a spring-loaded type configuration.

4. The apparatus as claimed in claim 3, wherein each of the contact elements is anchored on a respective elastic O-ring.

5. The apparatus as claimed in claim 1, wherein the contact elements are fabricated from a heat conducting material.

6. The apparatus as claimed in claim 5, wherein the contact elements each comprises a first bulk material coated, at a contact area of the contact element, with a second material.

7. The apparatus as claimed in claim 6, wherein the first bulk material comprises copper and the second material comprises gold.

8. The apparatus as claimed in claim 1, wherein the chamber further comprises an inlet and an outlet for forming a continuous flow of the cooling fluid.

9. The apparatus as claimed in claim 1, wherein the first ends of the contact elements are formed integrally with or are attached to respective cooling fins.

5 10. The apparatus as claimed in claim 1, wherein the chamber is configured to allow inspection of the silicon substrate by at least one of a solid immersion lens (SIL) and an air gap lens.

10 11. A system for inspecting and testing of integrated circuits on a semiconductor device, the system comprising the cooling apparatus as claimed in claim 1.

12. A method for cooling a semiconductor device, the method comprising the steps of:

15 providing a cooling fluid in a chamber;

providing a plurality of contact elements comprising respective first ends disposed within the chamber; and

coupling respective second ends of the contact elements to a silicon substrate of the semiconductor device for transferring heat generated in the
20 semiconductor device to the cooling fluid.

13. The method as claimed in claim 12, wherein the cooling fluid comprises a cooling gas or a cooling liquid.

25 14. The method as claimed in claim 13, wherein the cooling gas comprises super-cooled air.

15. The method as claimed in claim 13, wherein the cooling liquid comprises water or diluted glycol.

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