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### Optical module

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#### Abstract

An optical module is disclosed. The optical module includes a carrier and a lid disposed over the carrier. The carrier and the lid are collaboratively define a first cavity for accommodating a photonic component. The optical module also includes a first electrical contact disposed over a first side of the lid and configured to provide an electronic connection for the optical module. A first aperture penetrating the lid is formed at the first side of the lid and corresponds to a light transmission/reception area of the photonic component.

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## Background/Summary

### BACKGROUND

#### 1. Field of the Disclosure

(1) The present disclosure relates to an optical module.

#### 2. Description of the Related Art

(2) Photonic integrated circuits (PICs) are expected to be more reliable and highly integrated to support high-speed data communication that is not available with electronic integrated circuits (EICs) alone. A PIC includes multiple optical devices formed over a substrate. Conventionally, a molding compound may be used to encapsulate the PIC. The molding compound overlies the substrate, and the applied force and stress may inadvertently ruin the optical devices.

(3) In addition, it may be desirable to reduce the size of a PIC to fit more optical devices on the same substrate, and using a molding compound to encapsulate the PIC may be disadvantageous with respect to achieving size reduction. Furthermore, when the optical devices are densely packed, optical routing paths may become more complicated, impacting the optical performance.

### SUMMARY

(4) In some arrangements, an optical module includes a carrier and a lid disposed over the carrier. The carrier and the lid are collaboratively define a first cavity for accommodating a photonic component. The optical module also includes a first electrical contact disposed over a first side of the lid and configured to provide an electronic connection for the optical module. A first aperture penetrating the lid is formed at the first side of the lid and corresponds to a light transmission/reception area of the photonic component.

(5) In some arrangements, an optical module includes an interconnection structure including a first

aperture, an electronic component disposed over the interconnection structure, and a photonic component electrically connected to the electronic component through the interconnection structure. The photonic component is configured to change a first propagation direction of a first light to a second propagation direction toward the first aperture. The first propagation direction is different from the second propagation direction.

(6) In some arrangements, an optical module includes a carrier and a lid disposed over the carrier. An electrical contact is disposed over a side of the lid and configured to provide an electronic connection for the optical module. A first aperture penetrates the first side of the lid and is configured to provide a light passage for the optical module.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) Aspects of some arrangements of the present disclosure are readily understood from the following detailed description when read with the accompanying figures. It is noted that various structures may not be drawn to scale, and dimensions of the various structures may be arbitrarily increased or reduced for clarity of discussion.

(2) FIG. 1A illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(3) FIG. 1B illustrates a top view of an example of an optical module according to some arrangements of the present disclosure.

(4) FIG. 1C illustrates a top view of an example of an optical module according to some arrangements of the present disclosure.

(5) FIG. 1D illustrates a schematic diagram of an example of an optical phase array (OPA) according to some arrangements of the present disclosure.

(6) FIG. 2 illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(7) FIG. 3 illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(8) FIG. 4A illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(9) FIG. 4B illustrates a top view of an example of an optical module according to some arrangements of the present disclosure.

(10) FIG. 5 illustrates an interactive diagram of an optical module and an object according to some arrangements of the present disclosure.

(11) FIG. 6A illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(12) FIG. 6B illustrates a side view of an example of an optical module according to some arrangements of the present disclosure.

(13) FIGS. 7A, 7B, and 7C illustrate cross-sectional views in one or more stages of a method of manufacturing an optical module in accordance with an arrangement of the present disclosure.

### DETAILED DESCRIPTION

(14) Common reference numerals are used throughout the drawings and the detailed description to indicate the same or similar components. Arrangements of the present disclosure will be readily understood from the following detailed description taken in conjunction with the accompanying drawings.

(15) The following disclosure provides many different arrangements, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to explain certain aspects of the present disclosure. These

are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include arrangements in which the first and second features are formed or disposed in direct contact, and may also include arrangements in which additional features may be formed or disposed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various arrangements and/or configurations discussed.

(16) FIG. 1A illustrates a side view of an example of an optical module **1a** according to some arrangements of the present disclosure. The optical module **1a** may include a carrier **10**, an interconnection structure **11**, a photonic component **12**, an optical emitter **13**, an optical receiver **14**, and electronic components **15**, **16**.

(17) The carrier **10** may include a substrate. The carrier **10** may include a printed circuit board (PCB), such as a paper-based copper foil laminate, a composite copper foil laminate, or a polymer-impregnated glass-fiber-based copper foil laminate. In some arrangements, the carrier **10** may include an interconnection structure, such as a redistribution layer (RDL) or a grounding element.

(18) The carrier **10** may include a surface **101** and a surface **102** opposite to the surface **101**. The carrier **10** may include one or more conductive pads **10p** in proximity to, adjacent to, or embedded in and exposed from the surface **101** and/or the surface **102**. The carrier **10** may include a solder resist (not shown) on the surface **101** and/or the surface **102** to fully expose or to expose at least a portion of the conductive pads **10p** for electrical connections.

(19) The interconnection structure **11** may be disposed over or on the surface **102** of the carrier **10**. The interconnection structure **11** may be electrically connected to the carrier **10** using electrical contacts **10e** over (e.g., contacting directly) the conductive pads **10p**. In some arrangements, the electrical contacts **10e** may include a solder ball, such as a controlled collapse chip connection (C4) bump, a ball grid array (BGA), a land grid array (LGA), and so on. In some arrangements, the electrical contacts **10e** may include a conductive pad, a conductive via, a conductive pillar, a conductive wire, or a combination thereof.

(20) The interconnection structure **11** may include a surface **111** facing the carrier **10** and a surface **112** facing away from the carrier **10** and opposite to the surface **111**. The interconnection structure **11** may be spaced apart from the surface **102** of the carrier **10**. For example, the interconnection structure **11** may not directly contact the carrier **10**. For example, there may be a gap between the surface **111** of the interconnection structure **11** and the surface **102** of the carrier **10**. The electrical contacts **10e** may be disposed in the gap. The electrical contacts **10e** may be disposed between the surface **111** of the interconnection structure **11** and the surface **102** of the carrier **10**.

(21) The interconnection structure **11** may include a lid, a housing, a covering, a wall, etc. In some arrangements, the interconnection structure **11** may have a base portion **11b** and an extending portion (or a sidewall) **11x** extending from the base portion **11b**. The base portion **11b** may have or define the surface **112** and a surface **113** opposite to the surface **112**. The extending portion **11x** may extend between the surface **113** and the surface **111**. The extending portion **11x** may be located over a periphery of the base portion **11b**. The extending portion **11x** may define a central hole over the base portion **11b**. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may include a monolithic structure. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may be formed of one piece. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may be pieces separately formed and then combined together.

(22) The interconnection structure **11** may have or define an opening or a cavity **11c**. The cavity **11c** may be recessed from the surface **111** and covered by the carrier **10**. The surface **113** may constitute a bottom surface of the cavity **11c**. The extending portion **11x** may constitute a sidewall of the cavity **11c**.

(23) The cavity **11c** may include an air-filled physical cavity, or the cavity **11c** may be filled with a material other than the material forming the interconnection structure **11**. For example, the cavity **11c** may be filled with a light transmissive material. In some arrangements, the light transmissive material may be a clear epoxy or other light transmissive epoxy or other resin or polymer. In some arrangements, a width **11cw** of the cavity **11c** may be from about 9 millimeters (mm) to about 15 mm, such as 10 mm, 11 mm, 12 mm, 13 mm, or 14 mm.

(24) In some arrangements, the cavity **11c** may be configured to accommodate the photonic component **12**, the optical emitter **13**, the optical receiver **14**, and the electronic components **15**, **16**. The carrier **10** and the interconnection structure **11** may collectively or collaboratively define a space to accommodate the photonic component **12**, the optical emitter **13**, the optical receiver **14**, and the electronic components **15**, **16**. The extending portion **11x** of the interconnection structure **11** may surround the photonic component **12**, the optical emitter **13**, the optical receiver **14**, and the electronic components **15**, **16**.

(25) The interconnection structure **11** may have or define recessed portions **11r1** and **11r2**. The recessed portions **11r1** and **11r2** may be formed in the based portion **11b** of the interconnection structure **11**. The recessed portions **11r1** and **11r2** may each be recessed from the surface **113**. The electronic component **15** may be disposed or received in the recessed portion **11r1** and the electronic component **16** may be disposed or received in the recessed portion **11r2**.

(26) The recessed portions **11r1** and **11r2** may be separated by a protruding portion **11s**. The protruding portion **11s** may protrude from the surface **113**. The electronic components **15** and **16** may be isolated or spaced apart by the protruding portion **11s**. The protruding portion **11s** may function as a stopper to prevent bridge issues (e.g., solder or other connection material flows from the recessed portion **11r1** to the recessed portion **11r2**, or vice versa) when the electronic components **15** and **16** are connected to the interconnection structure **11** by heat and compression technique(s).

(27) The interconnection structure **11** may have or define a hole, a through hole, or an aperture **11a1**. The aperture **11a1** may be formed at the surface **112**. The aperture **11a1** may extend between the surface **112** and the surface **113**. The aperture **11a1** may penetrate the base portion **11b** of the interconnection structure **11**. The aperture **11a1** may extend from the surface **112** to the cavity **11c**. The cavity **11c** may be exposed to air through the aperture **11a1**.

(28) The aperture **11a1** may include an air-filled physical cavity, or the aperture **11a1** may be filled with a material other than the material forming the interconnection structure **11**. For example, the aperture **11a1** may be filled with a light transmissive material. In some arrangements, a width **11a1w** of the aperture **11a1** may be greater than an active area (such as an optical phased array (OPA) **12a**) of the photonic component **12**.

(29) In some arrangements, the aperture **11a1** may be configured to provide a light passage for the optical module **1a**. In some arrangements, the aperture **11a1** may be configured to allow light to pass through. For example, the light radiated from the photonic component **12** may pass through the aperture **11a1**. A light transmission area of the photonic component **12** may be at least partially exposed from the surface **112** of the interconnection structure **11**. As such, the surface **112** of the interconnection structure **11** may function as a light transmission surface of the optical module **1a**. The interconnection structure **11** may have or define multiple apertures. For example, the interconnection structure **11** may have apertures **11a1** and **11a2** shown in FIG. 1B. In some arrangements, different apertures may be configured to allow different lights (such as lights from different light sources) to pass through. For example, the aperture **11a2** shown in FIG. 1B may be configured to allow light outside of the optical module **1a** to pass through and be detected by the optical receiver **14**. A light reception area of the optical receiver **14** may be at least partially exposed from the surface **112** of the interconnection structure **11**. As such, the surface **112** of the interconnection structure **11** may function as a light reception surface of the optical module **1a**. In some arrangements where the interconnection structure **11** having the apertures **11a1** and **11a2**, the

surface **112** of the interconnection structure **11** may function as a light transceiving surface of the optical module **1a**.

(30) In some arrangements, the surface **112** of the interconnection structure **11** and/or the sidewall of the aperture **11a1** may be coated with an anti-reflection coating to improve coupling of light into the cavity **11c**.

(31) The interconnection structure **11** may be configured to provide input/output (I/O) access, such as I/O pads, for the optical module **1a** with an external component (e.g., external circuits or circuit boards). For example, electrical contacts **11e** may be disposed over or on the surface **112** of the interconnection structure **11**. The electrical contacts **11e** may be similar to the electrical contacts **10e** and a description thereof is not repeated hereinafter for conciseness. In some arrangements, since the aperture **11a1** (and/or the aperture **11a2** shown in FIG. **1B**) and the electrical contacts **11e** are over or on the same surface (i.e., the surface **112** of the interconnection structure **11**), the I/O access for optical routing paths and the I/O access for signal routing paths may be arranged over the same side of the optical module to increase the space utilization and achieve size reduction. The electrical contacts **11e** and the electrical contacts **10e** may respectively be adjacent to opposite sides of the interconnection structure **11**.

(32) The interconnection structure **11** may be configured to provide I/O access, such as I/O pads, for the electronic components **15** and **16** to the carrier **10**. For example, the electronic components **15** and **16** may be electrically connected with the carrier **10** through the interconnection structure **11**.

(33) The interconnection structure **11** may include an encapsulant **11m** and conductive elements **11v1**, **11v2**. In some arrangements, the encapsulant **11m** may include an epoxy resin having fillers, a molding compound (e.g., an epoxy molding compound or another molding compound), a polyimide, a phenolic compound or material, a material with a silicone dispersed therein, or a combination thereof. In some arrangements, the encapsulant **11m** may include an opaque material. In some arrangements, the opaque material may be an opaque epoxy (e.g., a black epoxy) or other opaque resin or polymer.

(34) The conductive elements **11v1** and **11v2** may each at least partially penetrate the encapsulant **11m** and contact a conductive pad. The conductive elements **11v1** and **11v2** may each include a conductive pillar, a conductive via (such as a through mold via (TMV)), a conductive trace, a conductive wire, or other feasible connectors.

(35) The interconnection structure **11** may include one or more conductive pads **11p** in proximity to, adjacent to, or embedded in and exposed from the surface **111**, the surface **112** and/or the surface **113**. A width of one of the conductive pads **11p** may be greater than a width of one of the conductive elements **11v1** and **11v2**.

(36) The conductive elements **11v1** may connect the conductive pads **11p** exposed from the surface **112** with the conductive pads **11p** exposed from the surface **111**. The conductive elements **11v2** may connect the conductive pads **11p** exposed from the surface **112** with the conductive pads **11p** exposed from the surface **113**. In some arrangements, a length of one of the conductive elements **11v1** may be greater than a length of one of the conductive elements **11v2**.

(37) However, in some arrangements, the conductive pads **11p** may be omitted and the conductive elements **11v1** and **11v2** may each be exposed from the surface **111**, the surface **112** and/or the surface **113**. For example, the conductive elements **11v1** may penetrate the base portion **11b** and the extending portion **11x** of the interconnection structure **11**. The conductive elements **11v1** may extend between the surface **111** and the surface **112** of the interconnection structure **11**. The conductive elements **11v2** may penetrate the base portion **11b** of the interconnection structure **11**. The conductive elements **11v2** may extend between the surface **112** and the surface **113** of the interconnection structure **11**.

(38) In some arrangements, one or more of the conductive elements **11v1** and **11v2** may taper toward the carrier **10**. In some arrangements, one or more of the conductive elements **11v1** and

**11v2** may taper away from the carrier **10**. In some arrangements, one or more of the conductive elements **11vl** and **11v2** may have a constant width.

(39) The photonic component **12** may be disposed over or on the carrier **10**. The photonic component **12** may be electrically connected to the carrier **10** through solder bonding, Cu-to-Cu bonding, wire bonding, or hybrid bonding. For example, the photonic component **12** may be electrically connected to the carrier **10** through a conductive wire **12w**.

(40) The photonic component **12** may be physically separated from the interconnection structure **11**. The photonic component **12** may be spaced apart from the interconnection structure **11**.

(41) The photonic component **12** may include a silicon photonics substrate, and one or more optical devices and/or photonic integrated circuits. In some arrangements, the silicon photonics substrate may include a Silicon on Insulator (SOI) substrate including a silicon substrate, an oxide layer disposed on the silicon substrate, and a silicon layer disposed on the oxide layer. Examples of the optical devices and/or photonic integrated circuits may include an optical transmitter, an optical receiver, an optical transceiver, optical waveguides, optical gratings, optical resonators, optical multiplexers, optical demultiplexers, optical modulators, optical switches, optical transducers, and so on.

(42) The photonic component **12** may have a surface **121** facing and contacting the carrier **10** and a surface **122** opposite to the surface **121**. The surface **121** of the photonic component **12** may include a backside surface. The surface **122** of the photonic component **12** may include an active surface. As used herein, the term “active side” or “active surface” of a component may refer to a side or a surface of a component over which electrical or contact terminals such as contact pads, conductive studs or conductive pillars are disposed, for transmission of electrical signals or power. The “backside,” “backside surface,” “inactive side,” or “inactive surface” of a component may refer to a surface of the component over which no contact terminals are disposed.

(43) The surface **122** of the photonic component **12** may be spaced apart from the interconnection structure **11**. The surface **122** of the photonic component **12** may be at least partially exposed to air through the cavity **11c**.

(44) In some arrangements, the photonic component **12** may include an optical phased array (OPA) **12a**. The OPA **12a** may be configured to control the phase and/or amplitude of light generated by the optical emitter **13**, to adjust the wavefront of the light, to steer the direction of light, and to form a desired radiation pattern. The OPA **12a** may include an active area of the photonic component **12**. The OPA **12a** may include a light transmission area, a light reception area, or a light transceiving area. The OPA **12a** may be at least partially exposed to air through the cavity **11c**. The details of the OPA **12a** will be further described with respect to FIG. 1D. The OPA **12a** may be spaced apart from the interconnection structure **11**.

(45) The optical emitter **13** may be disposed over the surface **122** of the photonic component **12**. The optical emitter **13** may be configured to generate light or other electromagnetic radiation in the ultraviolet, visible, and/or infrared spectral regions. In some arrangements, the light generated by the optical emitter **13** may be guided through optical devices of the photonic component **12** and may be radiated through the OPA **12a** and the aperture **11a1**. In some arrangements, the propagation direction of the light generated by the optical emitter **13** may be changed or adjusted by the photonic component **12**. In some arrangements, the propagation direction of the light generated by the optical emitter **13** may be different from the propagation direction of the light radiated by the OPA **12a**. In some arrangements, the light generated by the optical emitter **13** may propagate toward the photonic component **12** in a direction substantially perpendicular to the surface **122** of the photonic component **12**. In some arrangements, the light generated by the optical emitter **13** may propagate toward the OPA **12a** in a direction substantially parallel to the surface **122** of the photonic component **12**. In some arrangements, the light radiated by the OPA **12a** may propagate toward the aperture **11a1** in a direction substantially perpendicular to the surface **122** of the photonic component **12**.

(46) The optical emitter **13** may include a light emitting diode (LED), a laser diode (such as vertical cavity surface-emitting laser (VCSEL)), a lamp, a laser, any other suitable light source, or a combination thereof. For example, the optical emitter **13** may include a light source that emits visible light of one or more wavelengths (or frequencies, or bandwidths), such as red, blue, and green light. In some other arrangements, the optical emitter **13** may include a light source that emits invisible light of one or more wavelengths (or frequencies, or bandwidths), such as infrared light. The optical emitter **13** may include any number of light sources, such as an array of pixels.

(47) The optical receiver **14** may be disposed over the surface **122** of the photonic component **12**. The optical receiver **14** may be configured to receive the light passing through an aperture of the interconnection structure **11** (such as the aperture **11a2** illustrated in FIG. **1B**) and generate electrical signals (e.g., an electrical current) to the electronic components **15** and/or **16**. For example, the optical receiver **14** may convert light energy in the form of photons into an electric current. The electrical signals may be related to one or more properties of the light, such as luminous flux (or luminous power or brightness), luminous intensity, propagation direction, wavelength (or frequency, or bandwidth), polarization state, etc.

(48) In some arrangements, the electrical signals generated by the optical receiver **14** may be transmitted to the electronic components **15** and/or **16** through the photonic component **12**, the carrier **10**, and the interconnection structure **11**.

(49) The optical receiver **14** may include a photo-detector, a photo-sensor, a photodiode (PD), a charge-coupled device (CCD), a photomultiplier tube, a camera, a spectrometer, or another light-sensitive electronic device.

(50) The positions and number of the optical emitter **13** and the optical receiver **14** in the optical module **1a** are not intended to limit the present disclosure. For example, there may be any number of optical emitter(s) in the optical module **1a** due to design needs. For example, there may be any number of optical receiver(s) in the optical module **1a** due to design needs.

(51) The electronic component **15** may be disposed over or on the interconnection structure **11** and in the recessed portion **11r1**. The electronic component **15** may be electrically connected to the interconnection structure **11** through solder bonding, Cu-to-Cu bonding, wire bonding, or hybrid bonding. For example, the electronic component **15** may be electrically connected to the interconnection structure **11** using electrical contacts over (e.g., contacting directly) the interconnection structure **11**. An underfill may be disposed over the interconnection structure **11** to cover or encapsulate the electrical contacts. The electronic component **15** may include an active surface facing the interconnection structure **11** and a backside surface facing away from the interconnection structure **11**.

(52) The electronic component **16** may be disposed over or on the interconnection structure **11** and in the recessed portion **11r2**. The electronic component **16** may be electrically connected to the interconnection structure **11** through solder bonding, Cu-to-Cu bonding, wire bonding, or hybrid bonding. For example, the electronic component **16** may be electrically connected to the interconnection structure **11** using electrical contacts over (e.g., contacting directly) the interconnection structure **11**. An underfill may be disposed over the interconnection structure **11** to cover or encapsulate the electrical contacts. The electronic component **16** may include an active surface facing the interconnection structure **11** and a backside surface facing away from the interconnection structure **11**.

(53) The electronic components **15** and **16** may each include a micro-electromechanical system (MEMS) or an integrated device or system that combine mechanical and electrical components. The electronic components **15** and **16** may each include a processor, a controller, a memory, or an input/output (I/O) buffer, etc.

(54) For example, the electronic components **15** and **16** may each include a central processing unit (CPU), a microprocessor unit (MPU), a graphics processing unit (GPU), a microcontroller unit (MCU), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA),



or another type of computing element or integrated circuit. For example, the electronic components **15** and **16** may each include a non-transitory memory or a non-volatile memory (such as a flash memory and a read-only memory (ROM)) or a volatile memory (such as a Dynamic Random Access Memory (DRAM)).

(55) In some arrangements, the electronic components **15** and/or **16** may be electrically connected to the optical emitter **13** and the optical receiver **14**. The electrical connections may be established by the interconnection structure **11**, the carrier **10**, and the photonic component **12**.

(56) In some arrangements, the electronic components **15** and/or **16** may be configured to process (e.g., analysis, modify, synthesize, convert to a digital signal, and amplify, etc.), to store, and/or to transmit the electrical signals generated by the optical receiver **14**. For example, the electrical signals may be further processed by the electronic components **15** and/or **16** to determine a biological parameter, such as a pulse travel time (PTT), an electroencephalogram (EEG), electrocardiogram (ECG), electromyogram (EMG), electrooculogram (EOG), galvanic skin response (GSR), sweat composition, pH, heart rate variability (HRV), or other biologically-relevant information. In some arrangements, the electronic components **15** and/or **16** may receive the electrical signals from the optical receiver **14** and control the optical emitter **13** based on the electrical signals.

(57) FIG. **1B** illustrates a top view of an example of the optical module **1a** according to some arrangements of the present disclosure. Some elements or components in FIG. **1A** are omitted in FIG. **1B** for conciseness.

(58) The aperture **11a2** may be spaced apart from the aperture **11a1**. The aperture **11a2** may be similar to the aperture **11a1** and a description thereof is not repeated hereinafter for conciseness.

(59) The OPA **12a** and the aperture **11a1** may be at least partially overlapped or aligned from the top view. The OPA **12a** may be at least partially exposed from the aperture **11a1**. The aperture **11a1** may be arranged over interconnection structure **11** according to a location of an active area of the photonic component **12** (such as a light transmission area, a light reception area, or a light transceiving area of the photonic component **12**). The aperture **11a1** may be arranged over interconnection structure **11** according to the location of the OPA **12a**. In some arrangements, the aperture **11a1** may be configured to allow light radiated by the OPA **12a** to pass through. In some arrangements, a width **11a1w** of the aperture **11a1** may be greater than (e.g., is about 10% greater than, about 20% greater than, about 30% greater than, or more than about 30% greater than) a width of the OPA **12a**.

(60) The optical receiver **14** and the aperture **11a2** may be at least partially overlapped or aligned from the top view. The optical receiver **14** may be at least partially exposed from the aperture **11a2**. The aperture **11a2** may be arranged over interconnection structure **11** according to a location of a light reception area (such as the optical receiver **14**). In some arrangements, the aperture **11a2** may be configured to allow light to pass through and to be detected by the optical receiver **14**. In some arrangements, a width **11a2w** of the aperture **11a2** may be greater than (e.g., is about 10% greater than, about 20% greater than, about 30% greater than, or more than about 30% greater than) a width of the optical receiver **14**.

(61) The width **11a1w** and the width **11a2w** are not intended to limit the present disclosure. For example, the size of the apertures can be scaled down to prevent undesired light being detected and to thus increase the accuracy of the optical module **1a**.

(62) In some arrangements, the aperture **11a1** may be configured to provide the light transmission path and the aperture **11a2** may be configured to provide the light reception path. Arranging the light transmission path and the light reception path through different apertures may help reduce signal interference, and the sensing quality can be improved. However, in some arrangements, the OPA **12a** and the optical receiver **14** may each be at least partially exposed from the same aperture (as shown in FIG. **5**). As such, the space utilization may be increased.

(63) In a comparative arrangement, the photonic component **12** may be encapsulated by a molding

compound. The molding compound may overlie the photonic component **12** and the applied force and stress may unintentionally ruin the optical devices thereon.

(64) According to some arrangements of the present disclosure, by using the interconnection structure **11**, the surface **122** of the photonic component **12** may be spaced apart from the interconnection structure **11**. The surface **122** of the photonic component **12** may be at least partially exposed to air through the cavity **11c**. The risk of breaking the optical devices on the photonic component **12** is eliminated.

(65) In addition, the size of the optical module **1a** can be further reduced in comparison with using the molding compound. For example, as shown in FIG. **1A**, a height or thickness **1ah** of the optical module **1a** may be from about 0.7 mm to about 1.2 mm, such as 0.8 mm, 0.9 mm, or 1.1 mm. A width **1aw** of the optical module **1a** may be from about 13 mm to about 19 mm, such as 14 mm, 15 mm, 16 mm, 17 mm, or 18 mm.

(66) Furthermore, since the aperture **11a1** (and/or the aperture **11a2** shown in FIG. **1B**) and the electrical contacts **11e** are over or on the same surface (i.e., the surface **112** of the interconnection structure **11**), the I/O access for optical routing paths and the I/O access for signal routing paths may be arranged over the same side of the optical module to increase the space utilization and achieve size reduction.

(67) FIG. **1C** illustrates a top view of an example of an optical module **1c** according to some arrangements of the present disclosure. The optical module **1c** is similar to the optical module **1a** in FIG. **1B** except for the differences described as follows.

(68) The optical receiver **14** may be disposed over the carrier **10** and laterally spaced apart from the photonic component **12**. In some arrangements, the electrical signals generated by the optical receiver **14** may be transmitted to the electronic components **15** and/or **16** through the carrier **10** and the interconnection structure **11**. In comparison with the optical module **1a** in FIG. **1B**, the light reception path may be shorter, insertion loss may be decreased and sensibility of the optical receiver **14** may be improved.

(69) FIG. **1D** illustrates a schematic diagram of an example of the OPA **12a** according to some arrangements of the present disclosure. The OPA **12a** may include a light source **12a1**, one or more waveguides **12a2**, one or more light splitters **12a3**, one or more phase shifters **12a4**, and one or more radiators **12a5**.

(70) The light source **12a1** may include a laser. The light source **12a1** may be directly coupled to the waveguides **12a2** or may be coupled to the waveguides **12a2** through an optical fiber, a grating coupler or a beam inverter. The waveguides **12a2** may be configured to guide the light from the light source **12a1** to the radiators **12a5**. The waveguides **12a2** may be generally formed of semiconductor or an insulating material, and may have a structure of a rib or channel waveguide. The wavelength of the light source **12a1** may be selected from the wavelength band in which optical loss of the waveguides **12a2** is minimized. In some arrangements, the light source **12a1** may be a part of the optical emitter **13** in FIG. **1A** or may be implemented by using the optical emitter **13**.

(71) The light splitters **12a3** may include Y-branch splitters, directional couplers, multimode interference (MMI) couplers, etc. The light splitters **12a3** may be configured to split or distribute the light from the light source **12a1** to N rows of the phase shifters **12a4** (where N is a natural number greater than 1). The light splitters **12a3** may be prepared with a single light splitter for distributing light at 1:N or by connecting N light splitters to each other in a multiple stage manner. FIG. **1D** shows one example of the light splitters **12a3** in which 1:2 light splitters are connected in three stages for the purpose of 1:8 distribution.

(72) The phase shifters **12a4** may include grating couplers. The phase shifters **12a4** may be arranged in a periodic grid. The phase shifters **12a4** may affect the phases of the transmitted light. For example, the phase shifters **12a4** may be configured to control or tune delay lines of the transmitted light. As the delay lines are tuned, each radiator **12a5** emits light with a desired

amplitude and phase to form a desired radiation pattern through interference. In some arrangements, the thermo-optic actuation mechanism may be used to tune the delay lines.

(73) The radiators **12a5** may couple light out of the plane of the photonic component **12** in FIG.

**1A**. The radiators **12a5** may include, but are not limited to, antennas, gratings, holographic optical elements (HOE), mirrors, total internal reflection (TIR) interfaces, and lenses.

(74) FIG. **2** illustrates a side view of an example of an optical module **2** according to some arrangements of the present disclosure. The optical module **2** is similar to the optical module **1a** in FIG. **1A** except for the differences described as follows.

(75) As indicated by the dotted circle **20**, the interconnection structure **11** may define a cavity for accommodating or receiving the electrical contacts **10e**. The surface **111** of the interconnection structure **11** may contact (such as directly contact) the surface **102** of the carrier **10**. The electrical contacts **10e** may be disposed in the cavity recessed from the surface **111** of the interconnection structure **11** and may contact the conductive pads **11p**. In some arrangements, by forming the cavity for accommodating or receiving the electrical contacts **10e**, the electrical contacts **10e** can be sealed in the cavity and there may be no gap between the surface **111** of the interconnection structure **11** and the surface **102** of the carrier **10**. The interconnection structure **11** can be supported by the surface **102** of the carrier **10**, and the structural stability of the optical module **2** can be increased.

(76) FIG. **3** illustrates a side view of an example of an optical module **3** according to some arrangements of the present disclosure. The optical module **3** is similar to the optical module **1a** in FIG. **1A** except for the differences described as follows.

(77) The protruding portion **30** may protrude from the recessed portions **11r1** and **11r2**, and extend to the surface **122** of the photonic component **12**. The protruding portion **30** may contact the surface **122** of the photonic component **12**. In some arrangements, since the protruding portion **30** can provide structural support for the interconnection structure **11**, the structural stability of the optical module **3** can be increased.

(78) FIG. **4A** illustrates a side view of an example of an optical module **4a** according to some arrangements of the present disclosure. The optical module **4a** is similar to the optical module **1a** in FIG. **1A** except for the differences described as follows.

(79) As indicated by the dotted circle **40**, the optical receiver **14** may be disposed over or on the interconnection structure **11**. The optical receiver **14** may be electrically connected to the interconnection structure **11** through solder bonding, Cu-to-Cu bonding, wire bonding, or hybrid bonding. For example, the optical receiver **14** may be electrically connected to the interconnection structure **11** using electrical contacts over (e.g., contacting directly) the interconnection structure **11**.

(80) The interconnection structure **11** may have or define a recessed portion for accommodating or receiving the optical receiver **14**. The light reception area of the optical receiver **14** may face an aperture **11a3** of the interconnection structure **11**.

(81) The optical receiver **14** may be configured to receive the light passing through the aperture **11a3** of the interconnection structure **11**, generate electrical signals (e.g., an electrical current), and transmit the electrical signals to the electronic components **15** and/or **16**. In some arrangements, the electrical signals generated by the optical receiver **14** may be transmitted to the electronic components **15** and/or **16** through the interconnection structure **11**. In comparison with the optical module **1a** in FIG. **1A**, the light reception path may be shorter, insertion loss may be decreased and sensibility of the optical receiver **14** may be improved.

(82) FIG. **4B** illustrates a top view of an example of the optical module **4a** according to some arrangements of the present disclosure. Some elements or components in FIG. **4A** are omitted in FIG. **4B** for conciseness.

(83) The aperture **11a3** may be spaced apart from the aperture **11a1**. The aperture **11a3** may be similar to the aperture **11a1** and a description thereof is not repeated hereinafter for conciseness.

(84) The optical receiver **14** and the aperture **11a3** may be at least partially overlapped. The optical

receiver **14** may be at least partially exposed from the aperture **11a3**. In some arrangements, the aperture **11a3** may be configured to allow light to pass through and to be detected by the optical receiver **14**. In some arrangements, a width **11a1w** of the aperture **11a3** may be greater than (e.g., is about 10% greater than, about 20% greater than, about 30% greater than, or more than about 30% greater than) a width of the optical receiver **14**. In some arrangements, the size of the apertures can be scaled down to prevent undesired light being detected and to thus increase the accuracy of the optical module **4a**.

(85) FIG. 5A illustrates an interactive diagram of an optical module **5** and an object according to some arrangements of the present disclosure. The optical module **5** is similar to the optical module **1a** in FIG. 1A except for the differences described as follows.

(86) The optical module **5** may further include a carrier **50**, an optical emitter **51**, and an optical receiver **52**. The carrier **50**, the optical emitter **51**, and the optical receiver **52** may be similar to the carrier **10**, the optical emitter **13**, and the optical receiver **14**, respectively, of FIG. 1A. Therefore, some details of the carrier **50**, the optical emitter **51**, and the optical receiver **52** may correspond to the paragraphs described above for FIG. 1A, and a description thereof is not repeated hereinafter for conciseness.

(87) The carrier **50** may have or define a hole, a through hole, or an aperture **50a**. The aperture **50a** may be at least aligned with the aperture **11a1**. In some arrangements, the aperture **50a** may be configured to allow light to pass through. For example, the light radiated from the OPA **12a** of the photonic component **12** may pass through the aperture **50a**.

(88) For example, the light beam (such as the light beam **L1**) radiated from the OPA **12a** may pass through the aperture **11a1** and the aperture **50a** and may be received by (or may radiate) the object. The object may include any suitable object that is moving or stationary relative to the optical module **5**. The object may scatter or reflect at least a portion of light from the light beam **L1**, and the scattered or reflected light beam **L2** may return toward the optical module **5** and be received by the optical receiver **14**. FIG. 5 illustrates that the OPA **12a** and the optical receiver **14** are exposed from the same aperture **11a1**.

(89) In some arrangements, the light beam (such as the light beam **L3**) radiated from the optical emitter **51** may be received by (or may radiate) the object. The object may scatter or reflect at least a portion of light from the light beam **L3**, and the scattered or reflected light beam **L4** may return toward the optical module **5** and be received by the optical receiver **52**. The optical receiver **52** may have a receiving surface facing away from the carrier **50** and the interconnection structure **11**.

(90) The electronic component **15** and/or the electronic component **16** may be configured to analyze one or more characteristics of electrical signals from the optical receiver **14** and/or the optical receiver **52** to determine one or more characteristics of the object. The electronic component **15** and/or the electronic component **16** may control the optical emitter **13** and/or the optical emitter **51** based on the electrical signals from the optical receiver **14** and/or the optical receiver **52**.

(91) In some arrangements, the light beam (such as the light beam **L1**) radiated from the OPA **12a** and the light beam (such as the light beam **L3**) radiated from the optical emitter **51** may have different properties, such as different luminous flux (or luminous power, or brightness), different luminous intensity, different propagation direction, different wavelength (or frequency, or bandwidth), different polarization state, etc. In some arrangements, the electrical signals from the optical receiver **14** and the electrical signals from the optical receiver **52** may be used to determine different characteristics of the object, such as different biological parameters.

(92) In some arrangements, the optical receiver **14** may be disposed over the carrier **50**. For example, the optical receiver **14** may be disposed over or on a surface of the carrier **50** facing away from the interconnection structure **11**. For example, the optical receiver **14** may be disposed adjacent to the optical emitter **51** and/or the optical receiver **52**.

(93) FIG. 6A illustrates a side view of an example of an optical module **6a** according to some

arrangements of the present disclosure. The optical module **6a** is similar to the optical module **1a** in FIG. **1A** except for the differences described as follows.

(94) The optical module **6a** includes electronic components **60** and **61** disposed over or on the surface **101** of the carrier **10**. The electronic components **60** and **61** may be similar to the electronic components **15** and **16** and a description thereof is not repeated hereinafter for conciseness. The positions and number of the electronic components **60** and **61** in the optical module **6a** are not intended to limit the present disclosure. For example, there may be any number of electronic component(s) in the optical module **6a** due to design needs. The electronic components **60** and **61** may be electrically connected to the photonic component **12** through the carrier **10**.

(95) FIG. **6B** illustrates a side view of an example of an optical module **6b** according to some arrangements of the present disclosure. The optical module **6b** is similar to the optical module **6a** in FIG. **6A** except for the differences described as follows.

(96) The optical module **6b** includes an optical component **62** and an optical emitter **63**. The optical component **62** may be disposed over the carrier **10**. The optical component **62** may be disposed adjacent to the photonic component **12** or contact the photonic component **12**. The optical component **62** may have a top surface at least partially overlapped with the aperture **11a1** in a direction substantially perpendicular to the surface **101** and/or the surface **102** of the carrier **10**. The top surface of the optical component **62** may be higher than the surface **122** of the photonic component **12**.

(97) The optical component **62** may include a beam splitter, such as a polarization beam splitter (PBS). The optical component **62** may have a cube shape. The optical component **62** may include triangular glass prisms which are glued (using an index-matched adhesive, such as polyester, epoxy, or urethane-based adhesive) together at their base and have a coating in between. However, a beam splitter of any shape or size can be acceptable. In some arrangements, the optical component **62** may include one or more surfaces for receiving input light beams from the photonic component **12** and one or more surfaces for transmitting output light beams toward the aperture **11a1**. In some arrangements, the optical component **62** may be configured to split an input light beam into two or more output light beams based on one or more properties, such as luminous flux (or luminous power, or brightness), luminous intensity, propagation direction, wavelength (or frequency, or bandwidth), polarization state, etc.

(98) The optical emitter **63** may be disposed over the surface **122** of the photonic component **12** and laterally spaced apart from the optical emitter **13**. The optical emitter **63** may be similar to the optical emitter **13** and a description thereof is not repeated hereinafter for conciseness. In some arrangements, the optical component **62** may be replaced with the OPA **12a** shown in FIG. **1A** to increase the space utilization and achieve size reduction.

(99) FIGS. **7A**, **7B**, and **7C** illustrate cross-sectional views in one or more stages of a method of manufacturing an optical module in accordance with an arrangement of the present disclosure. In some arrangements, the optical module **1a** may be manufactured through the operations described with respect to FIGS. **7A**, **7B**, and **7C**.

(100) Referring to FIG. **7A**, the interconnection structure **11** is provided. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may include a monolithic structure. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may be formed of one piece. In some arrangements, the extending portion **11x** and the base portion **11b** of the interconnection structure **11** may be pieces separately formed and then combined together.

(101) In some arrangements, the encapsulant **11m** may be formed by molding, such as by printing, compressive molding, transfer molding, liquid encapsulant molding, vacuum lamination, spin coating, or other suitable processes. The aperture **11a1** may be formed in the interconnection structure **11** by a computer numerical controlled (CNC) machine. The aperture **11a1** may be formed by photolithography, chemical etching, laser drilling, or other suitable processes.

(102) The electronic component **15** may be disposed or received in the recessed portion **11r1** and the electronic component **16** may be disposed or received in the recessed portion **11r2**.

(103) Referring to FIG. 7B, the photonic component **12** may be disposed over or on the carrier **10**. The optical emitter **13** may be disposed over the surface **122** of the photonic component **12**. The optical receiver **14** may be disposed over the surface **122** of the photonic component **12**.

(104) Referring to FIG. 7C, the interconnection structure **11** may be disposed over or on the carrier **10** to cover the photonic component **12**. The interconnection structure **11** may be arranged so that the aperture **11a1** may be at least partially overlapped with the OPA **12a** in a direction substantially perpendicular to the surface **101** and/or the surface **102** of the carrier **10**.

(105) Spatial descriptions, such as “above,” “below,” “up,” “left,” “right,” “down,” “top,” “bottom,” “vertical,” “horizontal,” “side,” “higher,” “lower,” “upper,” “over,” “under,” and so forth, are indicated with respect to the orientation shown in the figures unless otherwise specified. It should be understood that the spatial descriptions used herein are for purposes of illustration only, and that practical implementations of the structures described herein can be spatially arranged in any orientation or manner, provided that the merits of arrangements of this disclosure are not deviated from by such an arrangement.

(106) As used herein, the terms “approximately,” “substantially,” “substantial” and “about” are used to describe and account for small variations. When used in conjunction with an event or circumstance, the terms can refer to instances in which the event or circumstance occurs precisely as well as instances in which the event or circumstance occurs to a close approximation. For example, when used in conjunction with a numerical value, the terms can refer to a range of variation less than or equal to +10% of that numerical value, such as less than or equal to +5%, less than or equal to +4%, less than or equal to +3%, less than or equal to +2%, less than or equal to +1%, less than or equal to +0.5%, less than or equal to +0.1%, or less than or equal to +0.05%. For example, two numerical values can be deemed to be “substantially” the same or equal if a difference between the values is less than or equal to +10% of an average of the values, such as less than or equal to +5%, less than or equal to +4%, less than or equal to +3%, less than or equal to +2%, less than or equal to +1%, less than or equal to +0.5%, less than or equal to +0.1%, or less than or equal to +0.05%.

(107) Two surfaces can be deemed to be coplanar or substantially coplanar if a displacement between the two surfaces is no greater than 5  $\mu\text{m}$ , no greater than 2  $\mu\text{m}$ , no greater than 1  $\mu\text{m}$ , or no greater than 0.5  $\mu\text{m}$ .

(108) As used herein, the singular terms “a,” “an,” and “the” may include plural referents unless the context clearly dictates otherwise.

(109) As used herein, the terms “conductive,” “electrically conductive” and “electrical conductivity” refer to an ability to transport an electric current. Electrically conductive materials typically indicate those materials that exhibit little or no opposition to the flow of an electric current. One measure of electrical conductivity is Siemens per meter (S/m). Typically, an electrically conductive material is one having a conductivity greater than approximately 10<sup>sup.4</sup> S/m, such as at least 10<sup>sup.5</sup> S/m or at least 10<sup>sup.6</sup> S/m. The electrical conductivity of a material can sometimes vary with temperature. Unless otherwise specified, the electrical conductivity of a material is measured at room temperature.

(110) Additionally, amounts, ratios, and other numerical values are sometimes presented herein in a range format. It is to be understood that such range format is used for convenience and brevity and should be understood flexibly to include numerical values explicitly specified as limits of a range, but also to include all individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly specified.

(111) While the present disclosure has been described and illustrated with reference to specific arrangements thereof, these descriptions and illustrations are not limiting. It should be understood by those skilled in the art that various changes may be made and equivalents may be substituted

without departing from the true spirit and scope of the present disclosure as defined by the appended claims. The illustrations may not be necessarily drawn to scale. There may be distinctions between the artistic renditions in the present disclosure and the actual apparatus due to manufacturing processes and tolerances. There may be other arrangements of the present disclosure which are not specifically illustrated. The specification and drawings are to be regarded as illustrative rather than restrictive. Modifications may be made to adapt a particular situation, material, composition of matter, method, or process to the objective, spirit and scope of the present disclosure. All such modifications are intended to be within the scope of the claims appended hereto. While the methods disclosed herein have been described with reference to particular operations performed in a particular order, it will be understood that these operations may be combined, sub-divided, or re-ordered to form an equivalent method without departing from the teachings of the present disclosure. Accordingly, unless specifically indicated herein, the order and grouping of the operations are not limitations of the present disclosure.

## Claims

1. An optical module, comprising: a carrier; a lid disposed over the carrier, wherein the carrier and the lid are collaboratively define a first cavity for accommodating a photonic component; and a first electrical contact disposed over a first side of the lid and configured to provide an electronic connection for the optical module, wherein a first aperture penetrating the lid and corresponds to a light transmission/reception area of the photonic component, and wherein the lid is configured to provide a vertically electrical path to electrically connect the first electrical contact, wherein the lid has a first portion extending from an upper surface of the carrier and a second portion connected to the first portion and over the photonic component, wherein the first electrical contact is disposed over an upper surface of the second portion.
2. An optical module, comprising: an interconnection structure including a first aperture; a die disposed over the interconnection structure; a photonic component electrically connected to the die through the interconnection structure, and configured to generate a first light transmitted along a first propagation direction and to emit a second light transmitted along a second propagation direction toward the first aperture, wherein the first propagation direction is different from the second propagation direction; and an optical receiver disposed over the photonic component, wherein the photonic component comprises an optical phased array, and wherein the photonic component is configured to emit a first optical signal through the optical phased array and receive a second optical signal through the optical receiver.
3. The optical module of claim 1, wherein a transmission direction of the vertically electrical path is substantially parallel to a transmission direction of a light transmitted to or from the light transmission/reception area of the photonic component.
4. The optical module of claim 1, wherein the lid is configured to provide a plurality of electrical paths penetrating the lid.
5. The optical module of claim 1, wherein the photonic component is electrically connected to the first electrical contact through the carrier.
6. The optical module of claim 1, wherein the vertically electrical path penetrates the second portion of the lid.
7. The optical module of claim 1, wherein the first electrical contact is protruded from the upper surface of the second portion of the lid.
8. The optical module of claim 1, wherein the first electrical contact comprises a solder material.
9. The optical module of claim 1, further comprising: a die disposed under a lower surface of the second portion of the lid and electrically connected to the first electrical contact through the lid.
10. The optical module of claim 9, wherein the second portion of the lid defines a recessed portion accommodating the die.

11. The optical module of claim 2, wherein the first aperture is configured to allow the first optical signal and the second optical signal to pass through.
  12. The optical module of claim 2, wherein an active surface of the photonic component faces the first aperture.
  13. The optical module of claim 2, wherein the die is disposed between the interconnection structure and the photonic component, and the die is spaced apart from the photonic component by air.
  14. The optical module of claim 13, wherein the die is attached to the interconnection structure through a solder material.
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