(12) UK Patent Application (19) GB (11) 2512379 (13) A

(43) Date of A Publication 01.10.2014

(21) Application No: 1305732.8

(22) Date of Filing: 28.03.2013

(71) Applicant(s):
International Business Machines Corporation
New Orchard Road, Armonk 10504, New York,
United States of America

(72) Inventor(s):
Bert Jan Offrein
Ibrahim Murat Soganci

(74) Agent and/or Address for Service:
IBM United Kingdom Limited
Intellectual Property Law, Hursley Park,
WINCHESTER, Hampshire, SO21 2JN,
United Kingdom

(51) INT CL:
G02B 6/43 (2006.01) ***G02B 6/42*** (2006.01)

(56) Documents Cited:
US 20120251033 A1 **US 20070147842 A1**

(58) Field of Search:
INT CL **G02B**
Other: **WPI, EPODOC, TXTE, INSPEC, TDB, XPESP, XPESP2, XPIOP, XPIPCOM, XPRD, XPAIP, XPI3E, XPIEE, XPMISC**

(54) Title of the Invention: **Photonic and/or optoelectronic packaging assembly**
Abstract Title: **Optical interposer for photonic and/or optoelectronic assembly.**

(57) A photonic and/or optoelectronic packaging assembly P has a photonic and/or optoelectronic device C, such as a photonic and/or optoelectronic chip, an optical interposer OI coupled to the device C on a first side and an optical transmission element L, such as a lens or microlens, on a second side. A deflector M, such as a mirror, and a waveguide W are positioned on the first side, with the waveguide W coupled at one end to the photonic and/or optoelectronic device C and at another end to the deflector M. The deflector M enables optical transmission between the waveguide W and the optical transmission element L through the optical interposer OI. The optical interposer OI is formed from a material allowing optical transmission.

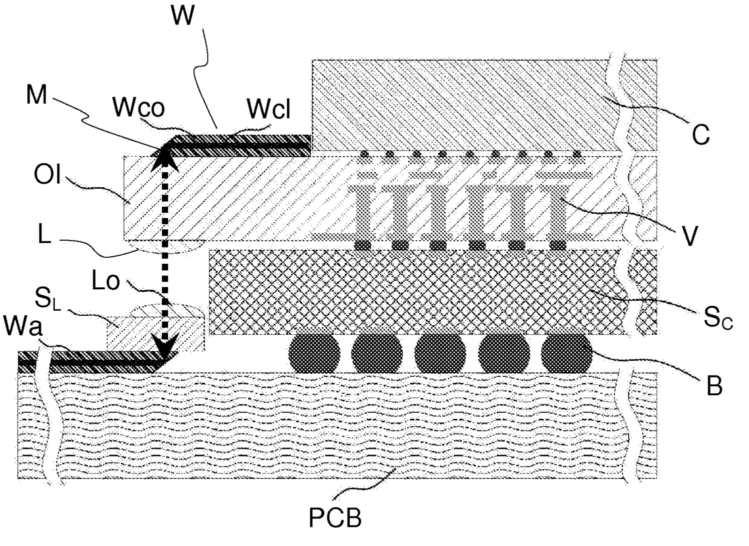

FIG. 4

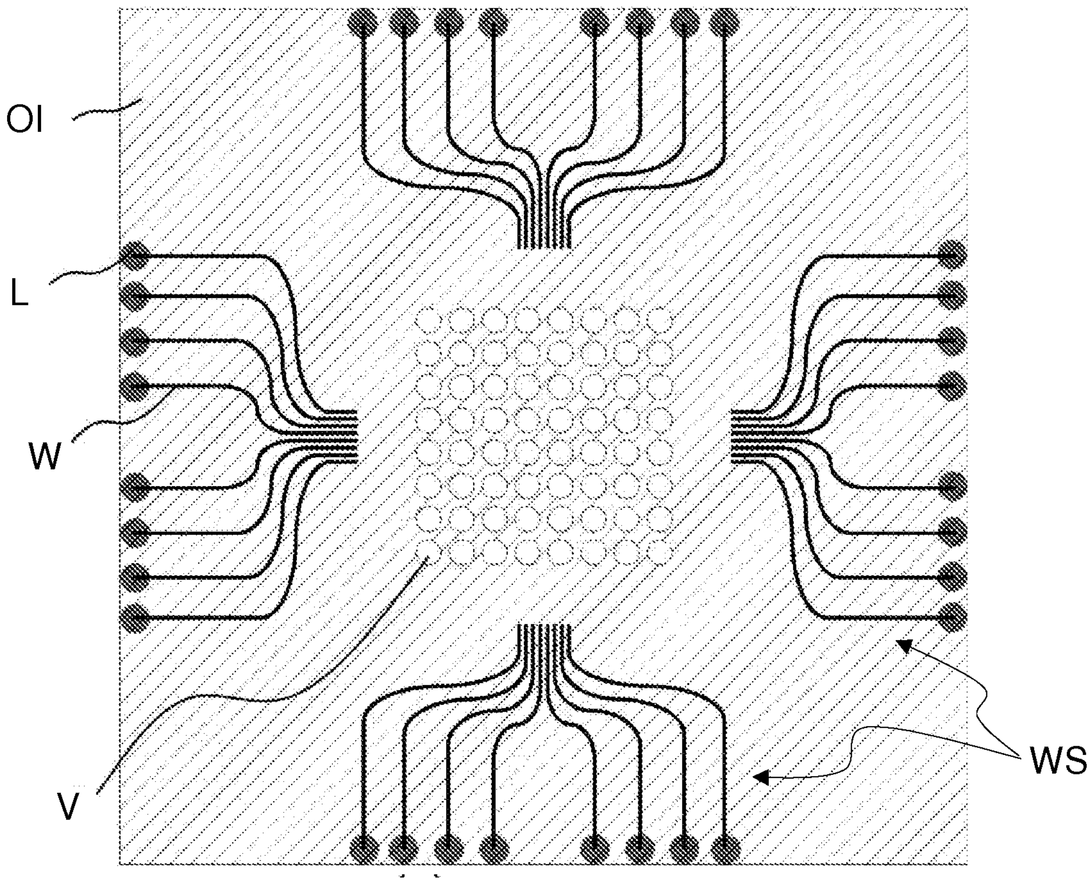

FIG. 2

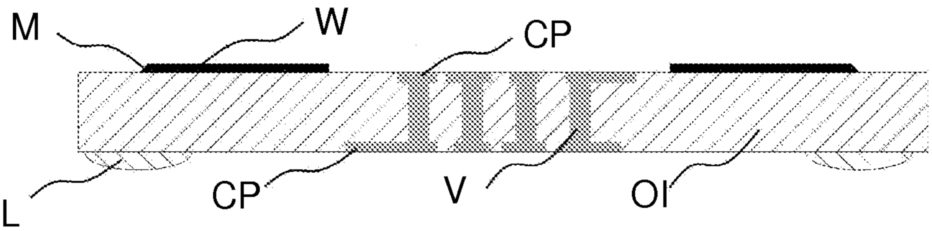

FIG. 3

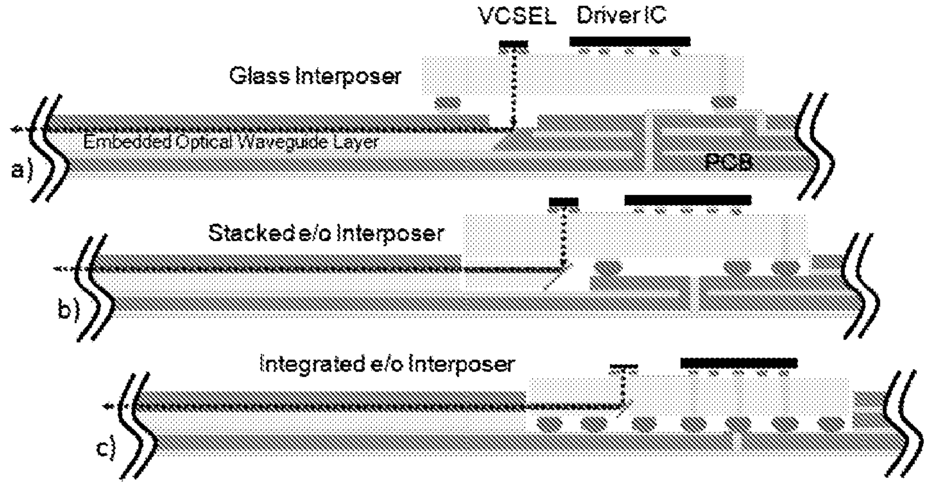

FIG. 1. (Prior Art)

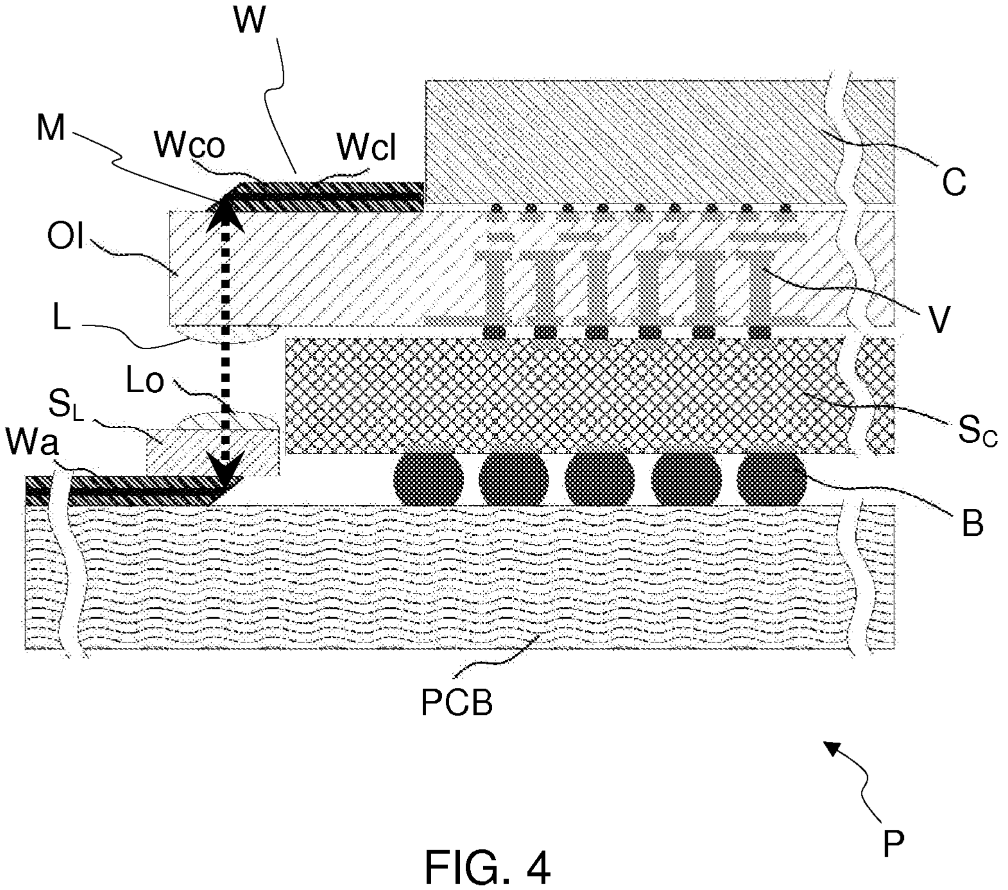

FIG. 4

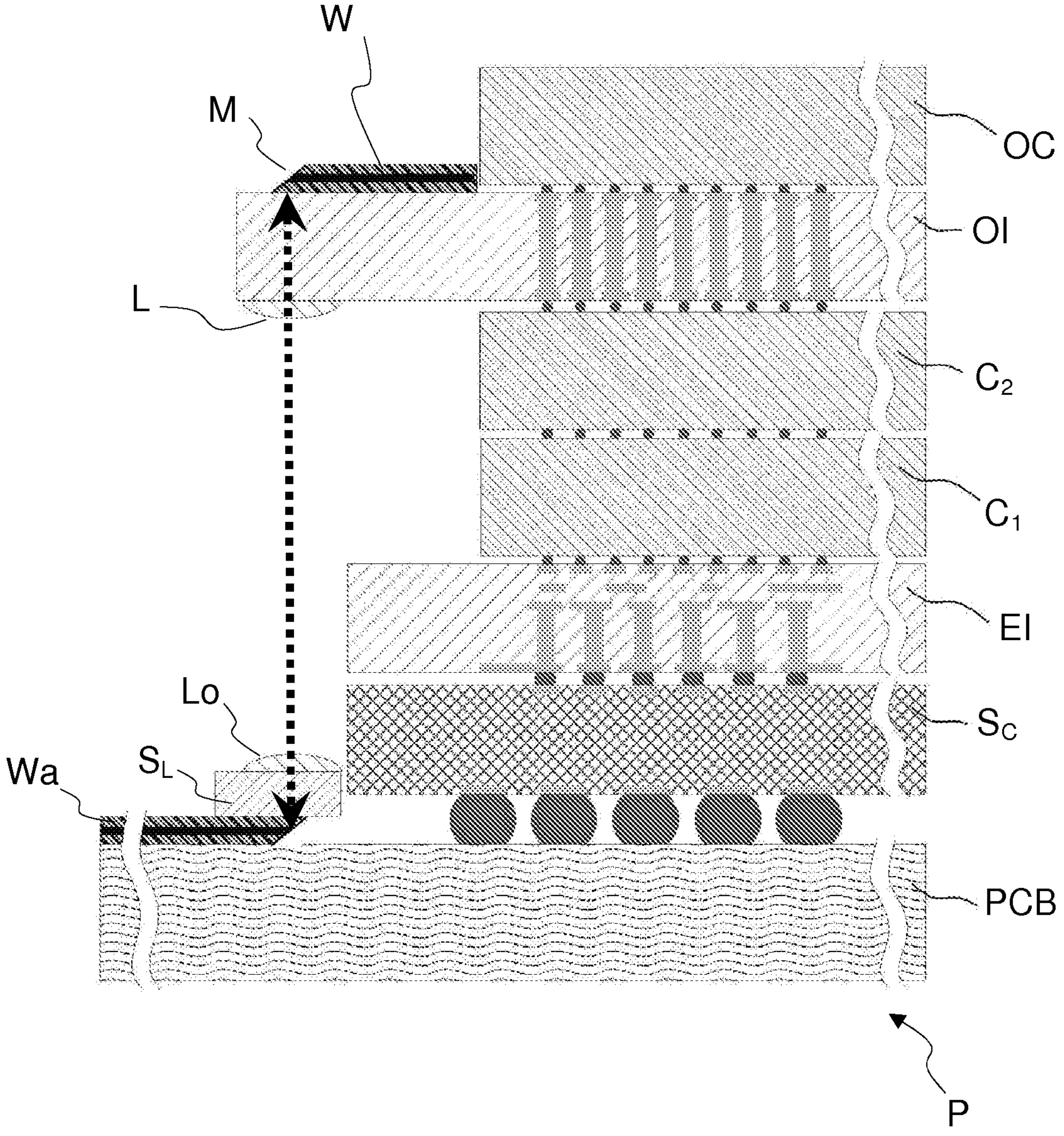

FIG. 5

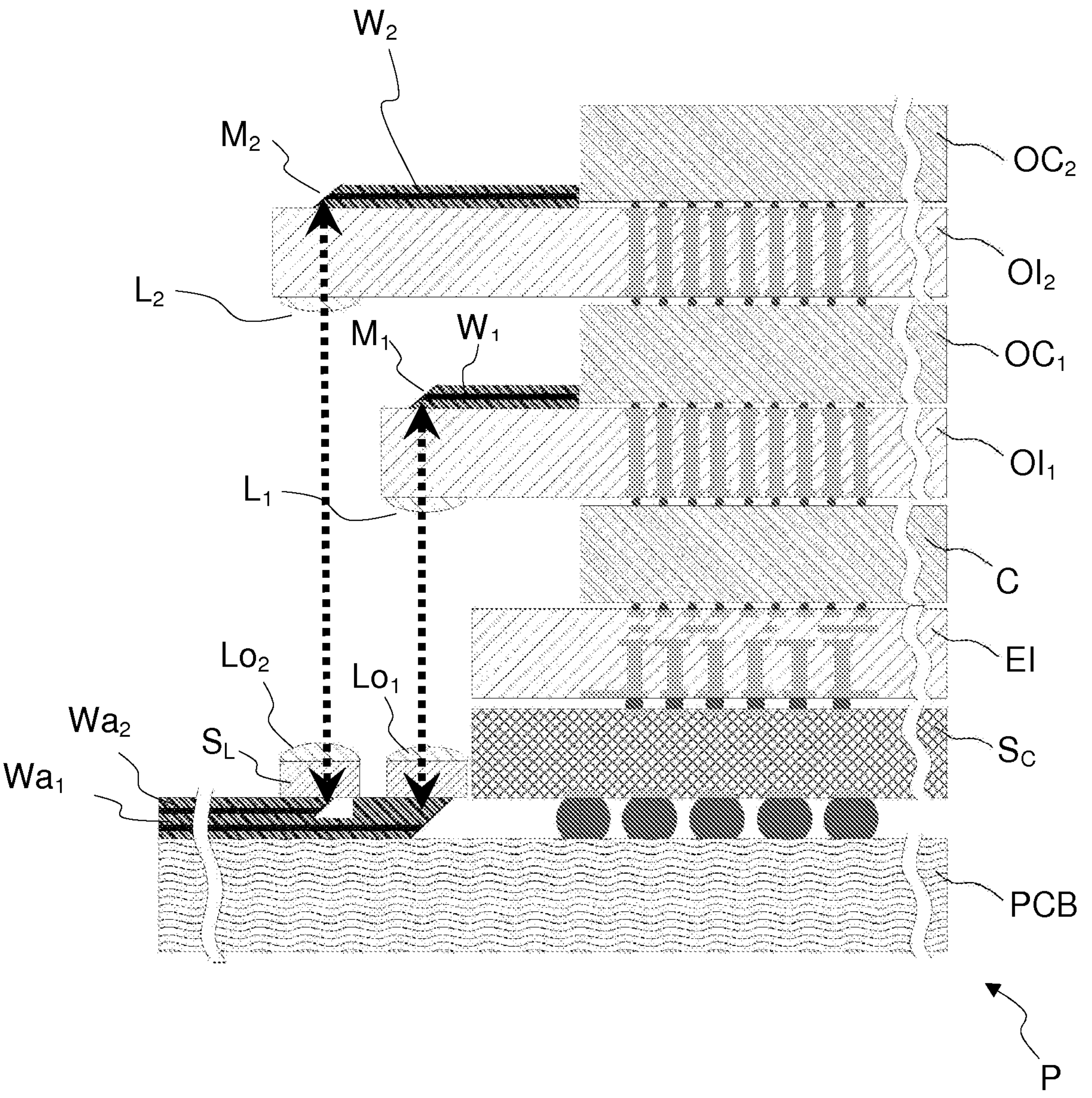

FIG. 6

PHOTONIC AND/OR OPTOELECTRONIC PACKAGING ASSEMBLY

FIELD OF THE INVENTION

The invention relates in general to the field of photonic and/or optoelectronic packaging assemblies. In particular, it is directed to a packaging assembly comprising an optical interposer, preferably an electro-optical interposer.

BACKGROUND OF THE INVENTION

The processing capacity of computing systems continues to increase considerably. The interconnection density of processing units has to increase at similar rates in order to maintain efficiency of such systems. Electrical interconnects, which are used for data transfer so far, are becoming a bottleneck. As an alternative, optical interconnects provide much denser data bandwidth, lower power consumption and no electromagnetic interference. Therefore, optical interconnects are being deployed at increasing portions of computing systems. Optical interconnects are expected to be employed in a large part of the data links reaching the processor package in a few years. Despite its clear advantages, optical interconnection brings new challenges to the assembly of computing systems. The common method of interfacing photonic transceivers to external components is based on connecting each on-chip waveguide, laser or photodetector to an optical fiber. Considering that a very large number of optical channels are expected to be required in the future, this process is condemned to remain very expensive, which can impede widespread employment of optical interconnects.

Present inventors have therefore designed and developed a novel concept of electro-optical packaging assembly, in order to reduce the aforementioned cost and complexity.

Useful indication may notably be found in the following background art:

1. US 7,366,375 B2, which discloses an optical waveguide device, on which optical lenses are bonded;
2. US 7,379,639 B2, which discloses an assembly that comprises optical waveguides with mirrors aligned to optical lenses;
3. P. Marcoux et al., "*Through silicon via (TSV) technology creates electro-optical interfaces,*" Proc. Optical Interconnects Conference, pp. 82-83, 2012, which discloses a silicon interposer that comprises through silicon vias and optical fiber channels;

4. L. Brusberg et al., "*Photonic system-in-package technologies using thin glass substrates,*" Proc. 11th, Electronics Packaging Technology Conference, pp. 930-935, 2009;
5. L. Brusberg et al., "*Chip-to-chip communication by optical routing inside a thin glass substrate,*" Proc. Electronic Components and Technology Conference, pp. 805-812, 2011; and
6. H. Schröder *et al., "glassPack — A 3D glass based interposer concept for SiP with integrated optical interconnects,"* Electronic Components and Technology Conference (ECTC), 2010 Proceedings 60th , vol., no., pp.1647,1652, 1-4 June 2010.

The last three references above relate to the so-called *glassPack*, a concept revolving around a glass interposer. They notably disclose a packaging of components that transmit and receive optical signals out of plane (e.g., vertical-cavity surface-emitting lasers (VCSEL) and photodetectors). These interposers disclosed comprise optical waveguides at the bottom side or embedded inside the interposer, which couple to components (VCSELS, photodetectors) that are located on the opposite surface of the interposer, via vertical beams.

FIG. 1 was extracted from ref. 6 above (Fig. 3 in ref. 6). In FIG. 1, three alternatives for transmitter module integration into electrical-optical circuit board (EOCB) are schematically shown. In FIG. 1a, a *glassPack* module is sketched without any internal optical beam deflecting element within the interposer. However, ion exchanged graded index lenses could be integrated for vertical beam collimation. The pads for the interposer TGV are redistributed in order to fit to the EOCB pitch. In the stacked concept version shown in FIG. 1b, the optical and electrical interconnects are separated in two different layers. The top layer is similar to FIG. 1a, but at the bottom side a glassy optical waveguide element is mounted. Both layers can be assembled using high precision wafer level technology. FIG. 1c shows the highest degree of integration. The optical waveguides and the beam deflection element are integrated into the interposer to provide horizontal optical interconnects and short vertical electrical TGV, to improve bandwidth and power performances.

BRIEF SUMMARY OF THE INVENTION

According to a first aspect, the present invention is embodied as a photonic and/or optoelectronic packaging assembly, comprising

a photonic and/or optoelectronic device, such as a photonic and/or optoelectronic chip;

an essentially planar optical interposer coupled to the photonic and/or optoelectronic device on a first side of the optical interposer and comprising an optical transmission element on a second side opposite to the first side;

a deflecting element such as a deflecting mirror; and

at least one optical waveguide on said first side, in-plane with the optical interposer,

wherein,

the waveguide is coupled at one end to the photonic and/or optoelectronic device and at another end to the deflecting element,

the deflecting element is configured to enable optical transmission between the waveguide and the optical transmission element, through the optical interposer; and

the optical interposer comprises, between the deflecting element and the optical transmission element, a material allowing for optical transmission.

In embodiments, the packaging assembly further comprises one or more further planar components on the second side of the optical interposer, and at least one of said additional planar components comprises a further optical transmission element vis-à-vis the optical transmission element of the optical interposer, whereby optical signal can be transmitted from the optical transmission element of the optical interposer to the further optical transmission element.

In preferred embodiments, the packaging assembly comprises a set of optical interposers, wherein each optical interposer of the set:

is an essentially planar component

is essentially parallel to the other optical interposers of the set;

is coupled, on a first side, to both

a respective photonic and/or optoelectronic device; and

at least one respective optical waveguide, the latter comprising a respective deflecting element and being:

in-plane with said each optical interposer and preferably bonded thereto; and

coupled to the respective photonic and/or optoelectronic device at an end and to the respective deflecting element at another end,

comprises a respective optical transmission element on a second side opposite to the first side, the respective deflecting element adapted to transmit optical signal from the respective waveguide to the respective optical transmission element and conversely, from the respective optical transmission element to the respective waveguide.

Preferably, in-plane positions of two optical transmission elements of two respective optical interposers of the set differ, whereby the two optical transmission elements are adapted to transmit two optical signals out-of-plane, and preferably to transmit two optical signals parallel to each other.

Preferably too, at least one optical transmission element of the packaging assembly is a microlens adapted for focusing optical signal to and/or from a deflecting element or another optical transmission element in vis-à-vis.

In embodiments, at least one optical interposer of the packaging assembly is an electro-optical interposer, comprising through-interposer vias for transmitting electrical signals to and/or from a photonic and/or optoelectronic device to which said at least one electro-optical interposer is coupled.

Preferably, at least one optical interposer of the packaging assembly is an electro-optical interposer, comprising silicon and/or glass and further comprising through-silicon vias and/or through-glass electrical vias, the vias adapted for transmitting electrical signals to and/or from a photonic and/or optoelectronic device to which said at least one electro-optical interposer is coupled.

In preferred embodiments, at least one optical waveguide of the packaging assembly is bonded to an optical interposer and comprises one of the following materials: polymer, silicon nitride, silicon dioxide and silicon oxynitride.

Preferably, at least one deflecting element of the packaging assembly is a deflecting mirror as obtained by one of or a combination of the following methods: laser ablation, blade cutting, two-photon absorption, gray-scale lithography and imprint.

In preferred embodiments, the packaging assembly has a 2.5D or a 3D packaging assembly configuration.

Preferably, at least one optical interposer of the packaging assembly is bonded to the photonic and/or optoelectronic device it is coupled to, on one side thereof.

In preferred embodiments, an optical interposer of the packaging assembly comprises one or more sets of optical waveguides on a first side thereof, wherein each waveguide of the set is:

in-plane with the optical interposer; and

coupled at one end to a photonic and/or optoelectronic device to which the optical interposer is coupled and at another end to a respective deflecting element, the latter configured to enable optical transmission between its respective waveguide and an optical transmission element, through the optical interposer.

Preferably, at least one optical waveguide is integral with the optical interposer it is coupled to, the at least one optical waveguide preferably protruding from the first side of this optical interposer; and more preferably, one or more of the following is integral with an optical interposer it is coupled to:

an optical transmission element on a second side opposite to the first side of the optical interposer;

a deflecting element coupled to this waveguide; and

through-interposer vias.

In embodiments, at least one, preferably each optical transmission element of the packaging assembly is an optical microelement, preferably a microlens, as obtained using one or a combination of the following methods: photoresist reflow, gray-scale lithography and two-photon absorption.

According to another aspect, the invention is embodied as a method of fabrication of a photonic and/or optoelectronic packaging assembly, the method comprising:

fabricating a photonic and/or optoelectronic packaging assembly according to any one of the above embodiments,

wherein fabricating preferably comprises one or more of the following steps:

fabricating at least one deflecting element as a deflecting mirror by one of or a combination of the following methods:

laser ablation,
blade cutting,
two-photon absorption,
gray-scale lithography and
imprint;

fabricating at least one optical transmission element as an optical microelement using one or a combination of the following methods:

photoresist reflow;
gray-scale lithography and
two-photon absorption.

Devices, components, packaging assemblies and methods embodying the present invention will now be described, by way of non-limiting examples, and in reference to the accompanying drawings.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

- FIG. 1 (prior art) shows a schematic drawing of three different concepts for the so-called "glassPack" electro-optical modules and appropriate PCB integration schemes, reproduced from reference 6 above;

- FIG. 2 is a top view of an electro-optical interposer, as involved in embodiments;

- FIG. 3 is a 2D cross-sectional view of an interposer such as depicted in FIG. 2;

- FIG. 4 schematically illustrates a cross section of a packaging assembly that comprises a photonic chip, an electro-optical interposer, an organic substrate and a printed circuit board (PCB) with optical waveguides, according to embodiments of this invention;

- FIG. 5 schematically illustrates a cross section of a packaging assembly that comprises a vertical stack of chips, including one with photonic functionality, vertically connected to an optical PCB, according to embodiments; and

- FIG. schematically illustrates a cross section of a packaging assembly comprising another vertical stack of chips, including two chips with photonic functionality, coupling to multilayer waveguides on an optical PCB, according to further embodiments

Technical features depicted in the drawings are not to scale.

DETAILED DESCRIPTION OF THE INVENTION

The following description is structured as follows. First, general embodiments and high-level variants are described (sect. 1). The next section addresses more specific embodiments and technical implementation details (sect. 2).

1. General embodiments and high-level variants

In reference to FIG. 2 to 6, an aspect of the invention is first described, which concerns photonic and/or optoelectronic integrated circuit devices. However, since "integrated circuit" usually refers to monolithic integrations, the terminology "packaging assembly" is preferred, hereafter mostly referred to as "packaging", for short.

First, this packaging P comprises a photonic and/or an optoelectronic device OC (also denoted by reference OC_n, $n = 1, 2, ...$ in FIG. 6 and related embodiments), such as a photonic and/or optoelectronic chip. Such a device shall hereafter be referred to as "OC device" or "OC chip" for simplicity. Such devices are known *per se*.

Second, the packaging P further makes use of an optical interposer OI, OI_n, which structurally speaking is essentially planar. An example of such an optical interposer is shown in FIG. 2 and 3. The interposer can be coupled to the OC device on a first side thereof, i.e., the upper side in FIGS. 3 – 6 or the top side in FIG. 2. This optical interposer comprises an optical transmission element, such as a microlens L, L_n on a second side opposite to the first side, i.e., the lower side of the interposer in FIGS. 3 – 6.

Third, the packaging P further includes at least one optical waveguide W, W_n extending on said first side, i.e., in-plane with the optical interposer OI. The waveguide W, W_n is coupled at one end to the OC device and at another end to a deflecting element M, M_n. The deflecting element M, M_n can be a reflection element (e.g., mirror), a diffractive element (e.g., grating coupler), or more generally any element, including a prism, a lens or even a curved waveguide, which allows for light to propagate from the waveguide W, W_n towards the transmission element L, or conversely, from L to W, i.e., any element allowing for "deflecting" optical signal. Yet, a simple mirror is preferred for ease of manufacture and cost reasons. In all cases, the deflecting element M, M_n is configured and/or arranged such as to enable optical transmission between the waveguide W, W_n and the optical transmission element L, L_n, and this, through the optical interposer OI, OI_n. More precisely, the deflecting element M, M_n may allow for optical signal transmission from the waveguide W, W_n to the optical transmission element and/or conversely, from the optical transmission element to the waveguide W, W_n.

How to confer unidirectional or bi-directional light propagation properties to such an optical transmission element is known in the art. All waveguides evoked herein may be standard optical waveguides, typically comprising a core Wco and a cladding Wcl as explicitly referred to in FIG. 4 and as otherwise usual *per se* in the art, unless otherwise stated.

The optical waveguide(s) W, W_n are used for routing and together with the integrated deflecting element and the optical transmission element allows for controlling the beam characteristics.

In all cases, optical transmission intervenes directly through the bulk of the optical interposer, without requiring any other optical propagation device, whence the name *optical* interposer. This means that the interposer must comprise a material that allows for optical transmission, at least in the region between the deflecting element M, M_n and the optical transmission element L, for wavelengths of interest in the field. Examples are given below.

Thus, the present solution relies first and foremost on an electro-optical interposer, which facilitates both optical and electrical connectivity to photonic and/or optoelectronic device(s). A main difference between the present invention and known solutions, see e.g., FIG. 1, is that the present invention enables both in-plane and out-of-plane optical coupling between one or more waveguides and an OC device (both on the interposer), and the possibility of both in-plane and out-of-plane coupling between the interposer and external components, with controllable beam characteristics e.g., direction, numerical aperture, diameter. Especially the possibility of both in-plane and out-of-plane coupling between waveguides and OC devices is important as this opens new possibilities for coupling. The most well-known out-of-plane coupling methods for photonic chips (except vertically-emitting lasers and vertically receiving photodetectors) make use of diffraction gratings in the photonic chip. Despite the research efforts on grating couplers, the loss of these couplers is still in the order of a few dB. Moreover, they are wavelength-sensitive devices by nature because of diffractive operation. Solutions that rely on out-of-plane coupling, such as the one in FIG. 1, are limited by the disadvantages of grating couplers. On the contrary, the present solution is compatible with other coupling methods, such as lensed in-plane coupling, adiabatic coupling, and directional coupling in addition to the grating-based coupling. The in-plane coupling methods mentioned above have lower coupling loss and wavelength dependence than grating-based coupling. In particular, present inventors have recently arrived at the conclusion that less than 1 dB coupling loss can be achieved using adiabatic coupling, in which silicon waveguide and polymer waveguide are in contact. To their knowledge, such a result can only be achieved thanks to present embodiments, i.e., with polymer waveguides on the top side of the interposer. Such low losses can for instance not be achieved with grating couplers.

In particular, in the so-called *glassPack*-related prior art, an optoelectronic device is mounted on a transparent interposer; a mirror and a waveguide are available on the other side of the interposer. Thus, light has to go through the transparent interposer and the mirror to couple between the optoelectronic device and the waveguide. On the contrary, in the present solution, the waveguide is on the same side of the interposer as the photonic/optoelectronic device/chip/component, such that direct coupling between the photonic/optoelectronic chip/component and the waveguide is possible. Direct coupling leads to lower optical loss than the prior art solution because each additional element (e.g. gratings on the OC chip and mirrors at the end of the polymer waveguides) introduces loss to the optical link.

The proposed combination of optical waveguides, integrated deflecting elements and optical transmission elements offers an unprecedented versatility of optical connectivity configurations, which makes it possible to use the proposed photonic/optoelectronic packaging for applications including, but not limited to, interconnection between a photonic chip and an optical printed circuit board, and optical interconnection to chips in 2.5 or 3D stacks. Moreover, all of the aforementioned components, i.e., optical waveguides, transmission elements (lenses), deflection elements (mirrors), and if necessary electrical vias (for added electrical connections to the OC device) can be fabricated integrally with the optical interposer OI, which offers potential for low cost fabrication. Owing to this versatility and compatibility with integration, the proposed solution has the potential to be an important building block of advanced packaging in the near future.

Typical embodiments of the invention shall involve several optical waveguides W, terminated at one end by a deflecting element M, as depicted in FIGS. 2 – 3, and even several sets WS of optical waveguides W, wherein each waveguide W of a set WS is:

- in-plane with the optical interposer OI; and
- coupled to both:
    - an OC device (preferably the same OC device), to which the optical interposer is otherwise coupled too); and
    - a respective deflecting element M, the latter configured to enable optical transmission through the optical interposer OI, as illustrated in the appended drawings by (dotted) double arrows.

The interposer is most preferably bonded to the OC device, on said first side. Yet, in variants, additional planar components may need to be inserted in between, for various reasons (contact, insulation, fabrication constraints, etc.).

The optical transmission element here is typically a lens or a microlens, or more generally any device capable of directing a light beam to/from the deflecting element M, M_n. More generally, any optical transmission element L, L_n, Lo evoked herein may be a microlens, that is, an optical element adapted for focusing optical signal to and/or from a deflecting element M, M_n or even another optical transmission element L, L_n, Lo located in vis-à-vis.

A packaging assembly according to the invention may further comprise a number of additional features, as described in embodiments below and as otherwise depicted in the accompanying drawings, such as

- a standard chip C, C_n, i.e., not a photonic and/or optoelectronic chip;
- an additional electrical interposer EI (not being an optical/electro-optical interposer as defined above);
- additional opposite lenses Lo;
- Lens substrates S_L, chip substrates S_C;
- Additional waveguides Wa;
- Through vias e.g., through-interposer vias V for electrical interconnection to an OC device/chip or another device/chip/component;
- Contact Pads CP and additional contacts;
- Optical printed circuit board PCB;
- Solder bumps B;
- Etc.

In particular, and referring now to FIGS. 4 to 6, the packaging P may further comprise one or more additional planar components S_L, S_C, C, PCB, EI, etc., on the lower side of the optical interposer OI. One of these additional components, e.g., a substrate S_L in the drawings, may comprise an additional optical transmission element Lo, such as a lens, or microlens Lo. This additional optical transmission element Lo is located vis-à-vis the optical transmission element L, L_n of the optical interposer OI, OI_n. Accordingly, optical signal may be transmitted from the optical transmission element L, L_n of the optical interposer OI to this additional optical transmission element Lo, and preferably from the further optical transmission element Lo to the optical transmission element L of the interposer OI as well. Several additional optical transmission elements Lo may in fact be involved, as to be discussed next in reference to FIG. 6.

Referring now to FIG. 6: the packaging P may, in embodiments, comprise a set of optical interposers OI_1, OI_2, … . Each optical interposer OI_n is in that case similar to the interposer described earlier, in that:

- It is an essentially planar component;
- It is coupled, on a first side, to both:
  - one (at least) respective photonic and/or optoelectronic device OC_1, OC_2, …; and

  - at least one (but likely several) respective optical waveguide W_1, W_2, ..., which comprises a respective deflecting element M_1, M_2, ... and is furthermore:
    - in-plane with the optical interposer OC_1, OC_2, ... it is coupled to (be it directly or not, e.g., preferably it is bonded to the interposer); and
    - coupled to:
      - a respective photonic and/or optoelectronic device OC_1, OC_2, ... at an end; and
      - to a respective deflecting element M_1, M_2, ... at another end;
- For completeness, each optical interposer OI_n further comprises a respective optical transmission element L_1, L_2, ... on a second (lower) side, opposite to the first side. Again, deflecting element M_1, M_2, ... are arranged and/or configured to enable optical coupling between a respective waveguide to a respective optical transmission element L_1, L_2, ...

Preferably, optical interposer OI_n are essentially parallel to each other, be it for reasons of manufacture.

In addition, and as illustrated in FIG. 5 or 6, an additional electrical interposer EI may be provided, for coupling to a chip C. The additional electrical interposer EI is not an optical interposer as defined earlier, e.g., it has no waveguide on it.

As further illustrated in FIG. 6, the in-plane positions of the two optical transmission elements L_1, L_2 (i.e., of two respective optical interposers OI_1, OI_2) preferably differ, i.e., the projections of said positions in a reference plane parallel to the average plane of the interposers OI_1, OI_2 differs. Thus, the two optical transmission elements L_1, L_2 are in that case adapted to transmit two optical signals out-of-plane, preferably parallel to each other, for instance to another level of waveguides Wa_1, Wa_2, which shall route optical signals to other components in the system, etc.

As best seen in FIG. 2 or 3, an optical interposer OI, OI_n as involved in embodiments is preferably an electro-optical interposer, that is, it comprises through-interposer vias V for transmitting electrical signals to and/or from a photonic and/or optoelectronic device to which it is coupled. It may further comprise upper and lower contact pads CP to that aim, as known *per se* in the art. For example, suitable electro-optical interposers OI, OI_n may comprise silicon and/or glass, and are therefore provided with through-silicon vias V and/or through-glass electrical vias V. For instance, suitable glass materials could be selected based on CTE matching to silicon dies they provide, their alkaline content, etc.

Borosilicate glass is advantageous as its CTE matches that of silicon. However, other types of glasses can also be used to fabricate interposers. The interposers usually comprise electrically conducting and insulating materials. Suitable conducting materials are Al, Cu, Sn, Ni, Au, and Ag. Suitable insulating materials are silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon oxynitride (SiON), polymers, tantalum pentoxide (Ta_2O_5), zircon (ZrO_2), and aluminum oxide (Al_2O_3). Various thicknesses, typically ranging from 20 μm to 250 μm, can be contemplated for the interposer. Preferably, the thickness is around 100 -200 μm. The width and length can vary because these interposers are fabricated on large wafers or panels and then singulated. Interposers of different sizes (e.g. 5 mm x 5mm, 20 mm x 20 mm) are available.

As touched earlier, optical interposers OI are preferably bonded to a respective OC device, on one side thereof. Similarly, optical waveguides W are preferably bonded directly to an optical interposer OI. Optical waveguides, as well as deflecting and transmission elements, are preferably fabricated integrally. Structurally, optical waveguides slightly protrude from a side of a corresponding optical interposer. Suitable optical waveguides may for instance comprise polymer, silicon nitride, silicon dioxide and/or silicon oxynitride. Deflecting elements may simply be provided as deflecting mirrors, e.g., as obtained by laser ablation, blade cutting, two-photon absorption, gray-scale lithography or imprint. Finally, transmission elements such microlenses may advantageously be fabricated integral with an interposer as well, using photoresist reflow, gray-scale lithography and/or two-photon absorption methods.

Photoresist reflow is nonetheless preferred because it is compatible with standard processing methods and easier to implement compared to gray-scale lithography and two-photon absorption. Polymer waveguides can be fabricated on the interposer using one of the thin-film deposition methods (e.g. spin coating, spray coating, doctor blading, and ink jet printing), followed by thermal and/or UV-exposure-based polymerization. Waveguides made of other materials (e.g. silicon nitride and silicon dioxide) are fabricated by using one of the deposition methods (e.g. chemical vapor deposition (CVD), sputtering or evaporation), and etching. Typical lens materials are silicon, silicon dioxide, silicon nitride, silicon oxynitride, glass, and polymer. The dimensions of the lenses vary depending on the applications. The lenses used for waveguide coupling usually have diameters of tens of micrometers up to a few hundred micrometers.

Next, according to another aspect, the invention can be embodied as a method of fabrication of a packaging P such as discussed above. A convenient process flow is the following: electrical parts of the interposer (e.g. vias, bond pads, insulators) are fabricated. After that, optical waveguides and transmission elements are processed on the interposer. The chip is bonded on the interposer to form electrical and optical coupling between the interposer and the chip. Thereafter, the interposer is bonded with the chip in a configuration that depends on the chosen architecture.

As said earlier, a significant advantage of present devices is that they can be obtained using conventional methods, such as mentioned above. In particular, waveguides, mirrors and lenses can be fabricated with inexpensive equipment. Present embodiments therefore make it possible to achieve low-cost photonic/optoelectronic chip packaging. The electro-optical interposers can be fabricated at low cost using known methods too, for instance wet or dry etching to make the through-silicon or through-glass vias. The insulators can be formed using thermal oxidation or chemical vapor deposition (CVD). The conducting materials can be deposited using, for example, electroplating. Electrical (only) interposers are known *per se* and can be fabricated using known methods.

The above embodiments have been succinctly described in reference to the accompanying drawings and may accommodate a number of variants. Several combinations of the above features may be contemplated. Examples are given in the next section.

2. Specific embodiments/Technical implementation details

The method/components as described above may be used in the fabrication of integrated circuit devices/packagings. The resulting integrated circuit chips can be distributed by the fabricator in raw wafer form (that is, as a single wafer that has multiple unpackaged chips), as a bare die, or in a packaged form. In the latter case the chip is typically mounted in a single chip package (such as a plastic carrier, with leads that are affixed to a motherboard or other higher level carrier) or in a multichip package (such as a ceramic carrier that has either or both surface interconnections or buried interconnections). In any case the chip can then be integrated with other chips, discrete circuit elements, and/or other signal processing devices as part of either (a) an intermediate product, such as a motherboard, or (b) an end product. The end product can be any product that includes integrated circuit chips, ranging from toys and other low-end applications to advanced computer products having a display, a keyboard or other input device, and a central processor.

In practical embodiments, the electro-optical interposers involved shall typically comprise multiple optical waveguides, mirrors and lenses in addition to electrical vias, as shown schematically in FIGS. 2 and 3. The waveguides W on the interposer OI are optically coupled to the waveguides W, lasers or photodetectors in the chip OC mounted on the interposer OI.

These waveguides route the signal to other parts of the interposer. As depicted in FIGS. 3 - 6, an out-of-plane mirror M rotates the optical axis by 90° and couples the light beam to a lens L on the other side of the interposer OI. The lens can operate for collimation, focusing and beam size conversion.

In variants, the out-of-plane mirror M can have a curvature to focus or collimate the light. In that case, no lens is required on the other side of the interposer. Rather, this is the lower interface of the interposer that would play the role of the optical transmission element in that case (appropriate optical interface condition is needed in that case, to prevent spurious effects).

The through-interposer vias V at the center carry electrical signals. There are multiple alternatives for implementing the electro-optical interposer. Silicon and glass are good candidates to be the substrate material, for several reasons. Electrical interposers have been fabricated from both materials making use of through-silicon vias and through-glass vias. Moreover, both materials are transparent to the light at the optical communication wavelengths of 1310 nm and 1550 nm, which means that optical beams can be routed through the interposer OI. Integrated lenses L can be fabricated in both material systems using known methods, such as etching after photoresist reflow. Integrated optical waveguides W can be made of dielectrics, such as polymers, silicon dioxide, silicon nitride, etc. There are several possible methods to fabricate the out-of-plane mirrors M at the edge of the waveguides M. Typical low-cost methods are blade cutting, laser ablation, and tilted exposure among others.

The devices described herein can be used in multiple configurations. In FIG. 4, the interposer is used as an interface to couple the optical signals between the photonic chip OC and the optical printed circuit board (PCB). The optical PCB comprises optical waveguides, which route the signals to other photonic elements. FIG. 5 shows another potential utilization of the present concept of packaging assembly. The electro-optical interposer OI can be used to facilitate optical connectivity between single or multiple photonic chips OC in a vertical stack and multi-layer waveguides in an optical PCB. This is a critical advantage as three-dimensional chip stacks are expected to reach widespread use in the near future. The configuration in FIG. 5 can offer very large data bandwidth owing to the multi-layer configuration and versatile connectivity. The configurations in FIGS. 4 – 5 are only two examples, a large number of packaging configurations are possible owing to the versatility of the present electro-optical interposer-based technology. This technology has a potential for application in photonic packaging because it markedly reduces complexity and costs of photonic chip packaging down to levels comparable to electronic chip packaging. Owing to the fact that fiber connections can be replaced by integrated optical waveguides both at the chip package and the PCB levels, the interconnect bandwidth of photonic chips can be increased without cost penalty.

While the present invention has been described with reference to a limited number of embodiments, variants and the accompanying drawings, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the present invention. In particular, a feature (device-like or method-like) recited in a given embodiment, variant or shown in a drawing may be combined with or replace another feature in another embodiment, variant or drawing, without departing from the scope of the present invention. Various combinations of the features described in respect of any of the above embodiments or variants may accordingly be contemplated, that remain within the scope of the appended claims. In addition, many minor modifications may be made to adapt a particular situation or material to the teachings of the present invention without departing from its scope. For instance, useful indications may be found in the background art documents listed in introduction. Therefore, it is intended that the present invention not be limited to the particular embodiments disclosed, but that the present invention will include all embodiments falling within the scope of the appended claims. In addition, many other variants than explicitly touched above can be contemplated. For example, only the waveguides could be fabricated integral with the interposers OI, and not the transmission elements or conversely, only the transmission elements L could be made integral with interposers OI.

REFERENCE LIST

Photonic and/or optoelectronic chip packaging	P
Photonic and/or optoelectronic chip	OC, OC_n
Chip	C, C_n
Chip/Interposer substrate	S_C
Optical (electro-optical) interposer	OI, OI_n
Electrical interposer	EI
Optical transmission element (microlens)	L, L_{nj}
Opposite lens	Lo
Lens substrate	S_L
Deflecting element (mirror)	M_{nj}
Waveguide	W, W_{nj}
Additional Waveguide(s)	Wa
Waveguide core	Wco
Waveguide cladding	Wcl
Waveguide set	WS
Through-interposer vias	V
Contact Pad	CP
Optical PCB	PCB
Solder bumps	B

CLAIMS

1. A photonic and/or optoelectronic packaging assembly (P), comprising

a photonic and/or optoelectronic device (OC, OC$_n$), such as a photonic and/or optoelectronic chip;

an essentially planar optical interposer (OI, OI$_n$) coupled to the photonic and/or optoelectronic device on a first side of the optical interposer and comprising an optical transmission element (L, L$_n$) on a second side opposite to the first side;

a deflecting element (M, M$_n$) such as a deflecting mirror; and

at least one optical waveguide (W, W$_n$) on said first side, in-plane with the optical interposer,

wherein,

the waveguide (W, W$_n$) is coupled at one end to the photonic and/or optoelectronic device (OC, OC$_n$) and at another end to the deflecting element (M, M$_n$);

the deflecting element (M, M$_n$) is configured to enable optical transmission between the waveguide (W, W$_n$) and the optical transmission element (L, L$_n$), through the optical interposer (OI, OI$_n$); and

the optical interposer comprises, between the deflecting element (M, M$_n$) and the optical transmission element (L, L$_n$), a material allowing for optical transmission.

2. The photonic and/or optoelectronic packaging assembly (P) of claim 1, further comprising one or more further planar components (S_L, S_C, C, PCB, EI) on the second side of the optical interposer, wherein at least one of said additional planar components comprises a further optical transmission element (Lo) vis-à-vis the optical transmission element (L, L$_n$) of the optical interposer (OI, OI$_n$), whereby optical signal can be transmitted from the optical transmission element (L, L$_n$) of the optical interposer to the further optical transmission element (Lo).

3. The photonic and/or optoelectronic packaging assembly (P) of claim 1 or 2, wherein the packaging assembly (P) comprises a set of optical interposers (OI1, OI2), wherein each optical interposer of the set:

is an essentially planar component

is essentially parallel to the other optical interposers (OI1, OI2) of the set;

is coupled, on a first side, to both

a respective photonic and/or optoelectronic device (OC1, OC2); and

at least one respective optical waveguide (W1, W2), the latter comprising a respective deflecting element (M1, M2) and being:

in-plane with said each optical interposer (OC1, OC2) and preferably bonded thereto; and

coupled to the respective photonic and/or optoelectronic device (OC1, OC2) at an end and to the respective deflecting element (M1, M2) at another end,

comprises a respective optical transmission element (L1, L2) on a second side opposite to the first side, the respective deflecting element (M, M_n) adapted to transmit optical signal from the respective waveguide (W, W_n) to the respective optical transmission element (L1, L2) and conversely, from the respective optical transmission element (L1, L2) to the respective waveguide (W, W_n).

4. The photonic and/or optoelectronic packaging assembly of claim 3, wherein in-plane positions of two optical transmission elements (L1, L2) of two respective optical interposers (OI1, OI2) of the set differ, whereby the two optical transmission elements (L1, L2) are adapted to transmit two optical signals out-of-plane, and preferably to transmit two optical signals parallel to each other.

5. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 4, wherein at least one optical transmission element (L, L_n, Lo) is a microlens adapted for focusing optical signal to and/or from a deflecting element (M, M_n) or another optical transmission element (L, L_n, Lo) in vis-à-vis.

6. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 5, wherein at least one optical interposer is an electro-optical interposer (OI, OI_n), comprising through-interposer vias (V) for transmitting electrical signals to and/or from a photonic and/or optoelectronic device to which said at least one electro-optical interposer is coupled.

7. The photonic and/or optoelectronic packaging assembly of claim 6, wherein at least one optical interposer is an electro-optical interposer (OI, OI_n), comprising silicon and/or glass and further comprising through-silicon vias (V) and/or through-glass electrical vias (V), the vias adapted for transmitting electrical signals to and/or from a photonic and/or optoelectronic device to which said at least one electro-optical interposer is coupled.

8. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 7, wherein at least one optical waveguide (W, W_n) is bonded to an optical interposer and comprises one of the following materials: polymer, silicon nitride, silicon dioxide and silicon oxynitride.

9. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 8, wherein at least one deflecting element is a deflecting mirror (M) as obtained by one of or a combination of the following methods: laser ablation, blade cutting, two-photon absorption, gray-scale lithography and imprint.

10. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 9, wherein the packaging assembly has a 2.5D or a 3D packaging assembly configuration.

11. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 10, wherein at least one optical interposer is bonded to the photonic and/or optoelectronic device it is coupled to, on one side thereof.

12. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 11, wherein an optical interposer (OI) comprises one or more sets (WS) of optical waveguides (W) on a first side thereof, wherein each waveguide of the set is:

in-plane with the optical interposer; and

coupled at one end to a photonic and/or optoelectronic device to which the optical interposer is coupled and at another end to a respective deflecting element (M), the latter configured to enable optical transmission between its respective waveguide (W) and an optical transmission element (L), through the optical interposer (OI).

13. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 11, wherein:

at least one optical waveguide (W, W_n) is integral with the optical interposer it is coupled to, the at least one optical waveguide (W, W_n) preferably protruding from the first side of this optical interposer; and

more preferably, one or more of the following is integral with an optical interposer it is coupled to:

an optical transmission element (L, L_n) on a second side opposite to the first side of the optical interposer;

a deflecting element (M, M_n) coupled to this waveguide (W, W_n); and

through-interposer vias.

14. The photonic and/or optoelectronic packaging assembly of any one of claims 1 to 13, wherein at least one, preferably each optical transmission element (L, L_n) is an optical microelement, preferably a microlens, as obtained using one or a combination of the following methods: photoresist reflow, gray-scale lithography and two-photon absorption.

15. A method of fabrication of a photonic and/or optoelectronic packaging assembly, the method comprising:

fabricating a photonic and/or optoelectronic packaging assembly according to any one of claims 1 to 14,

wherein fabricating preferably comprises one or more of the following steps, in any order:

fabricating at least one deflecting element (M, M_n) as a deflecting mirror by one of or a combination of the following methods:

laser ablation;
blade cutting;
two-photon absorption;
gray-scale lithography; and
imprint,

fabricating at least one optical transmission element (L, L_n) as an optical microelement using one or a combination of the following methods:

photoresist reflow;
gray-scale lithography; and
two-photon absorption.

Application No:	GB1305732.8	**Examiner:**	Mr Joseph Mitchell
Claims searched:	1-15	**Date of search:**	5 September 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 5 & 8-15	US 2012/251033 A1 (MATSUOKA et al) See figure 2 & paragraphs 0046-0049 in particular.
X	1, 2, 5, 8, 9, 10 & 13-15	US 2007/147842 A1 (HANEY et al) See figure 1A & associated text in particular.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G02B

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, TXTE, INSPEC, TDB, XPESP, XPESP2, XPIOP, XPIPCOM, XPRD, XPAIP, XPI3E, XPIEE, XPMISC

International Classification:

Subclass	Subgroup	Valid From
G02B	0006/43	01/01/2006
G02B	0006/42	01/01/2006