PHOTONIC COMMUNICATION PLATFORM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 62/961,448, entitled "PHOTONICS COMMUNICATIONS PLATFORM WITH SINGLE LITHOGRAPHIC MASK SET," filed on January 15, 2020 under Attorney Docket No. L0858.70013US02, which is hereby incorporated herein by reference in its entirety.

[0002] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 62/923,889, entitled "PHOTONICS COMMUNICATIONS PLATFORM WITH SINGLE LITHOGRAPHIC MASK SET," filed on October 21, 2019 under Attorney Docket No. L0858.70013US01, which is hereby incorporated herein by reference in its entirety.

[0003] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 62/814,444, entitled "PHOTONICS COMMUNICATIONS PLATFORM WITH LITHOGRAPHIC MASK SET," filed on March 6, 2019 under Attorney Docket No. L0858.70013US00, which is hereby incorporated herein by reference in its entirety.

FIELD OF INVENTION

[0004] The present application relates to photonic communication platforms and related methods.

BACKGROUND

[0005] Computer systems include random-access memories (RAM) for storing data and machine code. RAMs are typically volatile memories, such that the stored information is lost when power is removed. In modern implementations, memories take the form of integrated circuits. Each integrated circuit includes several memory cells. To enable access to stored data and machine code, memories are place in electrical communication with processors. Typically, these electrical communications are implemented as metal traces formed on the substrates on which the memories and the processors are disposed.

SUMMARY OF THE DISCLOSURE

[0006] According to a first aspect of the present invention, there is provided a photonic system comprising a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the

plurality of photonic modules including at least first and second photonic modules patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern. Each of the first and second photonic modules comprises first and second

[0016] There is disclosed a method for manufacturing a semiconductor wafer comprising: patterning each of at least some of a plurality of photonic modules on the semiconductor wafer using at least one common photomask, wherein patterning each of at least some of the plurality of photonic modules comprises: patterning an optical distribution network; patterning a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to a first boundary of the photonic module; and patterning a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to a second boundary of the photonic module.

[0017] In some embodiments, patterning each of at least some of the plurality of photonic modules comprises patterning the first and second optical waveguides using the at least one common photomask.

[0018] In some embodiments, the method further comprises dicing the semiconductor wafer to obtain a photonic substrate comprising: a first photonic module of the plurality of photonic modules; a first neighboring photonic module adjacent to the first boundary of the first photonic module; and a second neighboring photonic module adjacent to the second boundary of the first photonic module.

[0019] In some embodiments, the first and second boundaries of the first photonic module are opposite to one another.

[0020] In some embodiments, patterning each of at the at least some of the plurality of photonic modules further comprises: patterning a third optical waveguide optically coupling the optical distribution network to a third neighboring photonic module of the plurality of photonic modules, the third neighboring photonic module being adjacent to a third boundary of the photonic module; and patterning a fourth optical waveguide optically coupling the optical distribution network to a fourth neighboring photonic module of the plurality of photonic modules, the fourth neighboring photonic module being adjacent to a fourth boundary of the photonic module. The first and second boundaries are opposite to one another and the third and fourth boundaries are opposite to one another.

[0021] In some embodiments, patterning each of at least some of the plurality of photonic modules further comprises: patterning a first photonic module using a first photolithography shot in connection with the at least one common photomask; and patterning a second photonic

module using a second photolithography shot, subsequent to the first photolithography shot, in connection with the at least one common photomask.

[0022] According to a second aspect of the present invention, there is a computing system comprising a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the plurality of photonic modules including at least first and second photonic modules, each of the first and second photonic modules being patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern, wherein the first photonic module is optically coupled to the second photonic module; a first die in communication with the first photonic module; and a second die in communication with the second photonic module, wherein each of the first and second photonic modules comprises: first and second boundaries; an optical distribution network; a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to the first boundary; and a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to the second boundary.

[0023] In some embodiments, the first die comprises a processor and the second die comprises a memory.

[0024] In some embodiments, the computing system further comprises a laser die coupled to the photonic substrate.

[0025] In some embodiments, each of the first and second photonic modules comprises: first and second boundaries; an optical distribution network; a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to the first boundary; and a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to the second boundary.

[0026] In some embodiments, the first and second boundaries are opposite to one another.

[0027] In some embodiments, the first and second optical waveguides are patterned according to the at least one common photomask.

[0028] In some embodiments, each of the first and second photonic module comprises an out-of-plane optical coupler, wherein: the first die is optically coupled to the out-of-plane optical

coupler of the first photonic module, and the second die is optically coupled to the out-of-plane optical coupler of the second photonic module.

[0029] In some embodiments, the first die is coupled to a first side of the photonic substrate and the second die is coupled to a second side of the photonic substrate opposite the first side.

[0030] In some embodiments, the computing system further comprises a third die stacked on top of the first die.

[0031] In some embodiments, the first and second photonic modules share a boundary such that the first photonic module is adjacent to the second photonic module.

[0032] In some embodiments, the first die is mounted above or below the first photonic module; and the second die is mounted above or below the second photonic module.

[0033] In some embodiments, the first die is in electronic communication with the first photonic module, and the second die is in electronic communication with the second photonic module.

[0033a] According to a third aspect of the present invention, there is provided A computing system comprising:

a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the plurality of photonic modules including at least first and second photonic modules, each of the first and second photonic modules being patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern, wherein the first photonic module is optically coupled to the second photonic module and wherein each of the first and second photonic module comprises an out-of-plane optical coupler;

a first die optically coupled to the out-of-plane optical coupler of the first photonic module; and

a second die optically coupled to the out-of-plane optical coupler of the second photonic module.

[0034] There is disclosed a multi-node computing system comprising: a plurality of computing systems including at least first and second computing systems, each of the first and second computing systems comprising: a photonic substrate patterned with a plurality of photonic modules including at least first and second photonic modules, each of the first and second photonic modules being patterned according to at least one common photomask, wherein the first photonic module is optically coupled to the second photonic module; a first die in communication with the first photonic module; a second die in communication with the second photonic module; and a fiber connecting the first and second computing systems to one another.

[0035] In some embodiments, each of the first and second computing systems further comprises a fiber coupler, wherein the fiber optically couples respective fiber couplers of the first and second computing systems to one another.

[0036] In some embodiments, the first die comprises a processor and the second die comprises a memory.

[0037] In some embodiments, each of the first and second computing systems further comprises a laser coupled to the photonic substrate.

[0038] In some embodiments, each of the first and second photonic modules of the photonic substrate comprises: first and second boundaries; an optical distribution network; a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to the first boundary; and a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to the second boundary.

[0039] In some embodiments, the first and second optical waveguides are patterned according to the at least one common photomask.

[0040] In some embodiments, each of the first and second photonic modules comprises an out-of-plane optical coupler, wherein: the first die is optically coupled to the out-of-plane optical coupler of the first photonic module, and the second die is optically coupled to the out-of-plane optical coupler of the second photonic module.

[0041] In some embodiments, the first die is coupled to a first side of the photonic substrate and the second die is coupled to a second side of the photonic substrate opposite the first side.

[0042] In some embodiments, the multi-node computing system further comprises a third die stacked on top of the first die.

[0043] In some embodiments, the first and second photonic modules share a boundary such that the first photonic module is adjacent to the second photonic module.

[0044] In some embodiments, the first die is mounted above or below the first photonic module; and the second die is mounted above or below the second photonic module.

[0045] There is disclosed a photonic communication platform comprising: a photonic network comprising a plurality of optical switches formed on a semiconductor substrate; a plurality of dies in communication with the photonic network; an electronic switching network comprising a plurality of transistors co-integrated with the plurality of optical switches, the electronic switching network being configured to: at a first time, program the optical switches to form a first optical communication path coupling together a first subset of the plurality of dies, and at a second time subsequent to the first time, program the optical switches to form a second optical communication path coupling together a second subset of the plurality of dies, the second optical communication path being distinct from the first communication path.

[0046] In some embodiments, the plurality of transistors are formed on the semiconductor substrate.

[0047] In some embodiments, the semiconductor substrate is a first semiconductor substrate, and wherein the plurality of transistors are formed on a second semiconductor substrate, wherein the first and second semiconductor substrates are 3D-bonded together.

[0048] In some embodiments, programming the optical switches to form a first optical communication path comprises: identifying an optical communication path coupling together first subset of the plurality of dies; and programming the optical switches based on the identified optical communication path.

[0049] In some embodiments, identifying an optical communication path coupling together first subset of the plurality of dies comprises monitoring a usage of the photonic network.

[0050] In some embodiments, the electronic switching network is further configured to determine at least one characteristic of an optical signal at the first optical communication path;

CLAIMS

1. A photonic system comprising:

a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the plurality of photonic modules including at least first and second photonic modules patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern, each of the first and second photonic modules comprising:

first and second boundaries;

an optical distribution network;

a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to the first boundary; and

a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to the second boundary.

2. The photonic system of claim 1, wherein the first and second boundaries are opposite to one another.

3. The photonic system of claim 1, wherein the first and second optical waveguides are patterned according to the at least one common photomask.

4. The photonic system of claim 1, wherein each of the first and second photonic modules further comprises an out-of-plane optical coupler optically coupled to the optical distribution network.

5. The photonic system of claim 1, wherein the optical distribution network is configured to selectively place the first neighboring photonic module in optical communication with the second neighboring photonic module.

6. The photonic system of claim 1, wherein each of the first and second photonic modules is patterned according to a common set of photomasks, wherein the at least one common photomask is part of the common set of photomasks.

7. The photonic system of claim 1, wherein each of the first and second photonic modules further comprises:

third and fourth boundaries, wherein the first and second boundaries are opposite to one another and the third and fourth boundaries are opposite to one another;

a third optical waveguide optically coupling the optical distribution network to a third neighboring photonic module of the plurality of photonic modules, the third neighboring photonic module being adjacent to the third boundary; and

a fourth optical waveguide optically coupling the optical distribution network to a fourth neighboring photonic module of the plurality of photonic modules, the fourth neighboring photonic module being adjacent to the fourth boundary.

8. The photonic system of claim 7, wherein the optical distribution network is configured to selectively place the first neighboring photonic module in optical communication with the second neighboring photonic module or the third neighboring photonic module.

9. The photonic system of claim 1, wherein the optical distribution network comprises a plurality of optical switches.

10. The photonic system of claim 1, wherein the first and second photonic modules are adjacent to one another such that the second photonic module is the first neighboring photonic module for the first photonic module.

11. A computing system comprising:

a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the plurality of photonic modules including at least first and second photonic modules, each of the first and second photonic modules being patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern, wherein the first photonic module is optically coupled to the second photonic module;

a first die in communication with the first photonic module; and

a second die in communication with the second photonic module,

wherein each of the first and second photonic modules comprises:

first and second boundaries;

an optical distribution network;

a first optical waveguide optically coupling the optical distribution network to a first neighboring photonic module of the plurality of photonic modules, the first neighboring photonic module being adjacent to the first boundary; and

a second optical waveguide optically coupling the optical distribution network to a second neighboring photonic module of the plurality of photonic modules, the second neighboring photonic module being adjacent to the second boundary.

12. The computing system of claim 11, wherein the first die comprises a processor and the second die comprises a memory.

13. The computing system of claim 11, further comprising a laser die coupled to the photonic substrate.

14. The computing system of claim 11, wherein the first and second boundaries are opposite to one another.

15. The computing system of claim 11, wherein the first and second optical waveguides are patterned according to the at least one common photomask.

16. The computing system of claim 11, wherein each of the first and second photonic module comprises an out-of-plane optical coupler, wherein:

the first die is optically coupled to the out-of-plane optical coupler of the first photonic module, and

the second die is optically coupled to the out-of-plane optical coupler of the second photonic module.

17. The computing system of claim 11, wherein the first die is coupled to a first side of the photonic substrate and the second die is coupled to a second side of the photonic substrate opposite the first side.

18. The computing system of claim 11, further comprising a third die stacked on top of the first die.

19. The computing system of claim 11, wherein the first and second photonic modules share a boundary such that the first photonic module is adjacent to the second photonic module.

20. The computing system of claim 11, wherein:
the first die is mounted above or below the first photonic module; and
the second die is mounted above or below the second photonic module.

21. The computing system of claim 11, wherein:
the first die is in electronic communication with the first photonic module, and
the second die is in electronic communication with the second photonic module.

22. The computing system of claim 11, wherein the first and second photonic modules share at least one common layer pattern such that the first and second photonic modules share at least one common optical waveguide layer pattern.

23. The computing system of claim 11, wherein the first and second photonic modules share at least one common layer pattern such that the first and second photonic modules share at least one common metal trace layer pattern.

24. A computing system comprising:
a photonic substrate patterned with a plurality of photonic modules such that the plurality of photonic modules are embedded in the photonic substrate, the plurality of photonic modules including at least first and second photonic modules, each of the first and second photonic modules being patterned according to at least one common photomask such that the first and second photonic modules share at least one common layer pattern, wherein the first photonic

module is optically coupled to the second photonic module and wherein each of the first and second photonic module comprises an out-of-plane optical coupler;

a first die optically coupled to the out-of-plane optical coupler of the first photonic module; and

a second die optically coupled to the out-of-plane optical coupler of the second photonic module.

25. The computing system of claim 24, wherein the first and second photonic modules share a boundary such that the first photonic module is adjacent to the second photonic module.

26. The computing system of claim 24, wherein:
the first die is mounted above or below the first photonic module; and
the second die is mounted above or below the second photonic module.

27. The computing system of claim 24, wherein:
the first die is in electronic communication with the first photonic module, and
the second die is in electronic communication with the second photonic module.

28. The computing system of claim 24, wherein the first die comprises a processor and the second die comprises a memory.