

APPARATUS FOR WAFER LEVEL TESTING OF SEMICONDUCTOR DEVICE

FIELD OF THE INVENTION

The disclosures made herein relate generally to the semiconductor devices and more particularly to an apparatus for wafer level testing of a semiconductor device.

BACKGROUND OF THE INVENTION

Planar lightwave circuit (PLC) devices are typically fabricated on planar wafer substrate of various sizes. Characterization and qualification of devices on each die, while they are still on wafer, are crucial to ensure the quality of the wafer product before shipment. While some light emitters or detection devices allow electrical wafer-level testing, many optical devices still require a wafer-level tester to couple light into the chip and out of the chip.

In general, light can be coupled into a chip by two ways, namely surface grating coupling and edge coupling, as explained in Fig. 1 (a) and (b), respectively. Edge coupling has several important advantages over surface grating coupling including relatively lower loss and wider bandwidth. Therefore, wafer-level edge coupling measurement is essential for cost-effective mass production of photonic products.

However, to allow edge coupling, the PLC waveguide on each die must be accessible by input and output light probes of a wafer level tester, which is almost impossible due to the existence of neighbouring dies that will block the probe. Each die on wafer is usually isolated from neighbouring dies by a narrow (30-100 um wide) etched trench, which is not wide enough to be accessed by common light probe such as optical fiber or fiber array.

United States Patent No.: US 6,925,238 B2 discloses an optical probe consists of a waveguide with a reflective facet inclined with respect to a core of the waveguide for reflecting an incident light beam at 90 degrees with respect to the core. By this way a need for including special devices on a wafer under test for redirecting the light perpendicular to the probe.

Chinese Patent No.: CN 101859034 A discloses a double core optical fiber with a pair of electrodes positioned against opposite sides of an inner core and connected to a DC power supply. The electrodes form an optical switch embedded within the fiber without any moving parts. However, such fibers are highly complicated and expensive to manufacture and use. Furthermore, incorporating such fibers in wafer level testing broadens possibilities and accuracy of wafer level testing.

Hence, there is a need for an apparatus for wafer level testing of a semiconductor device in an accurate manner without a need for complicated, space consuming and time consuming setup.

SUMMARY OF THE INVENTION

The present invention relates to an apparatus for wafer level testing of a semiconductor device e.g. planar lightwave circuit (PLC) devices. The apparatus comprises an opto-electronic unit, at least one optical fiber array and an optical interface. The opto-electronic unit is configured to transmit one or more optical test signals to the semiconductor device and to receive one or more optical response signals from the semiconductor device for testing at least one function of the semiconductor device.

The optical fiber array is optically coupled to the opto-electronic unit for communicating the optical test signals and the response signals between the opto-electronic unit and the semiconductor device. The optical interface is configured to optically couple the optical fiber array and the semiconductor device. Furthermore, the optical interface includes a steering element for steering the optical test signals towards the semiconductor device and the response signals towards the optical fiber array.

The optical interface includes at least one optical manipulator element for manipulating at least one characteristic of the optical test signals and/or the response signals.

In a preferred embodiment, the optical manipulator element is at least one of polarizer, beam attenuator, interposer, optical switch, beam splitter and wavelength filter.

In one aspect of the present invention, the optical interface includes multiple optical manipulator elements, wherein an optical test signal passes through one of the optical manipulator elements and an optical response signal passes through another of the optical manipulator elements. Furthermore, each optical manipulator element is optically coupled to a different optical fiber in the optical fiber array through an optical channel in the optical interface. Similarly, each optical manipulator element is optically coupled to a different waveguide in the semiconductor device.

In one aspect of the present invention, the steering element includes a reflective surface to reflect an optical signal incident on the reflective surface. Furthermore, the steering element includes one or more lenses corresponding to each optical manipulator element for focusing or collimating the optical test signals and the optical response signals.

Additionally, the optical interface includes at least two optical channels corresponding to each optical manipulator element, wherein at least one of the optical channels corresponding to each optical manipulator element is matched with a corresponding optical fiber in the optical fiber array.

Since the optical interface incorporates the light manipulation function, the present invention avoids a need for separate light manipulator elements included in the opto-electronic unit for manipulating the light before it enters the optical probe, which in turn minimizes the cost, complexity, maintenance and footprint of the apparatus without compromising with testing accuracy. Furthermore, multiple optical manipulator components are embedded within the optical interface, and therefore enabling easy coupling of multiple components in a single step with minimal or no coupling losses, which in turn minimizes time consumption and increases productivity.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

The present invention will be fully understood from the detailed description given herein below and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, wherein:

In the appended drawings:

Figure 1a & 1b show conventional surface grating coupling and edge coupling processes, respectively;

Figure 2 shows a block representation of the apparatus for wafer level testing of a semiconductor device, in accordance with an exemplary embodiment of the present invention;

Figures 3 shows a perspective view of an optical interface positioned with respect to the semiconductor device during wafer level testing, in accordance with an exemplary embodiment of the present invention;

Figures 4 shows a side view of the semiconductor device during wafer level testing; and

Figures 5 shows a front view of an optical interface of the apparatus for wafer level testing of a semiconductor device, in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Detailed description of preferred embodiments of the present invention is disclosed herein. It should be understood, however, that the embodiments are merely exemplary of the present invention, which may be embodied in various forms. Therefore, the details disclosed herein are not to be interpreted as limiting, but merely as the basis for the claims and for teaching one skilled in the art of the invention. The numerical data or ranges used in the specification are not to be construed as limiting. The following detailed description of the preferred embodiments will now be described in accordance with the attached drawings, either individually or in combination.

Various terms as used herein are defined below. To the extent a term used in a claim is not defined below, it should be understood with the broadest definition given by persons in the pertinent art to that term as reflected in publications (e.g. dictionaries, article or published patent applications) and issued patents at the time of filing.

Definitions:

Characteristic of optical signal – property of light signal, such as polarization state, wavelength, phase and intensity

Planar lightwave circuit (PLC) devices – Optical waveguide devices fabricated on a planar wafer to perform light signal processing, wherein the cross section is preferably rectangular in shape.

Testing – Process of characterization of the performance of optical waveguide device, such as characterizing the insertion loss, wavelength dependent loss, polarization dependent loss and etc.

Manipulation – Intentional change of property of the light propagating on the PLC, such as change of polarization state, wavelength, phase, intensity, number of channels and direction.

The present invention relates to an apparatus for wafer level testing of a semiconductor device. The apparatus comprises an opto-electronic unit, at least one optical fiber array and an optical interface for optically coupling each optical fiber array to the semiconductor device. The optical interface includes at least one optical manipulator element for manipulating at least one characteristic of light signals propagating through the optical interface. Since the optical interface incorporates the light manipulation function, the present invention avoids a need for separate light manipulator elements included in the opto-electronic unit for manipulating the light before it enters the optical probe, which in turn minimizes the cost, complexity, maintenance and footprint of the apparatus. Furthermore, multiple optical manipulator components are embedded within the optical

interface, and therefore enabling easy coupling of multiple components in a single step with minimal or no coupling losses, which in turn increase productivity.

Referring to the accompanying drawings, **Figure 2** shows a block representation of an apparatus (1) for wafer level testing of a semiconductor device (10), in accordance with an exemplary embodiment of the present invention. The apparatus (1) comprises an opto-electronic unit (11), at least one optical fiber array (12) and an optical interface (13) for optically coupling each optical fiber array (12) to the semiconductor device (10).

The opto-electronic unit (11) transmits one or more optical test signals to the semiconductor device (10) and receives one or more optical response signals from the semiconductor device (10) with respect to each optical test signal for testing at least one function e.g. light signal modulation, light beam splitting, polarization splitting, wavelength demultiplexing/multiplexing, etc., of the semiconductor device (10). Each optical fiber array (12) is optically coupled to the opto-electronic unit (11) and configured to communicate the optical test signals and the response signals between the opto-electronic unit (11) and the semiconductor device (10).

The optical interface (13) includes at least one optical manipulator element (15, shown in **Figure 3**) for manipulating at least one characteristic of the optical test signals and/or the response signals. Furthermore, the optical interface (13) includes a steering element (14, shown in **Figure 3**) for steering the optical test

signals towards the semiconductor device (10) and the response signals towards the optical fiber array.

In a preferred embodiment, as shown in **Figure 3**, the steering element (14) includes a reflective surface (14a) to reflect an optical signal incident on the reflective surface (14a). More preferably, the reflective surface (14a) is inclined with respect to an axis of the optical interface (13). Most preferably, the reflective surface (14a) is configured to reflect an incident optical signal at 70-100° with respect to an axis of the fiber array (12). Furthermore, the optical interface (13) is formed of a transparent material to allow optical signals to pass through the optical interface.

In one embodiment, the reflective surface (14a) is formed by polishing a portion of the optical interface (13), wherein the optical signal is reflected due to total internal reflection characteristics of the optical interface (13), which in turn avoids a need for any reflective coating. In an alternate embodiment, the reflective surface (14a) is formed by coating a conventional reflective material on a surface of the optical interface (13) or by attaching any conventional reflector means to the surface. Since a direction of propagation of the optical signals are adjustable by means of the steering element (14), it is possible for the optical interface to optically couple with waveguides in the semiconductor device (10) through a narrow trench with a width starting from 20 micron, and therefore increasing a number of dies in a single wafer.

Optionally, the steering element (14) includes one or more microlenses (14b) provided at a surface opposite to the reflective surface (14a) for focusing or collimating an optical signal reflected by the reflective surface (14a). Each microlens (14b) corresponds to a different optical manipulator element (15) in the optical interface (13). Furthermore, each microlens (14b) is formed by means of attaching an epoxy microlens or by delivering and shaping an epoxy material on the surface of the optical interface (13).

Preferably, the optical manipulator element (15) is at least one of polarizer, beam attenuator, interposer, optical switch, beam splitter and wavelength filter. The optical interface (13) and each optical manipulator element (13) are fabricated from silica, doped silica or any other conventional materials used for fabricating such components.

In one embodiment, the optical interface (13) includes multiple optical manipulator elements (15), as shown in **Figure 5**, wherein an optical test signal passes through one of the optical manipulator elements (15) and an optical response signal passes through another of the optical manipulator elements (15). Furthermore, each optical manipulator element (15) is optically coupled to a different optical fiber in the optical fiber array (12) through an optical channel (16) in the optical interface (13). Similarly, each optical manipulator element (15) is optically coupled to a different waveguide (10a) in the semiconductor device (10). Alternatively, two or more optical manipulator elements (15) can also be coupled in series through a single optical channel (16), wherein an optical signal

can be manipulated for multiple times for same characteristic or for multiple characteristics. For example, a 1x4 beam splitter with a different wavelength filter at each of four output ports of the beam splitter allows beam splitting followed by wavelength filtering operation.

In one embodiment, the optical interface (13) is coupled to the semiconductor device (10) via optical coupling gel or mechanical clamp. An optical test signal generated at the opto-electronic unit (11) propagates through the fiber array (12), one or more channels (16) and then the corresponding optical manipulator elements (15) and incident on the steering element (15) and subsequently the test signal gets steered towards the semiconductor device (10) and enters into one or more corresponding waveguides (10a) in the semiconductor device (10).

In return, one or more response signals from the semiconductor device (10) are received at the optical interface (13). Preferably, the response signal is generated at the semiconductor device (10), wherein one or more opto-electronic elements in the semiconductor device (10) are activated by the test signals to generate the response signals. Alternatively, the response signals are a modified version of the corresponding test signals. For example, a polarity or mode of the test signal is modified to form the response signal. Furthermore, the response signals are steered back to the corresponding optical manipulator elements. In an alternate embodiment, the apparatus (1) includes two fiber arrays (12a, 12b) as shown in **Figure 4**, wherein one fiber array (12a) inputs the test signals to the semiconductor device (10), while the other fiber array (12b) receives the response

signals from the semiconductor device (10). Alternatively, one of the fiber arrays (12a, 12b) inputs a first set of test signals to the semiconductor device (10), while the other of the fiber arrays (12a, 12b) inputs a second set of test signals to the semiconductor device (10). Similarly, one of the fiber arrays (12a, 12b) receives a first set of response signals from the semiconductor device (10), while the other of the fiber arrays (12a, 12b) receives a second set of response signals from the semiconductor device (10). Furthermore, cross section of each fiber array (12a, 12b) can be circular, elliptical, rectangular, triangular or any other shape that allows low loss coupling with the optical interface (13).

The core aspect of the invention is the optical manipulating elements (15) provided between the fiber array (12) and the steering element (14), wherein optical manipulating elements (15) are mainly confined in a waveguide core sandwiched between two waveguide claddings. Various planar waveguide devices can be designed and introduced into the optical manipulating elements (15), such as multimode interferometer for power splitting and wavelength splitting, y-branch for power splitting, spot-size-converter for mode changing, pitch or channel changer for interposer, etc.

For example, a 1×8 power splitter can be introduced as an optical manipulating element, such that a single external laser input can be used to test a semiconductor device with 15 waveguide devices concurrently, thus avoiding a need for 8 external laser sources, which in turn minimizes the cost of operation and

maintenance of a testing apparatus and reduces a footprint of the apparatus without compromising with testing accuracy.

The optical interface (13) is a singulated optical chip fabricated via semiconductor wafer process, with one facet polished to an angle to create total reflection. Since the semiconductor wafer process is scalable, multiple optical manipulator elements can be fabricated on a single optical interface in one wafer process with no extra processing step needed, which makes the optical interface cost effective, versatile and scalable.

The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a", "an" and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises", "comprising", "including" and "having" are inclusive and therefore 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.

The method steps, processes and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed. The use of the expression "at least" or "at least one" suggests the use of one or

more elements, as the use may be in one of the embodiments to achieve one or more of the desired objects or results.

CLAIMS.

1. An apparatus (1) for wafer level testing of a semiconductor device (10), comprising:
 - (a) an opto-electronic unit (11) for transmitting one or more optical test signals to the semiconductor device (10) and receiving one or more optical response signals from the semiconductor device (10) for testing at least one function of the semiconductor device (10);
 - (b) at least one optical fiber array (12) optically coupled to the opto-electronic unit (11) for communicating the optical test signals and the response signals between the opto-electronic unit (11) and the semiconductor device (10);
 - (c) an optical interface (13) for optically coupling each optical fiber array (12) and the semiconductor device (10), wherein the optical interface (13) includes a steering element (14) for steering the optical test signals towards the semiconductor device (10) and the response signals towards the optical fiber array (12);characterized in that:
 - the optical interface (13) includes at least one optical manipulator element (15) for manipulating at least one characteristic of the optical test signals and/or the response signals.
2. The apparatus (1) of claim 1, wherein the optical manipulator element (15) is at least one of polarizer, beam attenuator, interposer, optical switch, beam splitter and wavelength filter.
3. The apparatus (1) of claim 1, wherein the optical interface (13) includes multiple optical manipulator elements (15), wherein an optical test signal passes through one of the optical manipulator elements (15) and an optical response signal passes through another of the optical manipulator elements (15).

4. The apparatus (1) of claim 3, wherein each optical manipulator element (15) is optically coupled to a different optical fiber in the optical fiber array (12) through an optical channel (16) in the optical interface (13).
5. The apparatus (1) of claim 3, wherein each optical manipulator element (15) is optically coupled to a different waveguide (10a) in the semiconductor device (10).
6. The apparatus (1) of claim 1, wherein the apparatus (1) comprises two optical fiber arrays (12a, 12b), wherein an optical test signal passes through one of the optical fiber arrays (12a, 12b) and an optical response signal passes through another of the optical fiber arrays (12a, 12b).
7. The apparatus (1) of claim 1, wherein the steering element (14) includes a reflective surface (14a) to reflect an optical signal incident on the reflective surface (14a).
8. The apparatus (1) of claim 7, wherein the reflective surface (14a) is inclined with respect to an axis of the optical interface (13).
9. The apparatus (1) of claim 7, wherein the reflective surface (14a) is formed by polishing a portion of the optical interface (13).
10. The apparatus (1) of claim 1, wherein the steering element (14) includes at least one microlens (14b) for focusing or collimating an optical signal.