# Compact and High-Density Opto-electronic Transceiver Module for Chip-to-Chip Optical Interconnects

**Tetsuya Mori, Makoto Fujiwara, Shinsuke Terada, and Koji Choki**
*Sumitomo Bakelite Co., Ltd., Circuitry with Optical Interconnection Business Development Dept.,*
*20-7 Kiyohara Kogyo Danchi, Utsunomiya, Tochigi, Japan*
*E-mail address: tetsuya@sumibe.co.jp*

**Abstract:** We fabricated an opto-electronic transceiver module on a flexible printed circuit board without using a lens array. 10Gbps data transmission through polynorbornene-based waveguide is achieved with low inter-channel cross talk.
**OCIS codes:** (250.0250) Optoelectronics; (250.3140) Integrated optoelectronic devices

## 1. Introduction

It's widely recognized in the optical interconnect community that in order to meet the increasing bandwidth demands of future high-performance computing systems, faster data transfer using polymer optical waveguides will become a promising technology in the emerging data-com market. Over the last few decades, much effort has been made toward making high performance opto-electronic (O/E) hybrid printed circuit boards (PCBs) to meet the demands [1,2].

Among others, "Terabus package" is perhaps the most successful in realizing more than 10Gbps data transfer [3]. In this system, a silicon carrier acted as a high-density, high-speed platform and dual-lens arrays were placed between the silicon carrier and a polymer waveguide, respectively to improve optical coupling efficiency.

However, this system requires complicated fabrication processes that include deep reactive ion etching (DRIE), chemical vapor deposition (CVD), backside grinding (BSG) and so on. Clearly this fact is not desirable from the point of view of low cost manufacture. Besides, incorporation of lens-arrays underneath the optochip makes it difficult to downsize the height of the overall package.

To overcome these issues, in this paper we propose a new concept of O/E transceiver module (Fig.1) where no lens arrays are used and copper wiring is made on a cost competitive conventional rigid/flex printed circuit board. As a preliminary test, a prototype to demonstrate this concept is fabricated and properties are discussed in detail.

## 2. Conceptual architecture of O/E module

Aiming at fabricating an O/E transceiver module, which comprises total of 48 waveguide channels in the near future, we propose a new conceptual architecture as illustrated in Figure 1. A number of solder bumps are fabricated onto a surrounding square rigid substrate. Vertical-cavity surface-emitting laser (VCSEL), photodiode (PD), driver IC and TIA and a limiting amplifier (TIA/LA) are surface mounted onto a FPC substrate located inside the rigid substrate. The architectural feature of this package is that the height of VCSEL/PD chips is designed not to exceed that of rigid substrate. Owing to this, it becomes possible to align the chips in close proximity to the 45-degree mirrors without using any lens arrays, since the chips and mirrors are facing each other through an intervening polyimide layer.

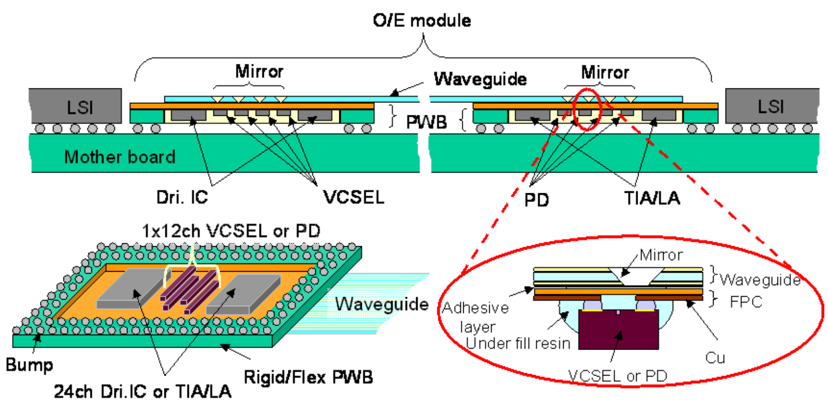



Figure 1. Overview of a conceptual architecture of O/E module

## 3. Fabrication of waveguide arrays with 45-degree mirrors

Both 40-cm and 12-cm long polynorbornene based waveguide arrays were fabricated using our proprietary "Photo-addressing" technique [4]. Thickness of the core is 40μm and to cope with higher-density optical interconnection, each width of Line/Pitch (L/P) is designed to be 40μm/62.5μm. Propagation loss of the waveguide was measured using a cut-back method and determined to be 0.043dB/cm. In the photo-patterning process, UV direct imaging method was employed instead of using a conventional photo-mask exposure method. Mirrors were fabricated using ArF excimer laser on specific designated areas as shown in Figure2.

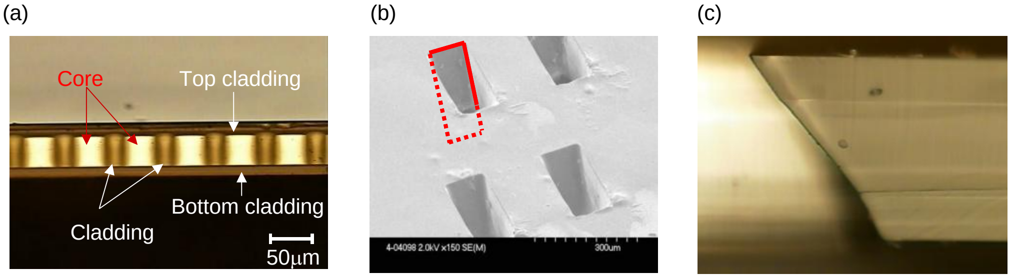



Figure 2. (a) a cross-sectional photograph of waveguide arrays, (b) a SEM image and (c) a cross-sectional photograph of 45-degree mirrors.

## 4. Fabrication of prototype O/E modules

To prove the concept more easily, Tx prototypes were fabricated where two 4-channel VCSEL chips and a driver IC were mounted on a FPC substrate. At chip mounting areas, the widths of L/P of copper wiring are designed to be 15μm/30μm. Two VCSEL chips were precisely flip-chip attached onto a FPC substrate directly above mirror portions as illustrated in Figure 3.

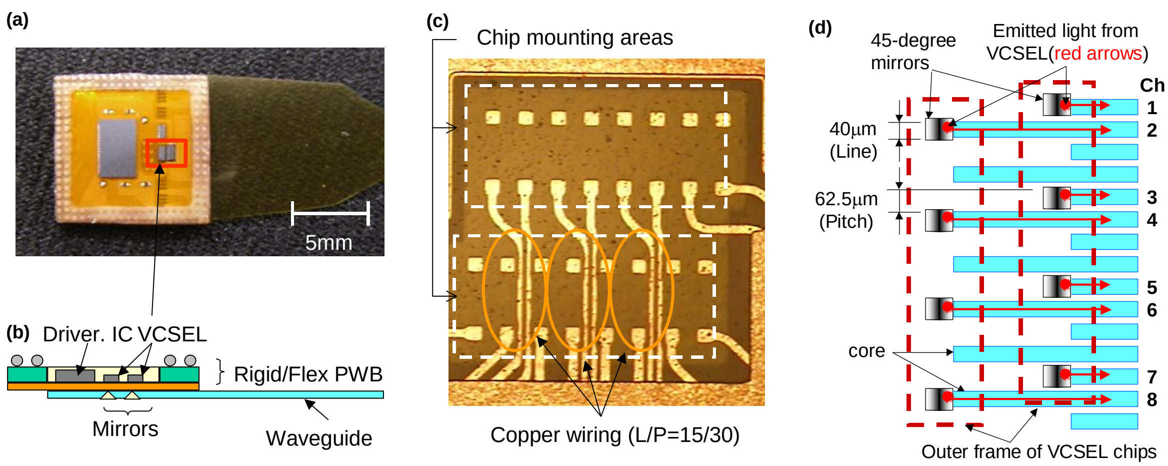
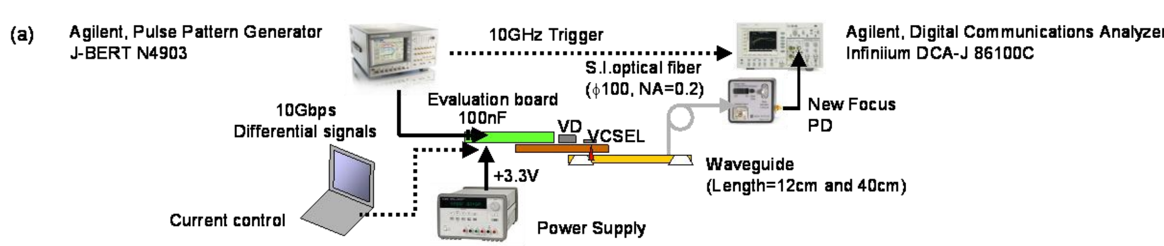



Figure 3 (a) a top view and (b) a cross-sectional view of the Tx prototype module. (c) Geometry of chip mounting areas and copper wiring design. (d) Geometry of VCSEL chips, mirrors and waveguide arrays.

## 5. 10Gbps data transmission

Differential signals with a data rate of 10Gbps were generated from a pulse pattern generator and conveyed through an evaluation board to a VCSEL chip. Emitted light at a wavelength of 850nm was reflected and guided into a waveguide via 45-degree mirror and the propagated light was collected using a 100μm diameter step index (SI) optical fiber.



(b)

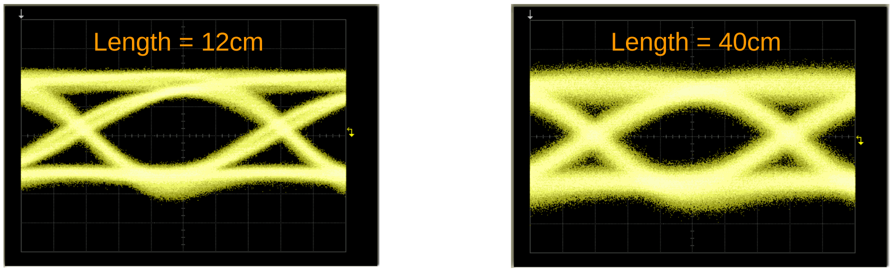



Fig.4. (a) Measurement setup and (b) eye diagrams

Finally, the output waveforms through 12-cm and 40-cm long waveguides were detected from an oscilloscope using co-axial cables. Eye diagrams in Figure 4 demonstrate 10Gbps data transmissions successfully.

## 6. Inter-Channel Crosstalk Properties

Crosstalk is defined as in the following equation (1), where $P_0$ is the output power of the emitted core and $P_x$ is the output power detected at a mirror portion in the corresponding adjacent cores.

$$\text{Crosstalk} = 10 \log (P_x/P_0) \qquad (1)$$

Each value of crosstalk at 850nm after propagation through 12-cm long waveguide is measured as shown in Figure 5. All of them are found to be smaller than –25dB.

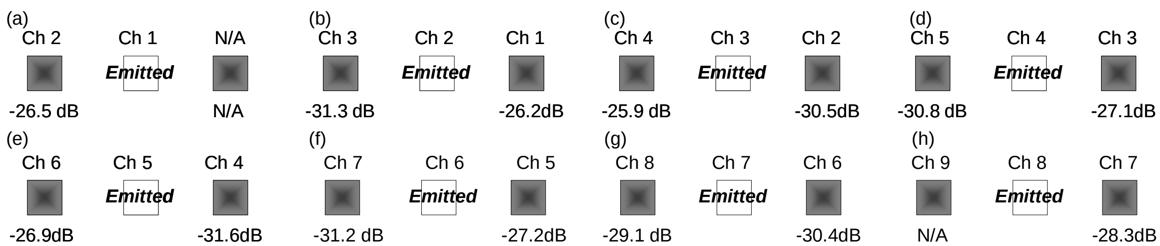



Fig.5. Inter-channel crosstalk

## 7. Conclusion

Tx prototype modules where two 4-channel VCSEL chips are mounted parallel to each other on a cost-effective rigid/flex printed circuit board are presented. To make a module as compact as possible, no micro lens arrays are employed. To pursue a high-density package, waveguide arrays with L/P of 40μm/62.5μm are successfully fabricated using “Photo-addressing" technique and dense copper wiring is pursued as well. The waveguides exhibit low propagation loss and capability of 10Gbps data transmission with low inter-channel crosstalk is demonstrated. We envision that these results will become strong foundations to realize a conceptual O/E transceiver module in the near future.

## 8. References

[1] Ma, H., Jen, A. K.-Y., and Dalton, L. R., "Polymer-Based Optical Waveguides: Materials, Processing, and Devices," Adv. Matter., 14/2002, Vol. 19, 1339-1365 (2002).
[2] P. Pepeljugoski et al, “Low Power and High Density Optical Interconnections for Future Supercomputers,” in Optical Fiber Communication Conference, OSA Technical Digest (CD), paper OThX2 (2010)
[3] Fuad E. Doany et al, “300-Gb/s 24-Channel Bidirectional Si Carrier Transceiver Optochip for Board-Level Interconnects,” in Electronic Components and Technology Conference, pp238 (2008)
[4] T. Mori et al, “Optical and electrical hybrid flexible printed circuit boards with unique photo-defined polymer waveguide layers,” in Proc. SPIE, Vol. 7607, 76070S (2010)