APPARATUS HAVING AN OFF-SUBSTRATE OPTICAL INTERCONNECT AND METHODS OF MAKING THE SAME

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ABSTRACT

Apparatus having an off-substrate optical interconnect and methods of making the same are disclosed. A disclosed apparatus includes a substrate; a mounting connector mounted to the substrate; an integrated circuit mounted to the mounting connector; an optical transceiver mounted to the mounting connector and coupled to the integrated circuit to export and/or import data from and/or to the integrated circuit; and an optical interconnect coupled to the optical transceiver to export and/or import the data from and/or to the optical transceiver without passing the data through the substrate.
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RELATED APPLICATION

[0001] This patent issued from a continuation-in-part of U.S. patent application Ser. No. 10/109,313, which was filed on Mar. 28, 2002, which is hereby incorporated by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] This disclosure relates generally to circuit architecture, and, more particularly, to apparatus having an off-substrate optical interconnect and methods of making the same.

BACKGROUND

[0003] Integrated circuits are frequently mounted to a substrate such as a printed circuit board (e.g., a motherboard) via a socket or other connector. As a result, it has been necessary to route both the power lines supplying power to the integrated circuit and the input/output lines carrying data to and from the chip through the substrate and mounting socket or connector. In instances where no socket or other mounting connector is employed, it has still been necessary to route both the power lines and the input/output lines through the substrate. The close proximity of the power lines and data lines required by this routing has resulted in interference between the same. Also, close routing of two or more data lines through the substrate and mounting connector (sometimes referred to as a “substrate package”) has sometimes resulted in undesirable cross-talk between those data lines.

[0004] There have been various attempts to address these problems. For example, to counteract undesirable interference and cross-talk, the power lines and/or the data lines have often been shielded through conventional line shielding techniques. In addition to line shielding, circuit designers have sometimes used complex routing methods to separate the lines as much as possible. For example, circuit designers have routed the power and/or data lines through multiple layers of the substrate in an effort to achieve line separation. Unfortunately, line shielding, complex routing techniques, and/or multiple layer substrates typically result in increased cost and/or size.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a schematic illustration of a first example circuit coupled to a second example circuit via an optical interconnect.

[0006] FIG. 2 is a more detailed schematic illustration of an example circuit employing an optical interconnect to export/import data.

DETAILED DESCRIPTION

[0007] FIG. 1 is a schematic illustration of a first example circuit 10 coupled to a second example circuit 100 via an optical interconnect 200. The first example circuit 10 includes a substrate 12. The substrate 12 may be any type of substrate. For example, the substrate 12 may be implemented by a printed circuit board.

[0008] In the illustrated example, an integrated circuit or chip 14 is mounted to the substrate 12. The integrated circuit 14 (e.g., a microprocessor) may perform any desired function and/or purpose, and may be mounted to the substrate 12 in any conventional fashion (e.g., the integrated circuit 14 may be implemented as a flip chip). For example, the integrated circuit 14 may be mounted to the substrate 12 via a conventional socket or connector of any type (collectively referred to herein as a “mounting connector” or “substrate package”). The integrated circuit 14 may be located within a package that cooperates with the mounting connector. Alternatively, the integrated circuit 14 may not be mounted within a package and/or the integrated circuit 14 may be mounted directly to the substrate 12 without using a mounting connector.

[0009] As shown in FIG. 1, the integrated circuit 14 is supplied with power via one or more power lines 16. The power lines 16 are routed to the integrated circuit 14 through the substrate 12 in a conventional fashion. If, as is conventional, the integrated circuit 14 is coupled to the substrate 12 via a mounting connector, the power lines 16 are coupled to corresponding lines formed in the mounting connector which, in turn, are connected to the integrated circuit 14.

[0010] Significantly, at least some of the data lines to input and/or output data to and/or from the integrated circuit 14 are not routed through the substrate or mounting connector. Instead, the circuit 10 shown in FIG. 1 is provided with an optical transceiver 18 which is coupled to the integrated circuit 14 to import and/or export data to and/or from the integrated circuit 14 without passing that data through the substrate 12 and/or through the mounting connector. The optical transceiver 18 may be integrated within the integrated circuit 14 or may be a separate structure. Irrespective of whether the optical transceiver 18 is separate from the integrated circuit 14, the optical transceiver 18 and the integrated circuit 14 may be mounted to the substrate 12 via the same mounting connector and/or contained within the same package. As shown in FIG. 1, like the integrated circuit 14, the optical transceiver 18 may be provided with power via a power line 16 routed through the substrate 12 and/or the mounting connector.

[0011] Persons of ordinary skill in the art will appreciate that, as used herein, the phrase “passing through the substrate” and the phrase “routing through the substrate” are intended to have the same meaning. In particular, both phrases are intended to mean “at least partially on or beneath a surface of the substrate.” Therefore, a circuit line that is printed on the top or bottom surface of a substrate, (either partially or in its entirety), and a circuit line that is located partially or entirely beneath a surface of the substrate (e.g., within the substrate, see line 16 of FIG. 1) all “pass through the substrate” as that phrase is used in this patent.

[0012] In the illustrated example, the second example circuit 100 is similar to the first example circuit 10. Like the first example circuit 10, the second example circuit 100 includes a substrate 112. The substrate 112 may be any type of substrate. For example, the substrate 112 may be implemented by a printed circuit board.

[0013] As with the first example circuit 10, an integrated circuit or chip 114 is mounted to the substrate 112 of the second example circuit 100. The integrated circuit 114 may perform any desired function and/or purpose, and may be
mounted to the substrate 112 in any conventional fashion. For example, the integrated circuit 114 may be mounted to the substrate 112 via a conventional mounting connector of any type or may be mounted directly to the substrate without an intervening mounting connector.

[0014] In the example of FIG. 1, the integrated circuit 114 is supplied with power via one or more power lines 116. In the illustrated example, the power lines 116 are routed through the substrate 112 in a conventional fashion, but other power delivery approaches may alternatively be employed. In the conventional approach, if the integrated circuit 114 is coupled to the substrate 112 via a mounting connector, the power lines 116 are coupled to corresponding lines formed in the mounting connector which, in turn, are connected to the integrated circuit 114.

[0015] As in the first example circuit 10, at least some of the data lines to input and/or output data to and/or from the integrated circuit 114 of the second example circuit 100 are not routed through the substrate 112 or the mounting connector. Instead, the circuit 100 shown in FIG. 1 is provided with an optical transceiver 118 which is coupled to the integrated circuit 114 to import and/or export data to and/or from the integrated circuit 114 without passing that data through the substrate or through the mounting connector. The optical transceiver 118 may be within the integrated circuit 114 or may be a separate structure. Regardless of whether the optical transceiver 118 is separate from the integrated circuit 114, the optical transceiver 118 and the integrated circuit 114 may be mounted to the substrate 112 via the same mounting connector and/or may be contained within the same package. As shown in FIG. 1, like the integrated circuit 114, the optical transceiver 118 may be provided with power via a power line 116 routed through the substrate 112 and/or the mounting connector.

[0016] In the example of FIG. 1, the optical transceiver 18 of the first example circuit 10 is coupled to the optical transceiver 118 of the second example circuit 100 via the optical interconnect 200. The optical interconnect 200 may be implemented by, for example, an optical cable such as a waveguide, an optical fiber, a waveguide array, and/or an optical fiber ribbon. Each end of the optical interconnect 200 includes a connector.

[0017] To couple the optical transceivers 18, 118 to the optical interconnect 200, each of the first and second circuits 10, 100 is provided with an optical interconnect 22, 122. Each of the optical interconnects 22, 122 of the illustrated examples includes a connector 24, 124, and an optical cable 26, 126 (such as a waveguide, an optical fiber, a waveguide array and/or an optical fiber ribbon) optically coupling the optical transceiver 18, 118 to its associated connector 24, 124. The connector 24, 124 may be implemented by any type of connector. For example, the connector 24, 124 may be a pluggable connector or a permanent connector such as a splice.

[0018] The optical cable 26, 126 may be mounted to the corresponding substrate 12, 112 or free from the substrate 12, 112. Each of the connectors 24, 124 is structured to couple to a respective one of the connectors of the optical interconnect 200 such that one or more optical data transmission paths are formed between the optical transceivers 18, 118. In some examples, the optical interconnect 200 is eliminated and the connectors 24, 124 of the optical interconnects 22, 122 are connected directly to one another to couple the first and second circuits 10, 100. As shown in FIG. 1, irrespective of whether the optical cables 26, 126 are secured to the substrate 12, 112, the optical data transmission paths do not pass through the substrates 12, 112 or through the mounting connectors. As a result, the power lines 16, 116 of the first and second example circuits 12, 112 are separated from the data path(s) formed by the optical interconnect 200 and/or the optical interconnects 22, 122 to thereby reduce interference between the power carried by the power lines 16, 116 and the optical signals transmitted between the optical transceivers 18, 118.

[0019] A more detailed example circuit 300 is shown in FIG. 2. The example circuit 300 of FIG. 2 is similar to the first and second example circuits 10, 100 in that it includes a substrate 312, an integrated circuit 314 mounted to the substrate 312, an optical transceiver 318 coupled to the integrated circuit 314 and mounted to the substrate 312, and an optical interconnect 322. In the example of FIG. 2, the substrate 312 is implemented by a printed circuit board, the integrated circuit 314 is implemented by a flip chip, and the optical interconnect 322 is implemented by a waveguide 326 terminated in a pluggable connector 324.

[0020] In the example of FIG. 2, the optical transceiver 318 is separate from the integrated circuit 314. However, the optical transceiver 318 and the integrated circuit 314 are both mounted to the substrate 312 via the same package 330. The package 330 may be any type of package such as, for example a pin grid array (PGA) or a ball grid array (BGA) and may be mounted to the substrate 312 either directly or via any suitable type of mounting connector. Further, the waveguide 326 of the example circuit 300 is mounted to the surface of the substrate 312, but may alternatively be built directly on the substrate through, for example, a layered process. The length of the waveguide 326 is selected in the example of FIG. 2 such that the optical connector 324 is located near an edge of the package 330.

[0021] The power line(s) of the example circuit 300 are routed through the substrate 312 and the mounting connector (if present), but at least some, and preferably all, of the data lines are not passed through the substrate 312 or the mounting connector. Instead, the data lines for importing and/or exporting data to and/or from the integrated circuit 314 are routed through the optical interconnect 322. As explained above, this separation of the data lines and the power delivery line(s) reduces electromagnetic interference (EMI), reduces the complexity of the substrate 312, increases the available bandwidth for data import and/or export, and reduces cross-talk between the data lines.

[0022] To assemble any of the example circuits 10, 100, 300 discussed above, a substrate 12, 112, 312 is first constructed via conventional methods. However, unlike conventional substrates, the substrate 12, 112, 312 may be constructed to include only the power delivery line(s) and/or to include some, but not all, of the data input and/or output lines. Once the substrate 12, 112, 312 is constructed, the integrated circuit 14, 114, 314 and/or the optical transceiver 18, 118, 318 are mounted on the substrate 12, 112, 312 using conventional mounting techniques. For example, a mounting connector may be mounted to the substrate 12, 112, 312 via soldering or the like and one or both of the integrated
circuit 14, 114, 314 and/or the optical transceiver 18, 118, 318 (which may be packaged together) may be mounted to the mounting connector.

[0023] Once the integrated circuit 14, 114, 314 and the optical transceiver 18, 118, 318 are mounted to the substrate 12, 112, 312, the optical cable (e.g., a waveguide or optical fiber) 26, 126, 326 of the optical interconnect 22, 122, 322 is aligned with the optical transceiver 18, 118, 318 and mounted to the substrate 12, 112, 312. The alignment of the optical transceiver 18, 118, 318 and the optical cable 26, 126, 326 may be passive or active. Persons of ordinary skill in the art will appreciate that an active alignment process is a process in which the optical transceiver 18, 118, 318 is energized and the downstream output through the optical cable 26, 126, 326 is measured while the relative positions of the optical transceiver 18, 118, 318 and the cable 26, 126, 326 are adjusted. Once the output through the cable 26, 126, 326 is maximized or substantially maximized, the relative positions of the optical transceiver 18, 118, 318 and the cable 26, 126, 326 are fixed.

[0024] The circuit 10, 100, 300 may then be coupled to a second circuit, (which may or may not be constructed in the manner explained above), by connecting an optical interconnect 22, 122, 200, 322 such as a fiber, a waveguide, a fiber ribbon, or a waveguide array to the optical connector 24, 124, 324 such that data may be passed in at least one direction between the first and second circuits without passing that data through the substrate 12, 112, 312 or a mounting connector coupled to the substrate 12, 112, 312.

[0025] From the foregoing, persons of ordinary skill in the art will appreciate that the above disclosed methods and apparatus are advantageous in that they are compact, they reduce or eliminate the need for line shielding, they simplify routing relative to conventional circuits, and they achieve reduced signal attenuation and, thus, may be used to carry signals over greater distances than traditional circuits. For example, the optical cable 24, 124, 324 is not limited to the motherboard dimensions, but instead may extend to many meters. Additionally, the disclosed apparatus are scalable since optical fibers have bandwidth in the terahertz range.

Further, these advantages are achieved while reducing electromagnetic interference (EMI) and cross-talk associated with other techniques.

[0026] Although certain example methods, apparatus and articles of manufacture have been described herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus and articles of manufacture fairly falling within the scope of the appended claims either literally or under the doctrine of equivalents.

What is claimed is:
1. A circuit comprising:
a substrate;
a mounting connector mounted to the substrate;
an integrated circuit mounted to the mounting connector;
an optical transceiver mounted to the mounting connector and coupled to the integrated circuit to import and/or export data to and/or from the integrated circuit; and
an optical interconnect coupled to the optical transceiver to import and/or export the data to and/or from the optical transceiver without passing the data through the substrate.
2. A circuit as defined in claim 1 wherein the optical interconnect comprises:
a connector; and
at least one of a waveguide and an optical fiber optically coupling the optical transceiver to the connector.
3. A circuit as defined in claim 1 wherein the optical transceiver and the integrated circuit are mounted within a common package.
4. A circuit as defined in claim 3 wherein the connector is disposed near an edge of the package.
5. A circuit as defined in claim 1 wherein the substrate comprises a printed circuit board.
6. A circuit as defined in claim 1 further comprising a power line routed through the substrate to deliver power to at least one of the integrated circuit and the optical transceiver.
7. A circuit as defined in claim 6 wherein the power line is separated from the optical interconnect to reduce interference between the power line and the data transmitted by the optical transceiver.
8. A circuit as defined in claim 1 wherein the optical transceiver is integrated with the integrated circuit.
9. A circuit as defined in claim 1 further comprising a second circuit, the second circuit being separate from the substrate and comprising a second optical transceiver coupled to the optical interconnect.
10. A circuit as defined in claim 9 wherein the optical interconnect comprises a connector, at least one of a first waveguide array and a first optical fiber ribbon optically couples the optical transceiver to the connector, and the second optical transceiver is coupled to the connector by at least one of a second fiber ribbon and a second waveguide array.
11. A circuit as defined in claim 9 wherein the second circuit comprises an integrated circuit disposed on a second substrate.
12. A circuit as defined in claim 1 wherein the integrated circuit comprises at least one of a microprocessor and a flip chip.
13. A method of constructing a circuit comprising:
mounting an integrated circuit and an optical transceiver on a mounting connector mounted on a substrate, the optical transceiver being coupled to the integrated circuit to export and/or import data to and/or from the integrated circuit; and
coupling the optical transceiver to an optical interconnect structured to carry data to and/or from the optical transceiver without passing the data through the substrate.
14. A method as defined in claim 13 wherein the optical interconnect comprises:
a connector; and
at least one of a waveguide and an optical fiber optically coupling the optical transceiver to the connector.
15. A method as defined in claim 13 wherein mounting the integrated circuit and the optical transceiver on the mounting
A method as defined in claim 6 wherein the substrate comprises a printed circuit board.

18. A method as defined in claim 13 further comprising routing a power line through the substrate to deliver power to at least one of the integrated circuit and the optical transceiver.

19. A method as defined in claim 18 wherein the power line is separated from the optical interconnect to reduce interference between the power carried by the power line and the data carried by the optical interconnect.

20. A method as defined in claim 13 wherein the optical transceiver is integrated with the integrated circuit.

21. A method as defined in claim 13 wherein the substrate comprises a first substrate, the optical transceiver comprises a first optical transceiver, and the optical interconnect comprises a first optical interconnect, and further comprising:

mounting at least one of a second optical transceiver on a second mounting connector mounted on a second substrate separate from the first substrate;

coupling the second optical transceiver to a second optical interconnect structured to carry the data to and/or from the second optical transceiver without passing through the second substrate; and

coupling the first and second optical interconnects.

22. A circuit comprising:

a substrate;
a mounting connector mounted to the substrate;
an integrated circuit mounted to the mounting connector;
an optical transceiver mounted to the mounting connector and coupled to the integrated circuit to import and/or export data to and/or from the integrated circuit;
an optical interconnect coupled to the optical transceiver to import and/or export the data to and/or from the optical transceiver without passing the data through the substrate; and

a pluggable connector coupled to the optical interconnect.

23. A circuit as defined in claim 22 wherein the optical interconnect further comprises at least one of a waveguide and an optical fiber optically coupling the optical transceiver to the pluggable connector.