Hybrid-Integrated Optical Transceiver on an OE PCB

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***Abstract*—An optical transceiver, integrating the receiver and transmitter optoelectronic modules with a polymer Y-splitter onto a low-cost single-layered FR4 substrate, is reported. The transceiver is produced with conventional PCB manufacturing methods, employs simple electro-optic connectors and supports bidirectional 10 Gb/s data transmission along a single optical fiber.**

Keywords- optical interconnects; opto-electronic printed circuit boards; polymer waveguides;

I. Introduction

Board-level optical interconnects have constituted an area of intensive research in recent years due to the increasing demand for large interconnection bandwidth in datacommunication systems and supercomputing applications. Successful integration of photonic components with electronics on conventional printed circuit boards (PCBs) requires the use of materials with suitable mechanical, thermal and optical properties and the development of cost-effective packaging and assembly processes. Polymer multimode waveguides are a promising candidate for use in board-level optical links as they can be cost-effectively integrated onto standard PCBs and offer relaxed alignment tolerances. Various board-level optical interconnection schemes deploying such waveguide structures have been demonstrated. These differ with respect to the board design, integration method and packaging and assembly schemes employed. In most cases, however, the on-board electro-optic integration is based on the use of either advanced optical components such as mirror structures and micro-lenses to achieve efficient optical coupling [1, 2] or multi-layered substrates pre-processed in order to interface the optical transmission medium with the electrical layer of the board [3, 4]. As a result, the overall cost and complexity of the fabrication and assembly of the opto-electronic (OE) PCB increase. In this paper, a straightforward alternative scheme for integrating optical waveguides onto low-cost single-layered FR4 substrates is reported. The integration method is based on the use of simple through-board connectors which are compatible with pick-and-place assembly processes and enable end-fired optical coupling schemes. The use of such optical coupling simplifies the design and fabrication of the optical transmission layer as the need for beam-turning elements is eliminated. An optical transceiver, integrating a polymer Y-splitter with the transmitter (Tx) and receiver (Rx) electrical modules on the same board, is produced with conventional PCB manufacturing processes. This transceiver, intended as a board-level optical network unit, can currently provide bidirectional communication either along a single optical fiber at data rates up to 10 Gb/s or between similar units at 6 Gb/s.

II. Electro-optic PCB integration and assembly

The design of the OE PCB is based on a single-layer FR4 substrate and assumes that the electronic and photonic components reside on different sides of the board. The top side of the board accommodates all electronic components and signal tracks, while the underside of the board supports the optical waveguides (Fig. 1). The interface between the optical and electrical layers of the board is achieved with simple electro-optic connectors that accommodate the active optoelectronic devices (laser and photodiode). These connectors are mounted in through-board slots appropriately produced to expose the waveguide facets and allow end-fired optical coupling in and out of the waveguides.

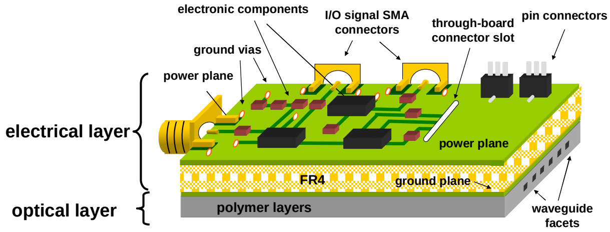

Figure 1. Schematic of OE PCB with various features noted.

The process flow for manufacturing the OE PCB comprises the following steps: (i) production of the electrical layouts on low-cost substrates, (ii) fabrication of the optical waveguides on the bottom board surface, (iii) attachment of the electronic components to the board with solder reflow process and (iv) production of the through-board connector slots using a milling machine. The substrate employed in this work consists of a 1 mm thick single-layered FR4 board with copper-plated vias and a uniform solder mask on the bottom copper surface (Fig. 2a). The electrical vias are employed to connect the ground tracks on the top of the board to the ground plane (bottom copper surface) while the uniform bottom solder mask is used to cover the vias, planarize the surface and minimize any mechanical and thermal stresses induced on the polymer layers during soldering. The polymer siloxane materials (OE-4140 and OE-4141) employed in this work are developed by Dow Corning and exhibit the essential mechanical and thermal properties to withstand the high-temperature environments associated with the soldering and lamination processes of standard PCB manufacturing [5]. The polymer materials are directly deposited over the solder mask on the underside of the

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board and can be patterned with various techniques such as printing and stamping. In this work, spin coating and photolithography are employed.

Having formed the optical and electrical layers of the OE PCB, compact L-shaped electro-optic connectors are used to accommodate the active devices, accurately position them opposite the waveguide facets and electrically connect them to the on-board circuits. The shape of the connectors is compatible with pick-and-place assembly tools and facilitates vertical and angular alignment with the waveguides owing to the two inside connector surfaces that serve as reference planes. Lateral alignment is achieved with alignment marks produced on the board surface and recognized by pick-and-place tools. The connectors are attached to the board with common adhesives, in this case Araldite. The electro-optic connectors used in this work are produced from 1.6 mm-thick FR4 substrates and carry device positioning pads as well as signal tracks and vias to efficiently route the signals from the board to the active devices (Fig. 2b).

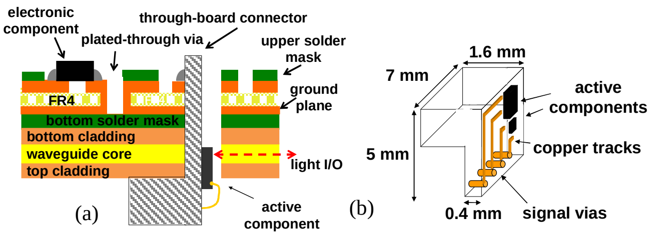

Figure 2. (a) Cross section of realised OE PCB with fitted electro-optic connector and (b) schematic of the L-connector with dimensions noted.

III. Optical Transceiver

The optical transceiver incorporates the Tx and Rx electrical modules and the polymer Y-splitter on a single-layered FR4 substrate (Fig. 3). The electrical layer comprises the laser and photodiode driving circuits, edge-mounted SMA connectors to provide the I/O data signals and voltage regulators to provide over-voltage protection to the circuits. All employed electronic components consist of low-cost commercially-available chips (Texas Instruments ONET8501V, ONET8511T) and surface-mount components. A low-cost multimode 850 nm 10 Gb/s VCSEL source and a 8 GHz GaAs photodiode with an aperture of 75 μm are used as the active components. The polymer Y-splitter has a cross section of 50×50 μm^2 and an index step of 0.2 to match standard 50/125 multimode fiber.

The data transmission performance of the optical transceiver is assessed with a digital communication analyzer and a bit-error-rate (BER) tester when the unit is interfaced with (i) external optical components (fiber-coupled high-speed receiver or VCSEL Fig. 4a) and (ii) a similar transceiver unit connected in a link configuration (Fig. 4b). When external optical components are employed, error-free (BER<10^{-12}) data transmission at 10 Gb/s is achieved for both the transmit and receive operation modes of the transceiver (Fig. 4c and 4d). For the link configuration, error-free data transmission at a lower rate of 6 Gb/s is obtained due to imperfections in the electrical driving circuits (Fig. 4e). The optimization of the electrical layer of the OE PCB is expected to enable 10 Gb/s operation for the link configuration. Results obtained from the optimized transceiver units will be presented in the conference.

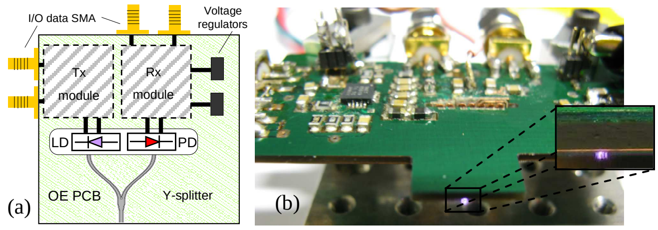

Figure 3. (a) Schematic of realised optical transceiver and (b) photograph of the actual unit with inset picture of illuminated output waveguide facet.

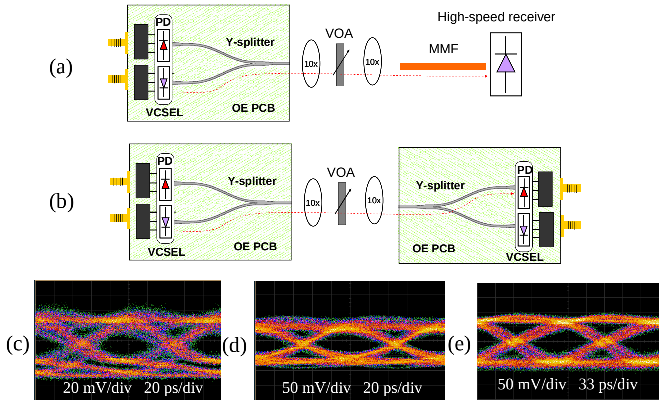

Figure 4. Link configurations when the optical transceiver is employed with: (a) an external optical component (high-speed fiber-coupled receiver) and corresponding received eye diagrams for (c) transmit and (d) receive operation mode at 10 Gb/s, and (b) in a link configuration with (e) corresponding received eye diagram at 6 Gb/s.

IV. Conclusion

A simple method of integrating photonics with electronic components onto low-cost substrates using conventional PCB manufacturing and pick-and-place assembly processes is presented. An optical transceiver incorporating a polymer Y-splitter along with the electronic circuitry on a single-layered FR4 substrate is produced. The transceiver supports bidirectional transmission along a single optical fiber at data rates up to 10 Gb/s.

References

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