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(54) **PHOTONICS INTEGRATED CIRCUIT PACKAGE**

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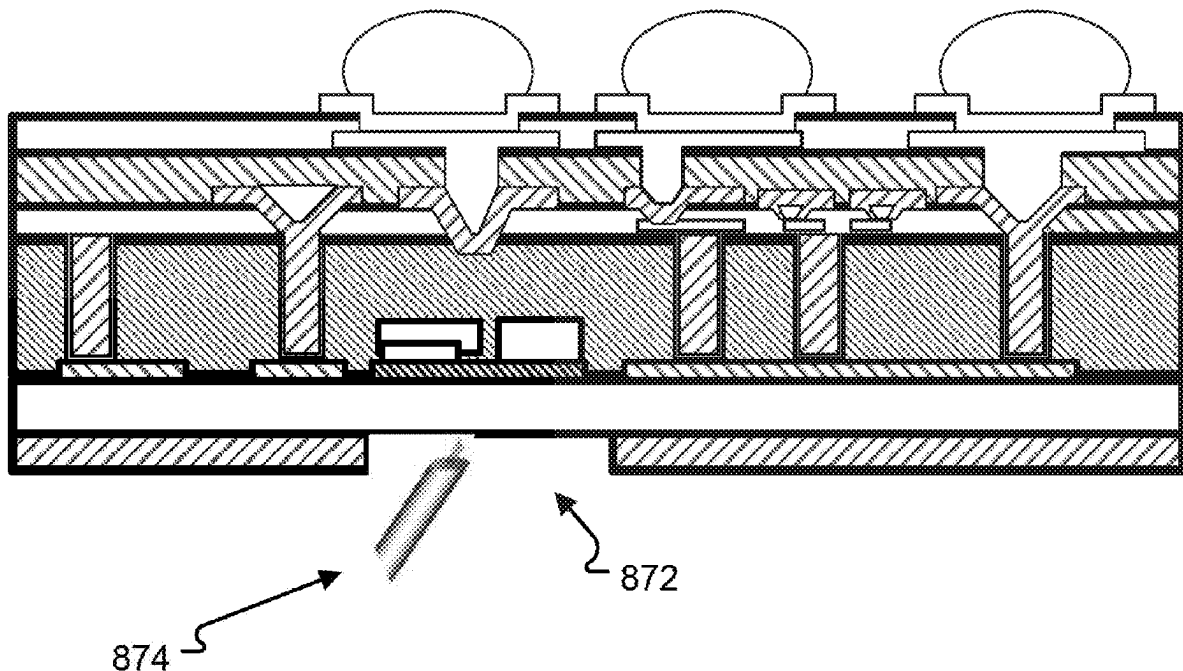
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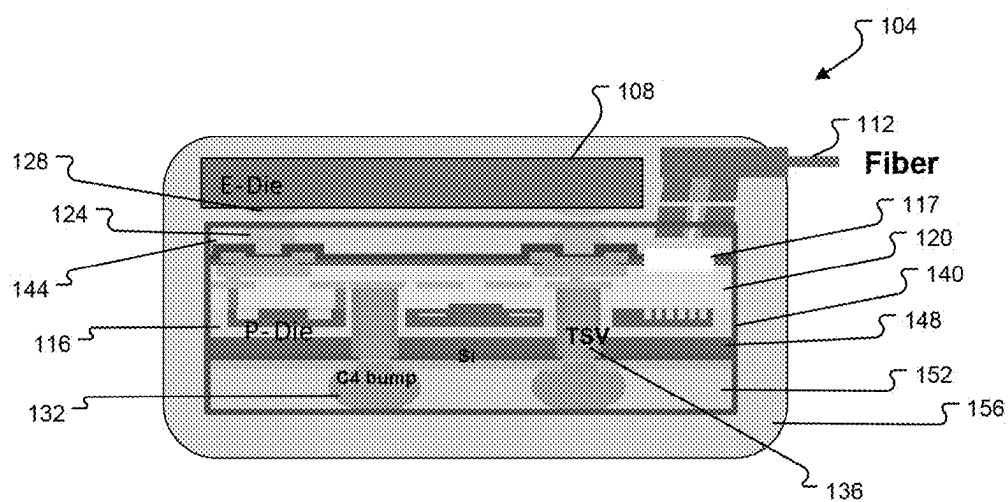
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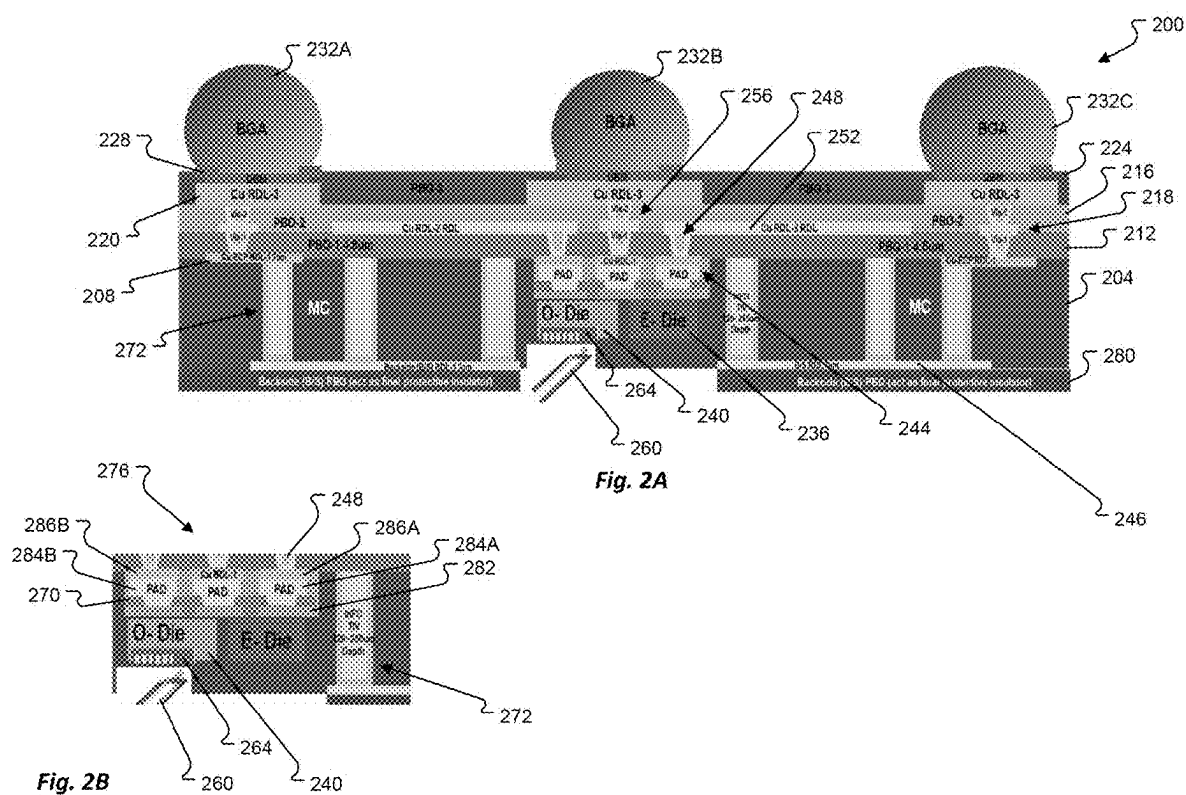
(57) **ABSTRACT**

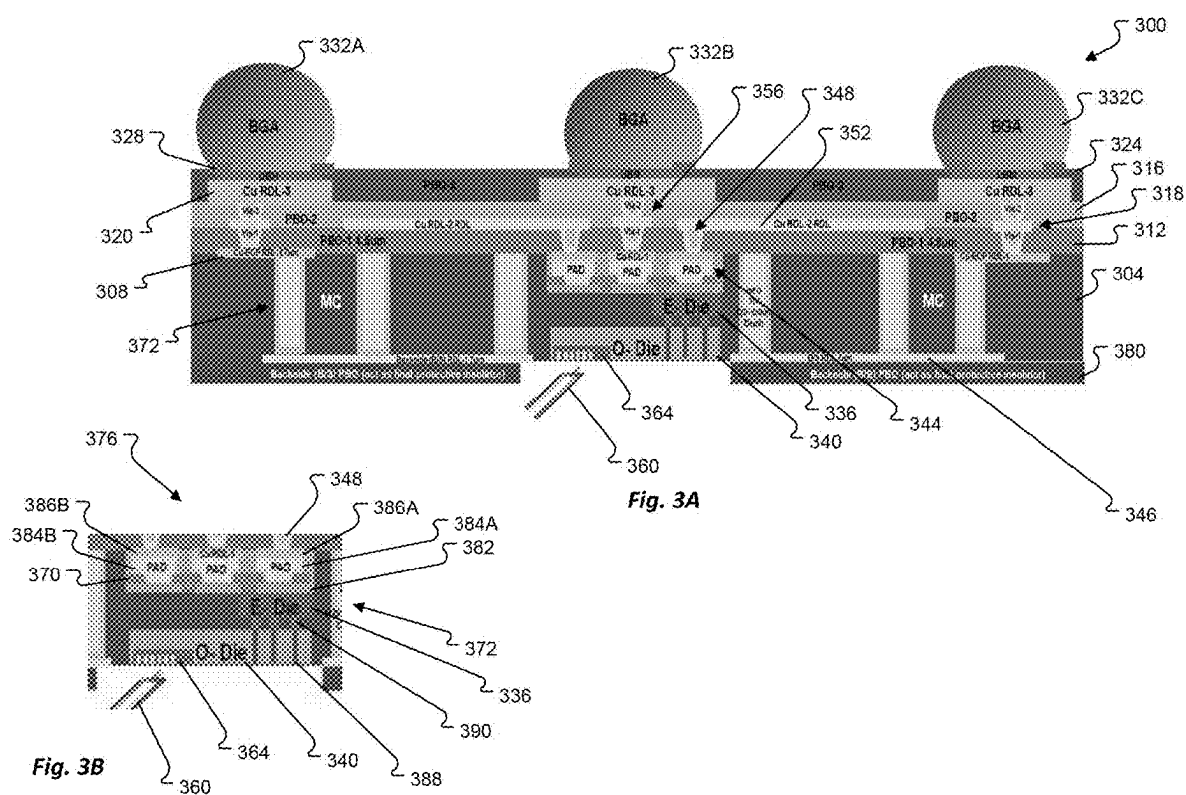
An integrated circuit package integrates a photonic die (oDie) and an electronic die (eDie). More specifically, the integrated circuit package may include a plurality of redistribution layers communicatively coupled to at least one of the oDie and/or the eDie, where molded material at least partially surrounds the at least one of the oDie and/or the eDie.

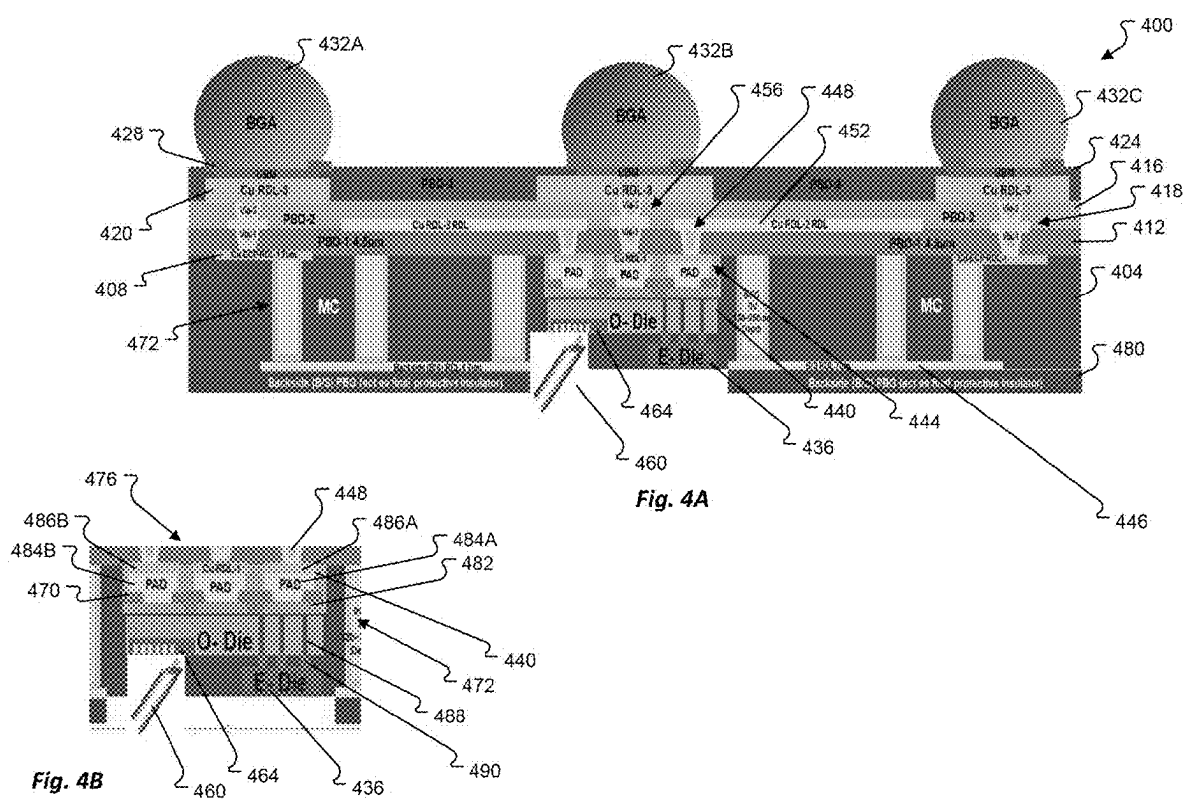


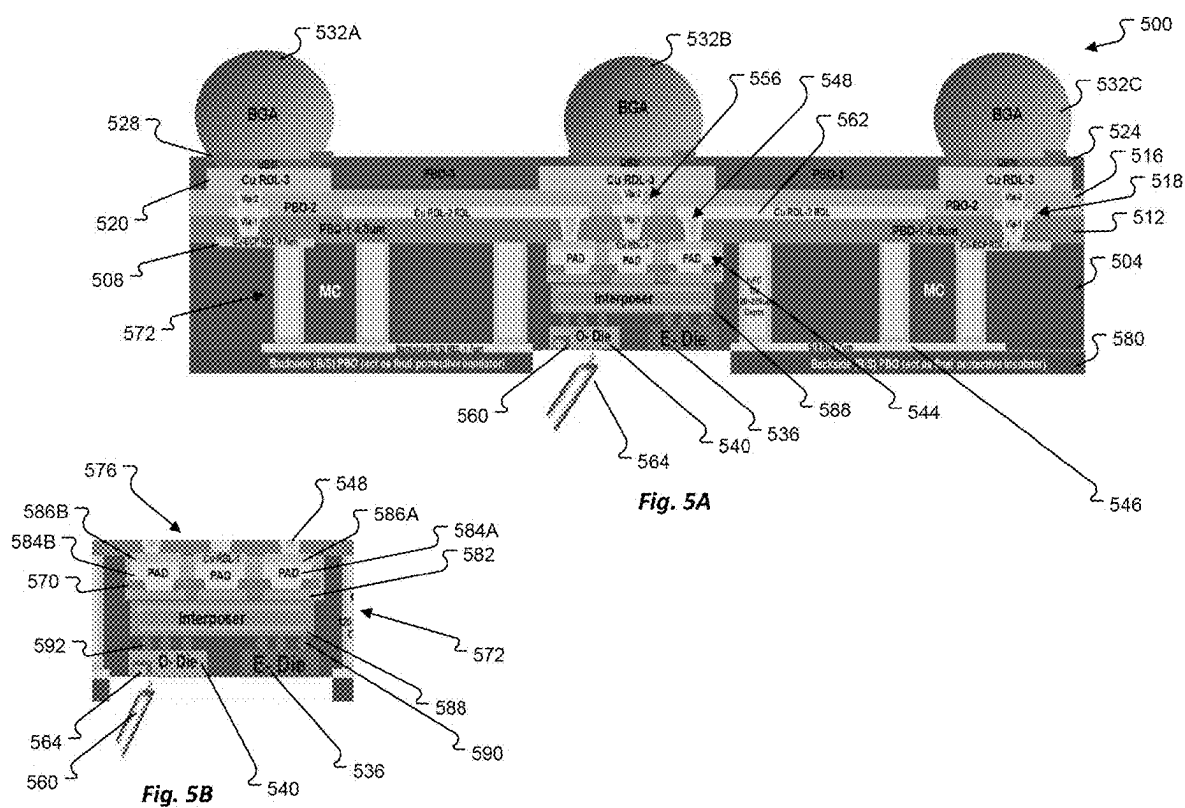


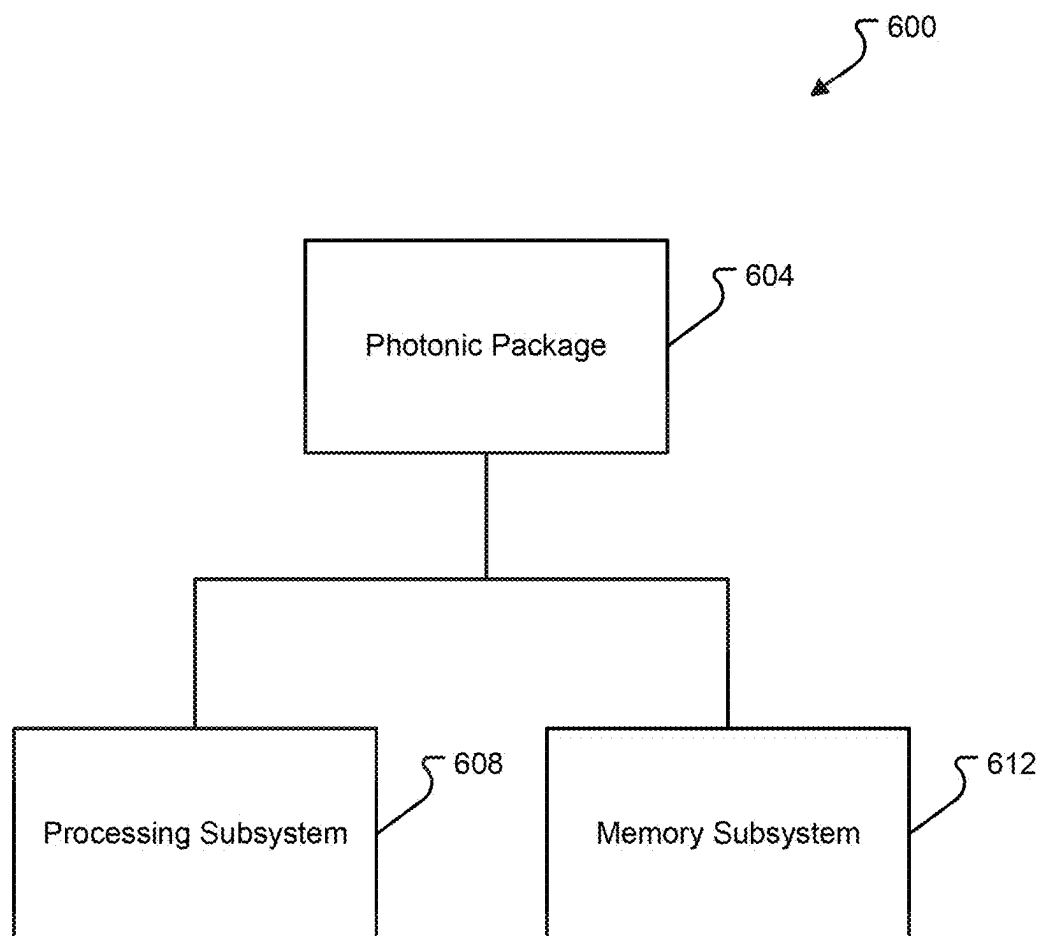
**Fig. 1**









**Fig. 6**

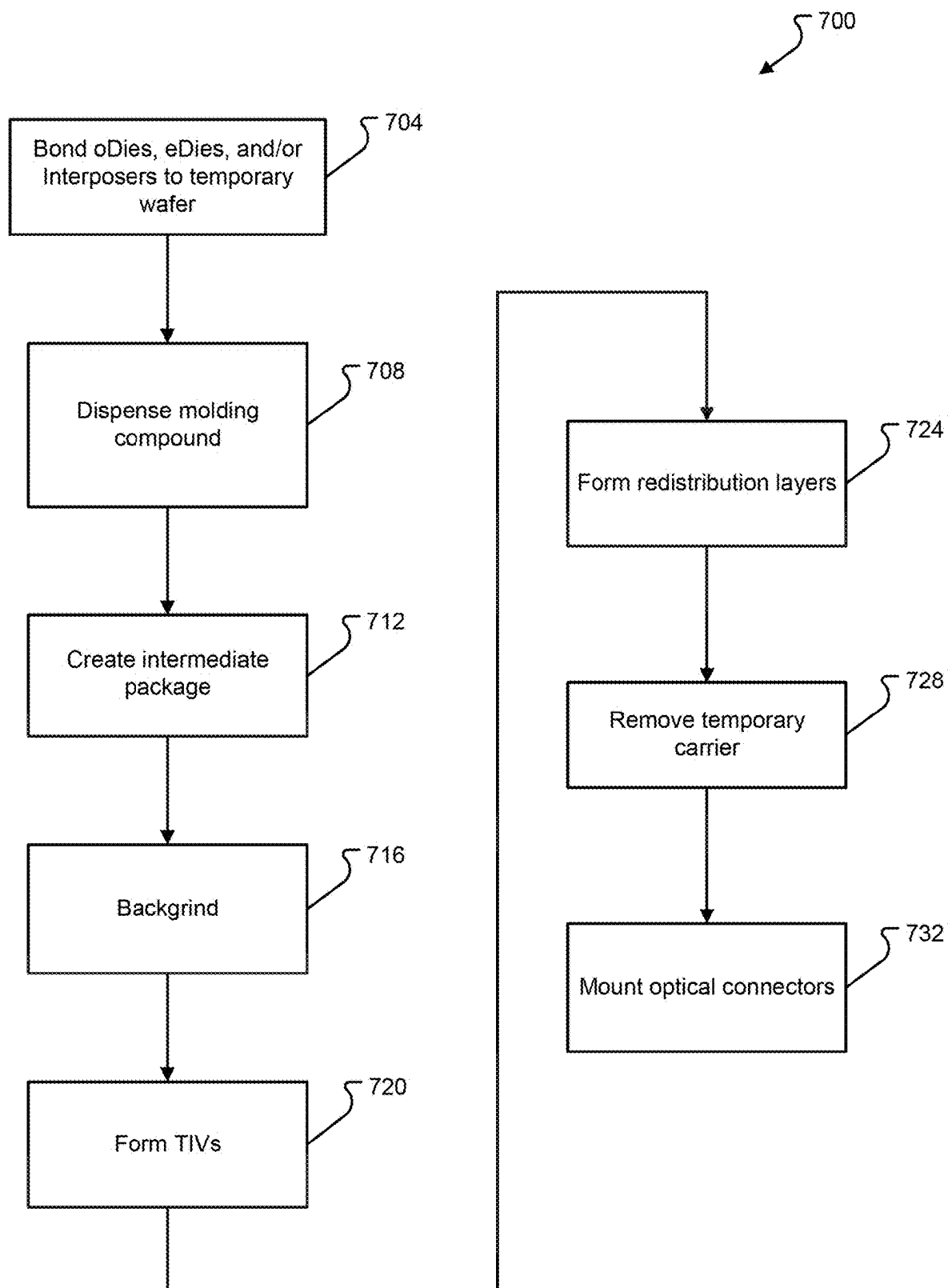
**Fig. 7**





Fig. 8A

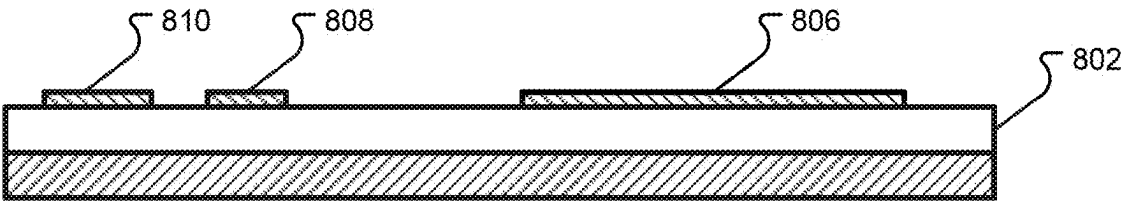


Fig. 8B

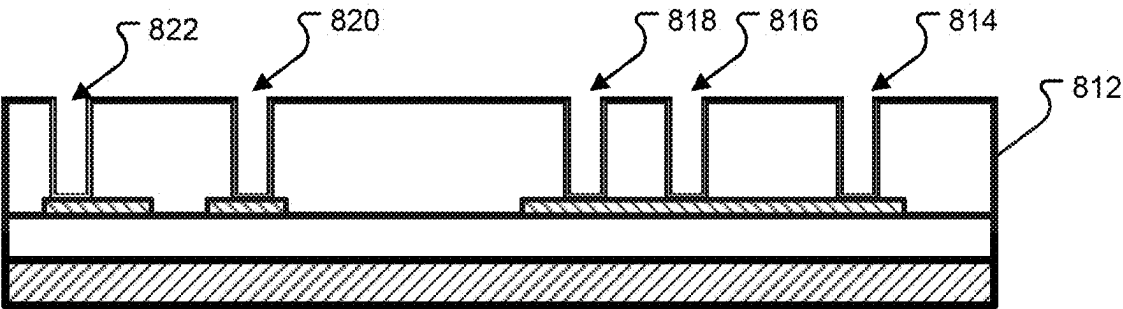


Fig. 8C

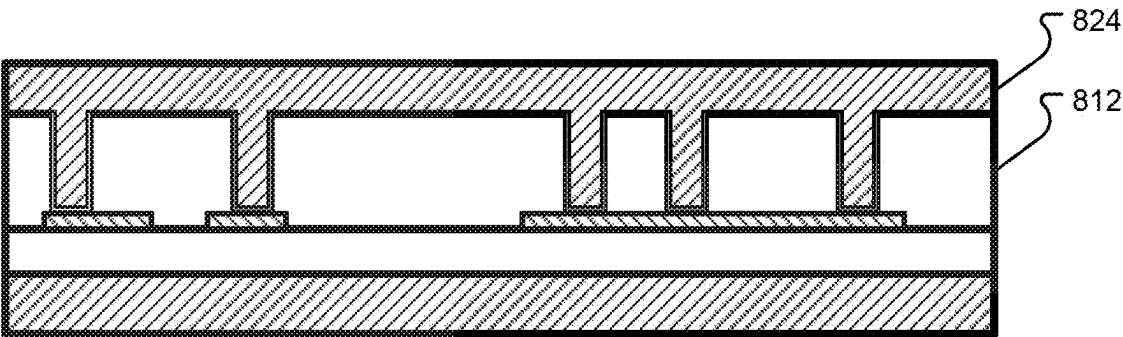
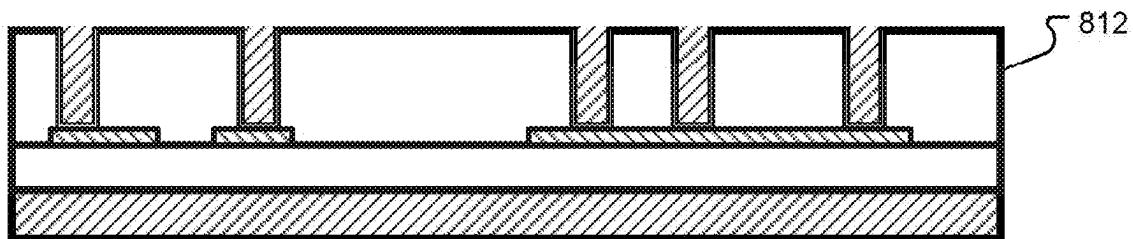
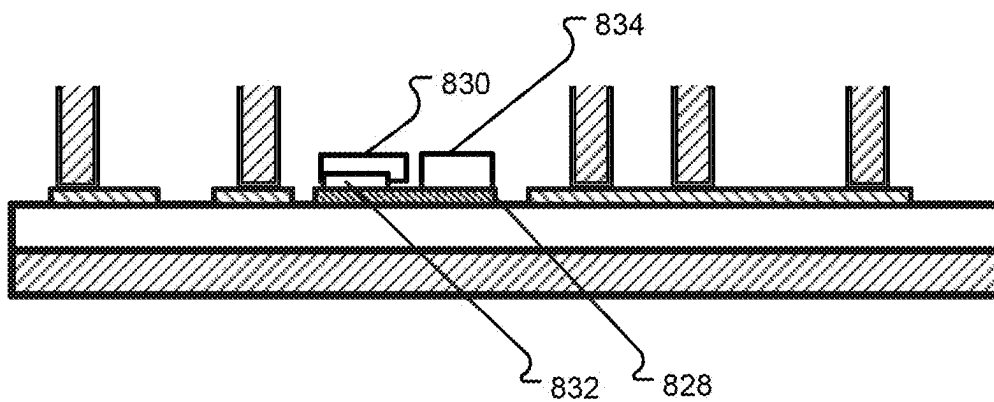


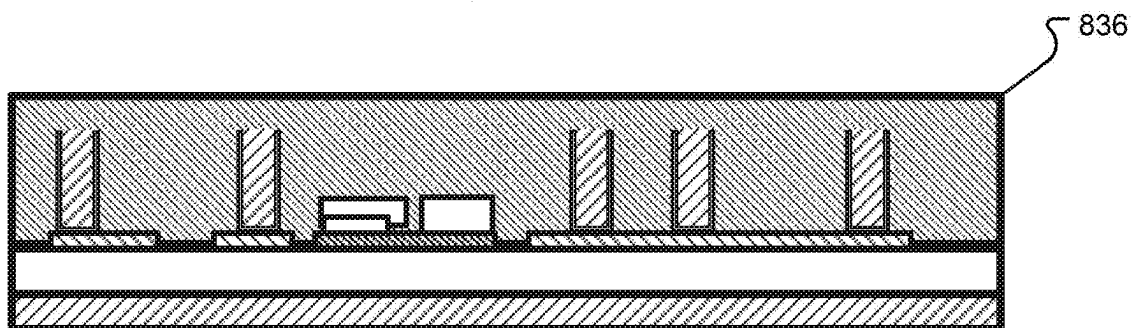
Fig. 8D



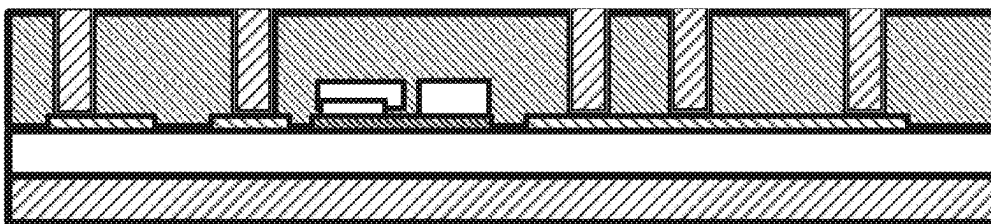
**Fig. 8E**



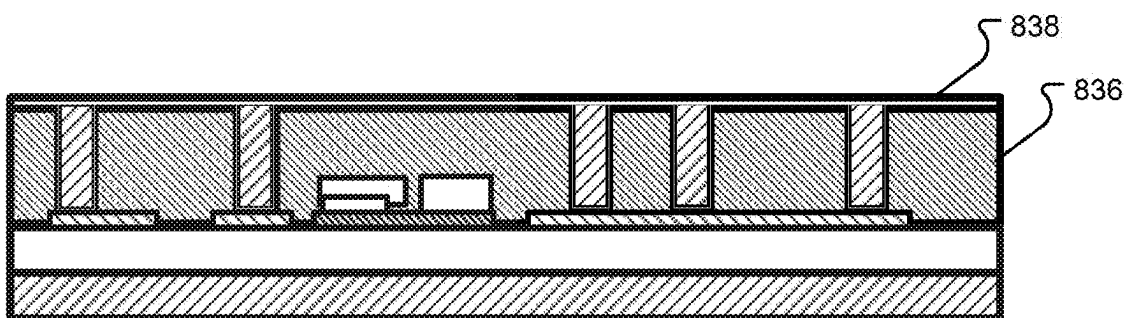
**Fig. 8F**



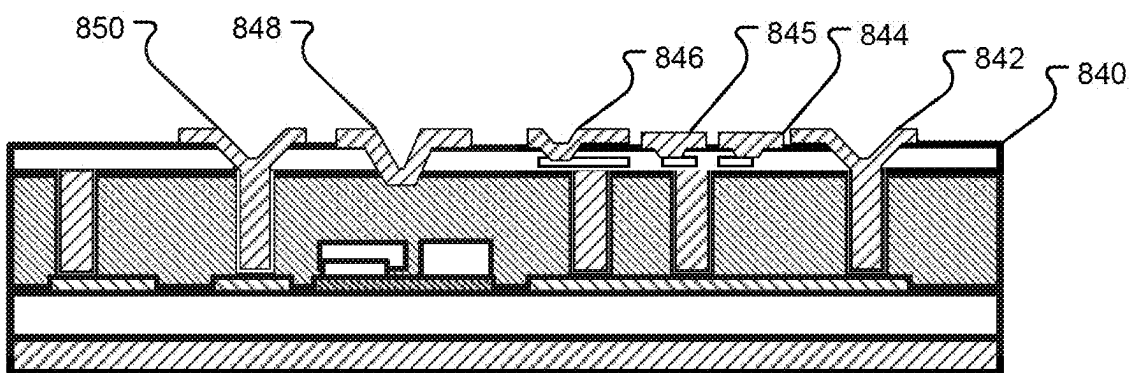
**Fig. 8G**



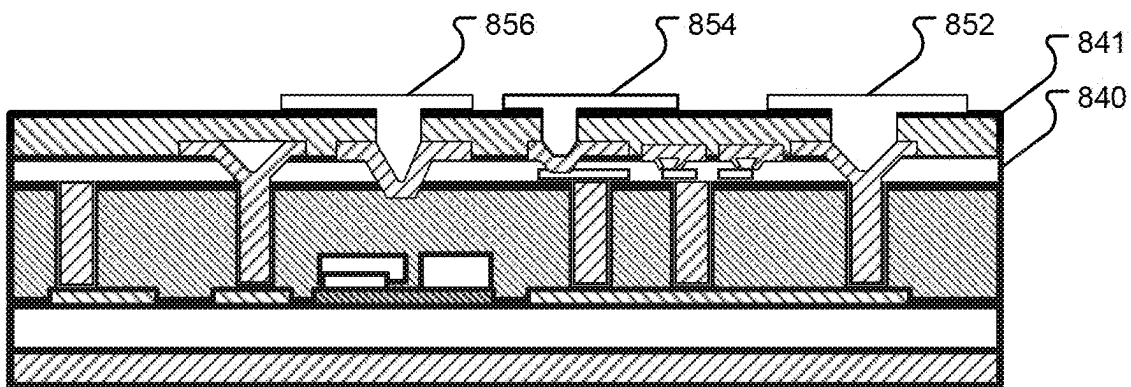
**Fig. 8H**



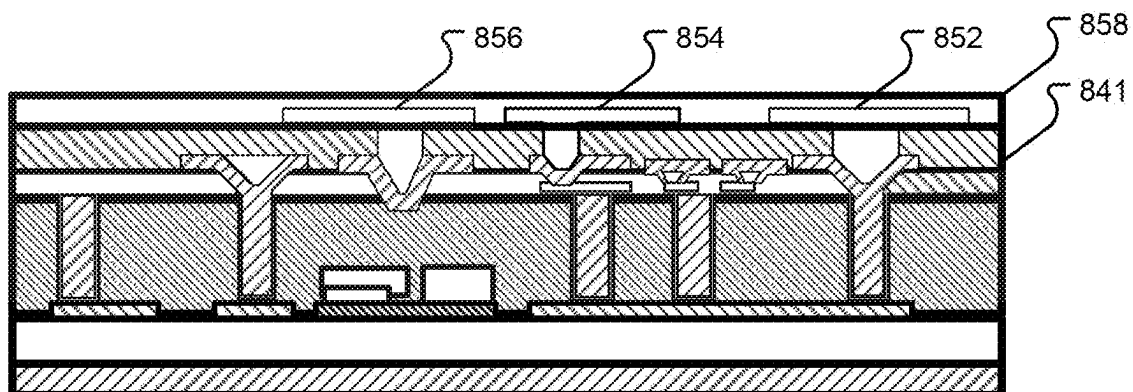
**Fig. 8I**



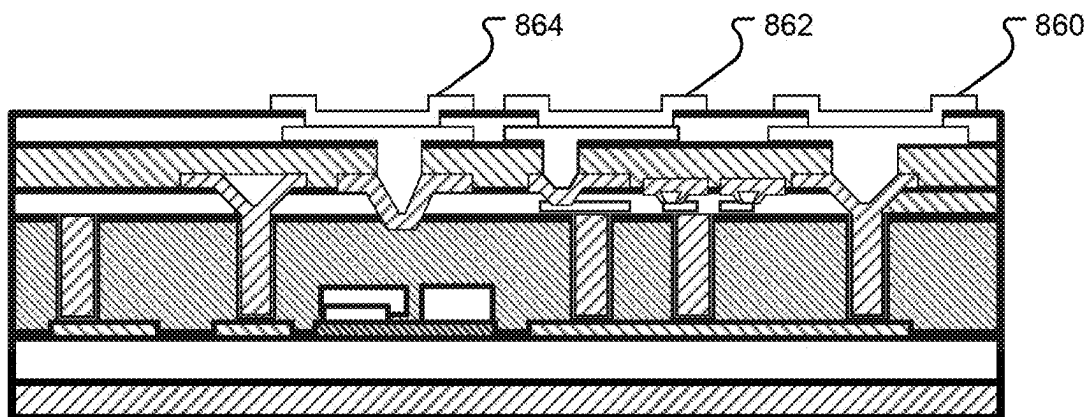
**Fig. 8J**



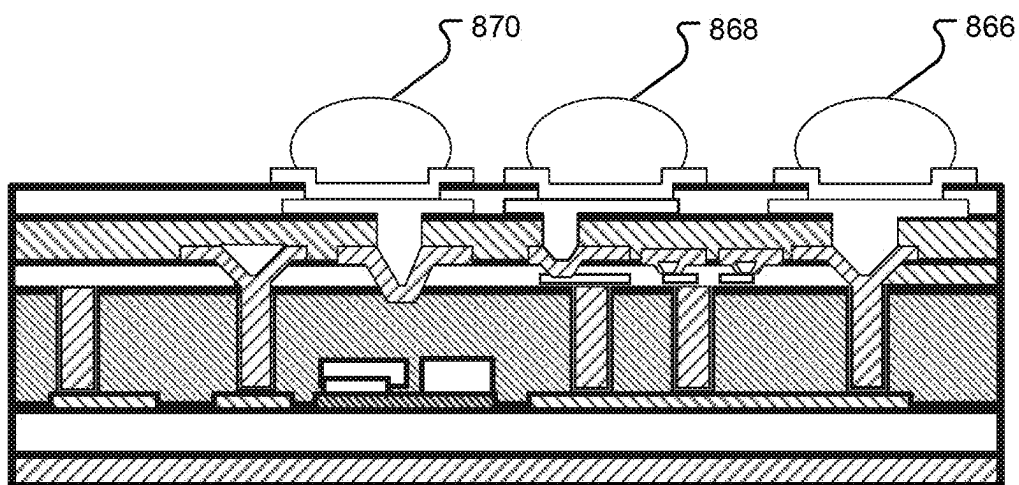
**Fig. 8K**



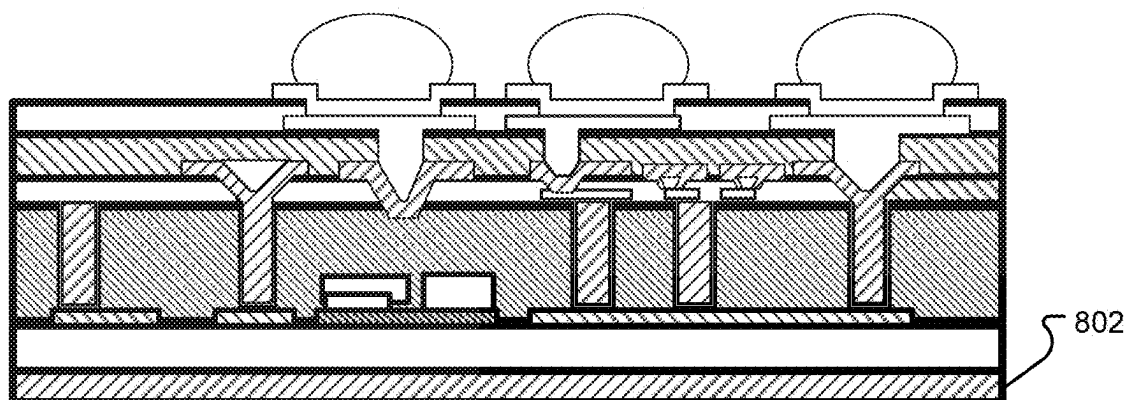
**Fig. 8L**



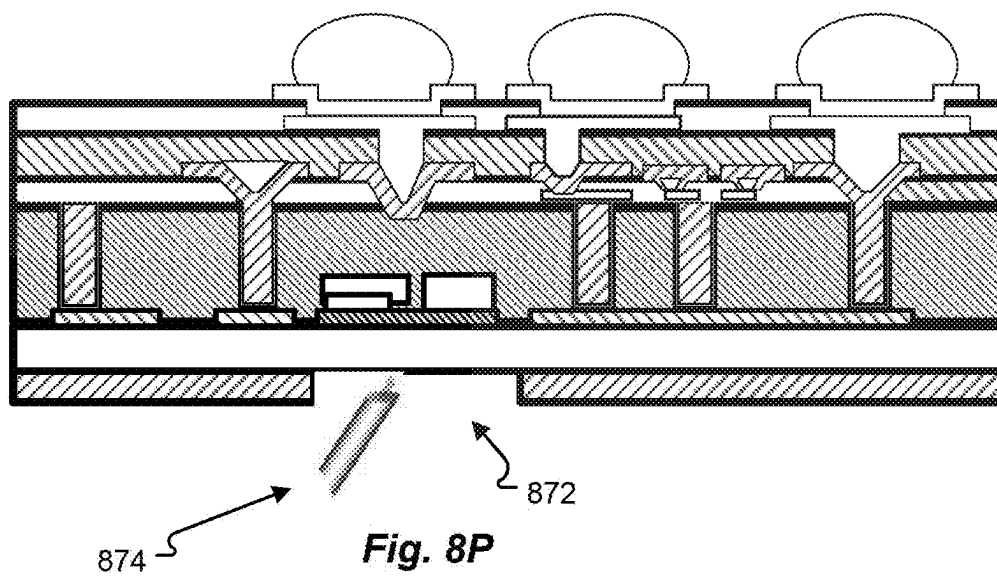
**Fig. 8M**



**Fig. 8N**



**Fig. 8O**



**Fig. 8P**

## PHOTONICS INTEGRATED CIRCUIT PACKAGE

### CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is a continuation application of U.S. patent application Ser. No. 18/440,0297, filed Feb. 13, 2024, which is a continuation application of U.S. patent application Ser. No. 17/708,666, filed Mar. 30, 2022, now U.S. Pat. No. 12,293,974, which is a divisional application of U.S. patent application Ser. No. 16/654,679, filed Oct. 16, 2019, now U.S. Pat. No. 11,315,878 which claims the benefit of U.S. Provisional Application No. 62/753,537 entitled “PHOTONICS InFO PACKAGE,” filed on Oct. 31, 2018, of which the disclosures of which are hereby incorporated by reference in their entireties. To the extent appropriate, a claim of priority is made to each of the above-disclosed applications.

### BACKGROUND

[0002] Conventional packaging technologies generally include dicing a wafer and then packaging individual dies on the diced wafer. Because the individual dies are packaged after the wafer has been diced, the package size tends to be considerably larger than the die size. By contrast, in standard wafer level packaging techniques, integrated circuits are packaged while still part of the wafer, and the wafer is then diced afterwards. Accordingly, a resulting package is generally the same size as the die itself. However, the advantage of having a small package comes with a downside because the number of external contacts that can be accommodated in the limited package footprint are limited. In some instances, this may become a significant limitation when complex semiconductor devices requiring a large number of contacts are considered.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0004] FIG. 1 depicts a cross-sectional view of a first example of a photonic package in accordance with some embodiments;

[0005] FIGS. 2A-2B depict cross-sectional views of a second example of a photonic package in accordance with some embodiments;

[0006] FIGS. 3A-3B depict cross-sectional views of a third example of a photonic package in accordance with some embodiments;

[0007] FIGS. 4A-4B. depict cross-sectional views of a fourth example of a photonic package in accordance with some embodiments;

[0008] FIGS. 5A-5B depict cross-sectional views of a fifth example of a photonic package in accordance with some embodiments;

[0009] FIG. 6 depicts a system incorporating a photonic package in accordance with some embodiments; and

[0010] FIG. 7 depicts a flowchart of a method for forming a photonic package in accordance with some embodiments.

[0011] FIGS. 8A-8P illustrate steps of a process for manufacturing a photonic package in accordance with some embodiments.

### DETAILED DESCRIPTION

[0012] The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to simplify 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 embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed 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 embodiments and/or configurations discussed.

[0013] Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0014] When incorporating optical components such as lasers, optical modulators, optical detectors and optical switches into packaged electronic modules, conventional packaging and standard wafer level packaging techniques often may result in low density pin counts, larger form factors, and higher cost. For example, an integrated circuit may be affixed to an interposer, such as a Silicon interposer, via microbumps and then attached to a printed circuit board via a conductive glue. While a fiber array is situated on the interposer, a connection, power and/or data from the integrated circuit interfacing with the fiber array is routed from the microbumps to an external pad situated at the PCB by one or more traces within the interposer and a wire-bond connection. While wire-bonding can be cost effective and flexible, wire-bonding techniques may suffer reliability issues and often result in larger package sizes.

[0015] Multi-chip modules that include one or more optical modules may include an integrated circuit in communication with an optical module. In some instances, flip-chip packaging techniques may be employed such that an integrated circuit and an optical module are communicatively coupled to one another and attached to a substrate utilizing one or more bumps. In some instances, an interposer may reside between the integrated circuit and the optical module such that connections, such as connections coupled to the integrated circuit and/or the optical module and the substrate may be spread to a wider pitch and/or to reroute a connection to a different connection. In some instances the interposer may utilize through-silicon vias (TSVs) to connect the interposer to the substrate while the integrated circuit and the optical module may be attached to the interposer utiliz-

ing existing connection methods, such as bump connections. In some instances the interposer may be a photonic interposer for directing, and/or guiding, light from a light sources such as a laser, to another location in the package. Such multi-chip modules often have a larger form factor, higher cost, and are generally of a lower density and pin counts.

**[0016]** Embodiments described herein disclose advanced packaging techniques that integrate a photonic die (oDie) and an electronic die (eDie) into one package. In some instances, components in addition to the oDie and the eDie may be included in the package. For example, a package may include an oDie, an eDie, and a switch ASIC forming an interconnect package. The components of the eDie can include, but are not limited to, at least one of: one or more serializer/deserializers (serdes), one or more transceivers, clocking circuitry, and control logic and circuitry. The integration of the eDie with the switch ASIC can reduce the distance between the serdes and the switch logic, which in turn may reduce the size and the power consumption of the serdes. In some instances, through-silicon vias may be utilized in a substrate to electrically connect the various components. In other embodiments described herein, an oDie may be integrated with one or more additional photonic components in a single integrated circuit package. An eDie may then be attached to the integrated circuit package via one or more bumps.

**[0017]** As described herein, a package may utilize Integrated Fan-Out (InFO) technology to integrate multiple dies that may include photonic integrated circuit applications in to an integrated circuit package, also referred to as a wafer level package. Accordingly, an advanced package capable of handling high pin counts, e.g., having a high pin and component density, while having a small form factor can be achieved. Since InFO technology may be utilized, such packages may be highly integrated and may be less expensive to manufacture than traditional packaging techniques. The advanced package may be suitable for high-speed circuits.

**[0018]** InFO packaging technology differs from other packaging technology at least because fan-out packaging utilizes individual dies and embeds them in a material such as epoxy mold compound or other material with space allocated between each die for additional I/O connection points. Thus, the use of silicon real estate to accommodate higher pin counts can be avoided. Moreover, a redistribution layer may be utilized to route/re-route some I/O connections to periphery regions, further adds to higher package pin count density and contact utilization.

**[0019]** FIG. 1 depicts a cross-section view of a first package 104 in accordance with some embodiments of the present disclosure. More specifically the first package may utilize integrated circuit packaging techniques, such as InFO packaging techniques, and provide a fiber 112 coupled to an optical interconnect 117, where the optical interconnect 117 may specifically configured to receive light and provide the received light to an oDie 116 for further processing. That is, when light is received via a fiber at the first package 104, the first package 104 is configured to convert the light into electric signals. The one or more optical interconnects 117 may receive the light, and direct or guide the light via an optical waveguide to one or more detectors located at the oDie 116. The one or more detectors of the oDie 116 may detect and then convert the light into one or more corresponding electric signals. The one or more electric signals

may flow through a redistribution layer 120, for example to the eDie 108, where the eDie 108 may further process the received one or more electric signals. The oDie 116 may be coupled to the eDie 108 via the redistribution layer 120 and one or more bumps, such as a microbump 124 of the oDie 116 and 128 of the eDie 108. The eDie 108 may process the one or more electric signals and provide one or more processed electric signals to a bump 132 via a redistribution layer 120 and a through silicon via 136 for connection to a printed circuit board of another die.

**[0020]** The first package 104 may include one or more portions. For example, the first package 104 may include the eDie 108, the fiber 112, and an oDie packaged portion 140. The oDie packaged portion 140 may include a first connection portion 144, one or more redistribution layers 120, one or more oDies 116, one or more Silicon layers 148, the one or more through silicon vias 136, and one or more second connection portions 152. The one or more first connection portions 144 may include one or more bumps 124 as previously discussed; the one or more second connection portions 152 may include the one or more bumps 132. The eDie 108, oDie packaged portion 140, and fiber 112 may be packaged in a protective material 156, where the one or more bumps 132 in the one or more second connection portion 152 may be exposed for connection to a printed circuit board, other die, and/or an external connections. For example, the first package 104 may be coupled to a log and/or memory.

**[0021]** FIG. 2A depicts a cross-section view of second package 200 in accordance with embodiments of the present disclosure. FIG. 2B depicts an enlarged portion of the second package 200 depicted in FIG. 2A. Similar to the first package 104, the second package 200 may utilize integrated circuit packaging techniques, such as InFO packaging techniques. The second package may include a substrate 204. The substrate 204 may include a mold material, silicon material and/or other generally insulative or semiconductor material. The package 200 may include a protective layer 212 formed on top of, directly contacting, and/or disposed on the substrate 204. The protective layer 212 may include Polyimide and/or Polybenzoxazole material. The protective layer 212 may be a stress relief coating used as a protective layer or “buffer coat” before packaging or redistribution layer 252. Prior to the forming of the protective layer 212, one or more redistribution layers 208 may be formed on top, directly, contacting, and/or disposed on at least a portion of the substrate 204. Another protective layer 216 may be formed on at least a portion of the protective layer 212 and the redistribution layer 252. In some embodiments one or more vias 218 may be formed within the protective layers 216 and/or 212. In some instances, a first via may be formed after the formation of the first protective layer 212, while a second via may be formed after the formation of the second protective layer 216. Alternatively, or in addition, a first and/or second via may be formed after the protective layers 212 and 216 have been formed. For example, one or more portions of the protective layer 216 may be removed; for instance the one or more portions may be etched, drilled, or and/or exposed to light to form a first hole in the protective layers 212 and/or 216. An insulating material may then be placed within the first hole to line the sides of the hole. Finally, a conductive material may be placed in the hole thereby forming one or more vias 218.

[0022] The package 200 may include one or more redistribution layers 220 formed on, on top of, directly contacting, or otherwise disposed on the protective layer 216. In one embodiment, a protective layer 224 may be formed on, on top of, directly contacting, or otherwise disposed on the protective layer 216. One or more portions of the protective layer 224 may be removed. For example, the one or more portions may be etched, drilled, exposed to light etc., and thereby forming a hole in the protective layer 224. Then a redistribution layer 220 may be formed within the one or more holes of the redistribution layer 220. Lastly, one or more under bump metallization layers 228 may be formed on the redistribution layer 224; the one or more under bump metallization layers 228 may be configured to receive a sold ball and/or connector 232A-C to form a ball grid array for example.

[0023] As previously discussed the package 200 may include a redistribution layer 208; the redistribution layer 208 may provide a signal path from one or more of the optical dies (oDies) 240 and/or one or more eDies 236 via an interface portion 276 to one or more of the connectors 232A-232C. The connection portion 244 may include one or more of the redistribution layers 286A and/or 286B, one or more pads 284A and 284B, one or more conductive portions 270, and one or more insulative portions 282. A through integrated circuit package via or through insulator via (TIV) 272 may be formed in the substrate 204. The TIV 272 may couple the redistribution layer 208 to a backside redistribution layer 246 for example. The backside redistribution layer 246 may couple the redistribution layer 208 to one or more redistribution layers 252 for example. Accordingly, a via 248 coupling the redistribution layer 252 to one or more copper redistribution layers 286A and/or 286B may be formed. The redistribution layer 268A and/or 286B may be formed directly on, or otherwise disposed on a pad 284A and/or 284B. The pad 284A and/or 284B may be disposed within an insulative portion 282 including an insulating material; accordingly, one or more of the pads 284A and/or 284B may be coupled to the oDie and/or the eDie 236 via a connector portion 270.

[0024] As previously discussed an oDie 240 may be coupled to an optical interconnect 264 which may be configured to receive light from a fiber 260 and/or forward the light to a detector portion of the oDie 240. Thus, an opening may exist at a fiber array receiving side of the package 200. The oDie 240 may convert the light into one or more electric signals and transmit or otherwise provide the one or more electric signals to the eDie 236 and/or an external connection, such as one or more of the connectors 232A-C. The one or more electric signals may be transmitted through the package 200 via one or more of the redistribution layers, the one or more vias, the one or more TIVs, one or more pads 284A and/or 286, and one or more connector portions 270.

[0025] In accordance with some embodiments of the present disclosure, the oDie 240 and the eDie 236 may reside within the package 200. For example, a cavity, hole, or other portion may be formed or otherwise exist in the substrate 204. Each of the one or more oDies 240 and/or the one or more eDies 236 may reside between TIVs on either side for example in a cross-section view. Further, the substrate material 204 may include or otherwise be an epoxy. In some

embodiments, the oDie 240 and/or eDie 236 may be directly connected to or otherwise be disposed on one or more of the connector portions 270.

[0026] FIG. 3A depicts a cross-section view of a third package 300 in accordance with embodiments of the present disclosure. FIG. 3B depicts an enlarged portion of the third package 300 depicted in FIG. 3A. Similar to the first package 104 and the second package 200, the third package 300 may utilize integrated circuit packaging techniques. The third package may include a substrate 304. The substrate 304 may include a mold material, silicon material and/or other generally insulative or semiconductor material. The package 300 may include a protective layer 312 formed on top of, directly contacting, and/or disposed on the substrate 304. The protective layer 312 may include Polyimide and/or Polybenzoxazole material. The protective layer 312 may be a stress relief coatings used as a protective layer or “buffer coat” before packaging or redistribution layer 352. Prior to the forming of the protective layer 312, one or more redistribution layers 308 may be formed on top, directly, contacting, and/or disposed on at least a portion of the substrate 304. Another protective layer 316 may be formed on at least a portion of the protective layer 312 and the redistribution layer 352. In some embodiments, one or more vias 318 may be formed within the protective layers 316 and/or 312. In some instances, a first via may be formed after the formation of the first protective layer 312, while a second via may be formed after the formation of the second protective layer 316. Alternatively, or in addition, a first and/or second via may be formed after the protective layers 312 and 316 have been formed. For example, one or more portions of the protective layer 316 may be removed; for instance the one or more portions may be etched, drilled, or and/or exposed to light to form a first hole in the protective layers 312 and/or 316. An insulating material may then be placed within the first hole to line the sides of the hole. Finally, a conductive material may be placed in the hole thereby forming one or more vias 318.

[0027] The package 300 may include one or more redistribution layers 320 formed on, on top of, directly contacting, or otherwise disposed on the protective layer 316. In one embodiment, a protective layer 324 may be formed on, on top of, directly contacting, or otherwise disposed on the protective layer 316. One or more portions of the protective layer 324 may be removed. For example, the one or more portions may be etched, drilled, exposed to light etc., and thereby forming a hole in the protective layer 324. Then a redistribution layer 320 may be formed within the one or more holes of the redistribution layer 320. Lastly, one or more under bump metallization layers 328 may be formed on the redistribution layer 320; the one or more under bump metallization layers 328 may be configured to receive a sold ball and/or connector 332A-C to form a ball grid array for example.

[0028] As previously discussed the package 300 may include a redistribution layer 308; the redistribution layer 308 may provide a signal path from one or more of the optical dies (oDies) 340 and/or one or more eDies 336 via an interface portion 376 to one or more of the connectors 332A-332C. The connection portion 344 may include one or more of the redistribution layers 386A and/or 386B, one or more pads 384A and 384B, one or more conductive portions 370, and one or more insulative portions 382. A through integrated circuit package via (TIV) or through insulator via



**372** may be formed in the substrate **304**. The TIV **372** may couple the redistribution layer **308** to a backside redistribution layer **346** for example. The backside redistribution layer **346** may couple the redistribution layer **308** to one or more redistribution layers **352** for example. Accordingly, a via **348** coupling the redistribution layer **352** to one or more redistribution layers **386A** and/or **386B** may be formed. The redistribution layer **368A** and/or **386B** may be formed directly on, or otherwise disposed on a pad **384A** and/or **384B**. The pad **384A** and/or **384B** may be disposed within an insulative portion **382** including an insulating material; accordingly, one or more of the pads **384A** and/or **384B** may be coupled to the eDie **336** via a connector portion **370**.

[0029] The oDie **340** may be coupled to an optical interconnect **364** which may be configured to receive light from a fiber **360** and/or forward the light to a detector portion of the oDie **340**. Thus, an opening may be exist at a fiber array receiving side of the package **300**. The oDie **340** may convert the light into one or more electric signals and transmit or otherwise provide the one or more electric signals to the eDie **336** and/or an external connection, such as one or more of the connectors **332A-C**. The one or more electric signals may be transmitted through the package **300** via one or more of the redistribution layers, the one or more vias, the one or more TIVs, one or more pads **384A** and/or **386**, and one or more connector portions **370**.

[0030] In accordance with some embodiments of the present disclosure, the oDie **340** and the eDie **336** may reside within the package **300**. For example, a cavity, hole, or other portion may be formed or otherwise exist in the substrate **304**. Each of the one or more oDies **340** and/or the one or more eDies **336** may reside between TIVs on either side for example in a cross-section view. Further, the substrate material **304** may include or otherwise be an epoxy such that the substrate material may be between one or more of the eDies **336**, the oDies **340** and the one or more TIVs. In some embodiments, the eDie **336** may be directly connected to or otherwise be disposed on one or more of the connector portions **370** and the insulative portion **382**.

[0031] As further depicted in FIGS. 3A-3B, the eDie **336** may be located between the oDie **340** and the insulative portion **382**. Accordingly, the oDie **340** may be coupled to the eDie **336** via one or more vias **388** and one or more bumps **390**. In accordance with at least one example, the oDie **340** may be flip-chip bonded to the eDie **346** while the package **300** employs integrated circuit packaging technologies.

[0032] FIG. 4A depicts a cross-section view of a fourth package **400** in accordance with embodiments of the present disclosure. FIG. 4B depicts an enlarged portion of the fourth package **400** depicted in FIG. 4A. Similar to the first package **104**, the second package **200**, and the third package **300**, the fourth package **400** may utilize integrated circuit packaging techniques. The fourth package may include a substrate **404**. The substrate **404** may include a mold material, silicon material and/or other generally insulative or semiconductor material. The package **400** may include a protective layer **412** formed on top of, directly contacting, and/or disposed on the substrate **404**. The protective layer **412** may include Polyimide and/or Polybenzoxazole material. The protective layer **412** may be a stress relief coatings used as a protective layer or “buffer coat” before packaging or redistribution layer **452**. Prior to the forming of the protective layer **412**, one or more redistribution layers **408**

may be formed on top, directly, contacting, and/or disposed on at least a portion of the substrate **404**. Another protective layer **416** may be formed on at least a portion of the protective layer **412** and the redistribution layer **452**. In some embodiments, one or more vias **418** may be formed within the protective layers **416** and/or **412**. In some instances, a first via may be formed after the formation of the first protective layer **412**, while a second via may be formed after the formation of the second protective layer **416**. Alternatively, or in addition, a first and/or second via may be formed after the protective layers **412** and **416** have been formed. For example, one or more portions of the protective layer **416** may be removed; for instance the one or more portions may be etched, drilled, or and/or exposed to light to form a first hole in the protective layers **412** and/or **416**. An insulating material may then be placed within the first hole to line the sides of the hole. Finally, a conductive material may be placed in the hole thereby forming one or more vias **418**.

[0033] The package **400** may include one or more redistribution layers **420** formed on, on top of, directly contacting, or otherwise disposed on the protective layer **416**. In one embodiment, a protective layer **424** may be formed on, on top of, directly contacting, or otherwise disposed on the protective layer **416**. One or more portions of the protective layer **424** may be removed. For example, the one or more portions may be etched, drilled, exposed to light etc., and thereby forming a hole in the protective layer **424**. Then a redistribution layer **420** may be formed within the one or more holes of the redistribution layer **420**. Lastly, one or more under bump metallization layers **428** may be formed on the redistribution layer **424**; the one or more under bump metallization layers **428** may be configured to receive a sold ball and/or connector **432A-C** to form a ball grid array for example.

[0034] As previously discussed the package **400** may include a redistribution layer **408**; the redistribution layer **408** may provide a signal path from one or more of the optical dies (oDies) **440** and/or one or more eDies **436** via an interface portion **476** to one or more of the connectors **432A-432C**. The connection portion may include one or more of the redistribution layers **486A** and/or **486B**, one or more pads **484A** and **484B**, one or more conductive portions **470**, and one or more insulative portions **482**. A through insulator via (TIV) **472** (or through integrated circuit package via) may be formed in the substrate **404**. The TIV **472** may couple the redistribution layer **408** to a backside redistribution layer **446** for example. The backside redistribution layer **446** may couple the redistribution layer **408** to one or more redistribution layers **452** for example. Accordingly, a via **448** coupling the redistribution layer **452** to one or more redistribution layers **486A** and/or **486B** may be formed. The redistribution layer **468A** and/or **486B** may be formed directly on, or otherwise disposed on a pad **484A** and/or **484B**. The pad **484A** and/or **484B** may be disposed within an insulative portion **482** including an insulating material; accordingly, one or more of the pads **484A** and/or **484B** may be coupled to the oDie **440** via a connector portion **470**.

[0035] The oDie **440** may be coupled to an optical interconnect **464** which may be configured to receive light from a fiber **460** and/or forward the light to a detector portion of the oDie **440**. Thus, an opening may be exist at a fiber array receiving side of the package **400**. The oDie **440** may

convert the light into one or more electric signals and transmit or otherwise provide the one or more electric signals to the eDie 436 and/or an external connection, such as one or more of the connectors 432A-C. The one or more electric signals may be transmitted through the package 400 via one or more of the redistribution layers, the one or more vias, the one or more TIVs, one or more pads 484A and/or 486, and one or more connector portions 470.

[0036] In accordance with some embodiments of the present disclosure, the oDie 440 and the eDie 436 may reside within the package 400. For example, a cavity, hole, or other portion may be formed or otherwise exist in the substrate 404. Each of the one or more oDies 440 and/or the one or more eDies 436 may reside between TIVs on either side for example in a cross-section view. Further, the substrate material 404 may include or otherwise be an epoxy such that the substrate material may be between one or more of the eDies 436, the oDies 440 and the one or more TIVs. In some embodiments, the oDie 440 may be directly connected to or otherwise be disposed on one or more of the connector portions 470 and the insulative portion 482.

[0037] As further depicted in FIGS. 4A-3B, the oDie 440 may be located between the eDie 436 and the insulative portion 482. Accordingly, the eDie 436 may be coupled to the oDie 440 utilizing one or more bumps 490. One or more vias 488 may facilitate the oDie 440 connection to the connector portion 470 and/or the eDie 436. In accordance with at least one example, the eDie 436 may be flip-chip bonded to the oDie 440 while the package 400 employs integrated circuit packaging technologies.

[0038] FIG. 5A depicts a cross-section view of a fifth package 500 in accordance with embodiments of the present disclosure. FIG. 5B depicts an enlarged portion of the fifth package 500 depicted in FIG. 5A. Similar to the first package 104, the second package 200, the third package 300, and the fourth package 400, the fifth package 500 may utilize integrated circuit packaging techniques. The fifth package may include a substrate 504. The substrate 504 may include a mold material, silicon material and/or other generally insulative or semiconductor material. The package 500 may include a protective layer 512 formed on top of, directly contacting, and/or disposed on the substrate 504. The protective layer 512 may include Polyimide and/or Polybenzoxazole material. The protective layer 512 may be a stress relief coatings used as a protective layer or “buffer coat” before packaging or redistribution layer 552. Prior to the forming of the protective layer 512, one or more redistribution layers 508 may be formed on top, directly, contacting, and/or disposed on at least a portion of the substrate 504. Another protective layer 516 may be formed on at least a portion of the protective layer 512 and the redistribution layer 552. In some embodiments one or more vias 518 may be formed within the protective layers 516 and/or 512. In some instances, a first via may be formed after the formation of the first protective layer 512, while a second via may be formed after the formation of the second protective layer 516. Alternatively, or in addition, a first and/or second via may be formed after the protective layers 512 and 516 have been formed. For example, one or more portions of the protective layer 516 may be removed; for instance the one or more portions may be etched, drilled, or and/or exposed to light to form a first hole in the protective layers 512 and/or 516. An insulating material may then be placed within the

first hole to line the sides of the hole. Finally, a conductive material may be placed in the hole thereby forming one or more vias 518.

[0039] The package 500 may include one or more redistribution layers 520 formed on, on top of, directly contacting, or otherwise disposed on the protective layer 516. In one embodiment, a protective layer 524 may be formed on, on top of, directly contacting, or otherwise disposed on the protective layer 516. One or more portions of the protective layer 524 may be removed. For example, the one or more portions may be etched, drilled, exposed to light etc., and thereby forming a hole in the protective layer 524. Then a redistribution layer 520 may be formed within the one or more holes of the redistribution layer 520. Lastly, one or more under bump metallization layers 528 may be formed on the redistribution layer 520; the one or more under bump metallization layers 528 may be configured to receive a sold ball and/or connector 532A-C to form a ball grid array for example.

[0040] As previously discussed the package 500 may include a redistribution layer 508; the redistribution layer 508 may provide a signal path from one or more of the optical dies (oDies) 540 and/or one or more eDies 536 via an interface portion 576 to one or more of the connectors 532A-532C. The connection portion may include one or more of the redistribution layers 586A and/or 586B, one or more pads 584A and 584B, one or more conductive portions 570, and one or more insulative portions 582. A through insulator via (TIV) 572 may be formed in the substrate 504. The TIV 572 may couple the redistribution layer 508 to a backside redistribution layer 546 for example. The backside redistribution layer 546 may couple the redistribution layer 508 to one or more redistribution layers 552 for example. Accordingly, a via 548 coupling the redistribution layer 552 to one or more redistribution layers 586A and/or 586B may be formed. The redistribution layer 568A and/or 586B may be formed directly on, or otherwise disposed on a pad 584A and/or 584B. The pad 584A and/or 584B may be disposed within an insulative portion 582 including an insulating material; accordingly, one or more of the pads 584A and/or 584B may be coupled to an interposer 588 which may couple the oDie 540 and eDie 536 to the connector portion 570.

[0041] The oDie 540 may be coupled to an optical interconnect 564 which may be configured to receive light from a fiber 560 and/or forward the light to a detector portion of the oDie 540. Thus, an opening may be exist at a fiber array receiving side of the package 500. The oDie 540 may convert the light into one or more electric signals and transmit or otherwise provide the one or more electric signals to the eDie 536 and/or an external connection, such as one or more of the connectors 532A-C. The one or more electric signals may be transmitted through the package 500 via one or more of the redistribution layers, the one or more vias, the one or more TIVs, one or more pads 584A and/or 586, and one or more connector portions 570.

[0042] In accordance with some embodiments of the present disclosure, the oDie 540 and the eDie 536 may reside within the package 500 together with an interposer 588. For example, a cavity, hole, or other portion may be formed or otherwise exist in the substrate 504. Each of the one or more oDies 540, the one or more eDies 536, and the interposer 588 may reside between TIVs on either side for example in a cross-section view. Further, the substrate material 504 may

include or otherwise be an epoxy such that the substrate material may be between one or more of the eDies 536, the oDies 540, and the one or more TIVs. In some embodiments, the oDie 540 and the eDie 536 may be connected to the interposer 588 with one or more bumps 590 and 592, while the interposer 588 is directly connected to or otherwise be disposed on the one or more of the connector portions 570 and the insulative portion 582. As further depicted in FIGS. 5A-5B, the interposer 588 may be located between the oDie 540 and/or eDie 536 and the insulative portion 582. In accordance with at least one example, the eDie 536 and/or the oDie 540 may be flip-chip bonded to the interposer 588 in the package 500 that employs integrated circuit packaging technologies.

[0043] One or more of the preceding embodiments of the package illustrated in FIGS. 1-5B may be included in a system or device. More specifically, FIG. 6 illustrates a system 600 that includes photonic package(s) 604. The system 600 also includes a processing subsystem 608 (with one or more processors) and a memory subsystem 612 (with memory).

[0044] In general, the system 600 may be implemented using a combination of hardware and/or software. Thus, system 600 may include one or more program modules or sets of instructions stored in a memory subsystem 612 (such as DRAM or another type of volatile or non-volatile computer-readable memory), which, during operation, may be executed by processing subsystem 608.

[0045] The system 600 may include: a switch, a hub, a bridge, a router, a communication system (such as a wavelength-division-multiplexing communication system), a storage area network, a data center, a network (such as a local area network), and/or a computer system (such as a multiple-core processor computer system). Furthermore, the computer system may include, but is not limited to: a server (such as a multi-socket, multi-rack server), a laptop computer, a communication device or system, a personal computer, a work station, a mainframe computer, a blade, an enterprise computer, a data center, a tablet computer, a supercomputer, a network-attached-storage (NAS) system, a storage-area-network (SAN) system, a media player (such as an MP3 player), an appliance, a subnotebook/netbook, a tablet computer, a smartphone, a cellular telephone, a network appliance, a set-top box, a personal digital assistant (PDA), a toy, a controller, a digital signal processor, a game console, a device controller, a computational engine within an appliance, a consumer-electronic device, a portable computing device or a portable electronic device, a personal organizer, and/or another electronic device.

[0046] Moreover, the photonic package 604 can be used in a wide variety of applications, such as: communications (for example, in a transceiver, an optical interconnect or an optical link, such as for intra-chip or inter-chip communication), a radio-frequency filter, a bio-sensor, data storage (such as an optical-storage device or system), medicine (such as a diagnostic technique or surgery), a barcode scanner, metrology (such as precision measurements of distance), manufacturing (cutting or welding), a lithographic process, data storage (such as an optical-storage device or system) and/or entertainment (a laser light show).

[0047] FIG. 7 is a flowchart of a first example method for forming a photonic package in accordance with some embodiments. In one embodiment, the process of FIG. 7 can be used to construct the photonic package shown in FIGS.

1-5B. First, one or more oDies 116, eDies 108, and/or interposers 588 are bonded together in step 704 such that the resulting orientation results in an active-surface down. For example, one or more oDies, eDies, and/or interposers are bonded together as indicated in FIGS. 1-5B. Flip-chip bonding techniques may be applied to bond the one or more oDies, eDies, and/or interposers. The resulting bonded dies and/or interposers are secured to a temporary carrier wafer, which may include one or more connection sections, using a temporary adhesive. An intermediate package is formed by dispensing a molding compound in step 708 to encapsulate the oDies, eDies, and/or the interposer, and compression and curing operations may be performed on the dispensed molding compound to create the intermediate package in step 712. A back-grinding operation may be performed on the intermediate package in step 716 to reveal backsides of the oDies, eDies, and/or interposer. In step 720, through insulator vias (TIVs) are formed in the intermediate package. A redistribution layer (RDL) 220 is formed on one or more portions of a surface exposed by the back-grinding operation in step 724, wherein the RDL facilitates routing signals from the vias to solder balls. In some embodiments, one or more pads, additional RDLs, and more protection layers may be formed. The temporary carrier wafer is removed in step 728, and the resulting intermediate package is flipped over to expose the active surfaces of the oDies and/or eDies. In step 732, one or more optical connectors containing optical waveguides may be mounted to the intermediate package, so that the optical waveguides are optically coupled to the oDie.

[0048] FIGS. 8A-8P depict an example manufacturing process for manufacturing a photonic package in accordance with some embodiments. While steps 8A-8P are depicted as being separate steps, it should be understood that one or more steps may be combined with another step and/or divided into multiple additional steps. The manufacturing process may start at FIG. 8A where a film 802, for example a PBO film, may be applied to carrier substrate, such as a glass carrier substrate 804. The film 802 may be applied via a light transfer heat conversion process as one example. In accordance with embodiments of the present disclosure, the film 802 is applied to a backside of the glass carrier substrate 804, as will be apparent from the manufactured photonic package. At FIG. 8B, a seeding layer, for example of Ti/Cu may be applied to the film 804, followed by a conducting layer together with a photo patterning and wet acid etching to form the redistribution layers (RDL) 806, 808, and 810. The seeding layer Ti/Cu may be 1K/5 KA thick and the conducting layer may be 7  $\mu$ m thick for example. Of course, other thicknesses of the Ti/Cu layer are contemplated. At FIG. 8C, a photoresist layer 812 may be applied to the film 802 and/or the RDLs 806, 808, and 810. The photoresist layer 812 may be 180-250  $\mu$ m thick for example. Of course, other thicknesses of the photoresist layer 812 are contemplated. After the application of the photoresist layer 812, one or more through insulator vias (TIV) 814, 816, 818, 820, and 822 may be created in the photoresist layer 812. The TIVs 814, 816, 818, 820, and 822 are examples of TIVs that may be created; more or less TIVs are contemplated herein as is the location, orientation, and sizing. For example, the TIVs may include a 12  $\mu$ m diameter hole. Each of the holes may or may not include an insulative portion lining the inside of

the hole. In some instances, the insulative portion may only line a portion of the hole. In some instances, the insulative portion may not be present.

[0049] At FIG. 8D, the holes may be filled with a conductive material **824**. The conductive material **824** may include copper or other conductive material. In some instances, the conductive material **824** may be formed using an electrochemical plating process, such as but not limited to Cu-ECP. At FIG. 8E, the excess copper may be removed exposing the photoresist layer **812**. The excess copper may be removed using a chemical mechanical planarization (Cu-CMP) process for example. Of course, other removal processes are contemplated. At FIG. 8F, the photoresist layer **812** may be stripped leaving the TIVs. Further, a die attach film (DAF) **828** may be utilized to secure the optical interconnect **832**, O-Die **830**, and the E-Die **834**. The O-Die **830**, E-Die **834**, and optical interconnect **832** may be same as or similar to the previously described O-Die, E-Die, and optical interconnects previously described herein. In some instances, the DAF **828** may be pre-glue to known good dies and placed with a pick and place unit. In some examples, the DAF **828** may be 10 pick and place utilizing known good dies. In some examples, the DAF **828** may be less than or greater than 10  $\mu\text{m}$  thick. At FIG. 8G, an over molding compound (MC) **836** may be applied; the MC **836** may be 50  $\mu\text{m}$  thick; in some examples, the MC **836** may be less than or greater than 50  $\mu\text{m}$  thick. As depicted in FIG. 8H, the excess MC **836** may be removed; for example, the excess MC **836** may be removed via grinding and/or chemical mechanical planarization.

[0050] In accordance with embodiments, a conductive material **838** may be applied to the surface of the MC **836**. In some examples, the conductive material **838** may be the same as or similar to the conductive material **824**. In some examples, an electrochemical plating process, such as but not limited to Cu-ECP, may be utilized. The conductive material **824** may be electrically coupled to the conductive material **824**, and in some instances, one or more of the RDLS **806**, **808**, and **810**. As depicted in FIG. 8J, one or more portions of the conductive material **838** may be removed and a protective layer **840** may be formed on top of the MC **836** and the one or more portions of the conductive material **838**. In some examples, the conductive material **838** may 7  $\mu\text{m}$  thick. In some examples, the protective layer **840** may be 4.5  $\mu\text{m}$  thick; in other examples, the protective layer **840** may be less than or greater than 4.5  $\mu\text{m}$  thick in thickness. The protective layer may be the same as or similar to the protective layers, such as but not limited to protective layer **412**, previously described. In some examples, the protective layer **840** may include PBO material.

[0051] As depicted in FIG. 8J, some examples may include RDLS **842**, **844**, **846**, **848**, and **850**. The RDLS **842**, **844**, **845**, **846**, **848**, and **850** may include conductive material, such as copper, and a process, such as but not limited to a Cu-ECP patterning process may be utilized. As depicted in FIG. 8K, a protective layer **841** may be applied to the protective layer **840** and one or more portions of the RDLS **842**, **844**, **846**, **848**, and **850**. In accordance with some examples, conductive material forming RDLS **852**, **854**, and **856** may be patterned onto the protective layer **841**. As depicted in FIG. 8L, another protective layer **858** may be provided on the protective layer **840** and the RDLS **852**, **854**, and **856**. The protective layer **858** may be a PBO layer. The

RDLS **852**, **854**, and **856** may be applied utilizing a photo-masking and patterning process, and then followed by an etching process, such wet acid etching. In some examples, the protective layer **858** may be applied via spin coating. FIG. 8M depicts under bump mounts (UBM) **860**, **862**, and **864**. The UBMs **860**, **862**, and **864** may be applied using a photomask patterning process followed by an etching, such as but not limited to wet acid etching, process. The UBMs **860**, **862**, and **864** may then be deposited; in some examples, the UBMs **860**, **862**, and **864** may be copper, and may be deposited utilizing a Cu-ECP process. As depicted in FIG. 8N, the bumps **866**, **868**, and **870** may be formed on top of the corresponding UBMs **860**, **862**, and **864**.

[0052] As depicted in FIG. 8O, the glass carrier **804** may be removed after UV exposure to LTHC, where the protective layer **802** acts as a final protective layer for the assembled package. As depicted in FIG. 8P, a portion **872** of the backside region may be removed to accommodate the fiber array **874**. Although the manufacturing process has been illustrated utilizing a plurality of steps, such steps and/or the order of such steps should not be considered limiting.

[0053] In one embodiment, an integrated fan-out (InFO) package is provided as an integrated circuit package; the integrated circuit package may include a photonics die (oDie) including at least one optical component, an electronics die (eDie), and a molded portion, wherein the molded portion includes a plurality of redistribution layers communicatively coupled to at least one of the oDie and/or the eDie, and wherein the molded portion at least partially surrounds the at least one of the oDie and/or the eDie.

[0054] In another embodiment, a package comprising a photonics die (oDie) including at least one optical component and an electronics die (eDie) is provided. The package may include a molded portion having first and second sides, where the molded portion includes one or more redistribution layers coupling at least one of the oDie and/or the eDie located with the molded portion at the first side of the package to a conduction portion located at the second side of the package.

[0055] In some embodiments, a method for producing an integrated circuit package, such as a fan out (InFO) package is provided. The method may include electrically coupling at least one optical die (oDie) to an electronic die (eDie), forming an intermediate package including a molded portion around a portion of the oDie and a portion of the eDie, and removing at least a portion of the molded portion. Then, at least one redistribution layer may be formed at a location of the molded portion corresponding to the removed portion and at least one protection layer may be formed on the at least one redistribution layer, wherein the at least one redistribution layer located between the molded portion and a first side of the integrated circuit package couples at least one of the oDie and/or the eDie to a conductive portion located at the first side of the of the integrated circuit package.

[0056] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize

that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A method for producing an integrated circuit package, the method comprising:

electrically coupling at least one discrete optical die (oDie) to an electronic die (eDie);

forming a molded portion around a portion of the oDie and a portion of the eDie;

removing at least a portion of the molded portion;

forming at least one redistribution layer at a location of the molded portion corresponding to the removed portion;

forming at least one protection layer on the at least one redistribution layer, wherein the at least one redistri-

bution layer located between the molded portion and a first side of the integrated circuit package couples at least one of the oDie and/or the eDie to a conductive portion located at the first side of the of the integrated circuit package;

forming a plurality of through package vias, wherein the through package vias are located in a portion of the molded portion such that the at least one of the oDie and/or the eDie are located between two through package vias of the plurality of through package vias in a cross-section view; and

coupling an optical interconnect to the oDie, wherein the optical interconnect is arranged and configured to receive light from an optical fiber and to forward the light to a detector portion of the oDie.

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