European Conference on Optical Communication (ECOC) 2022 © Optica Publishing Group 2022

An 800 Gb/s, 16 channel, VCSEL-based, co-packaged transceiver with fast laser sparing

D. Kuchta(1), M. Meghelli(1), P. Pepeljugoski(1), L. Schares(1), M. Schultz(1), P. Maniotis(1), P. Fortier(2), E. Tucotte(2), C. Bureau(2), M. Pion(2), Y. Cossette(2), G. Jutras(2), B. Sow(2), B. Parikh(3), S. Ostrander(3), S. Li(3), D. Becker(3), F. Gholami(3), H. Bagheri(3), M. Kapfhammer(3), H. Toy(3), F. Flens(4), G. Light(4), B. Wang(4)

(1) IBM Thomas J. Watson Research Center, Yorktown Heights, NY 10598, USA, kuchta@us.ibm.com
(2) IBM Bromont, 23 Boul De L'eroport, Bromont QC Canada J2L 1S8
(3) IBM Systems, Poughkeepsie, NY 12601, USA
(4) II-VI Finisar Inc. 48800 Milmont Drive, Fremont CA 94538, USA

Abstract *We report on high speed, low power, and sparing characteristics of the transmitter portion of an 800 Gb/s co-packaged transceiver using VCSELs and 2:1 sparing for improved reliability. The transmitter consumes 2.7 pJ/bit including the laser. The spare VCSEL can be enabled in < 100ns. ©2022 The Author(s)*

Introduction

Co-packaging of optical transceivers on first level packages with either large processor or switch ICs has become a recent topic of great interest. In the past year, the major conferences in this field have both hosted workshops [1,2] and panel sessions related to co-packaging as well as numerous invited and contributed talks. There is also activity within the Optical Internetworking Forum (OIF) to create a framework and specification for co-packaged optical transcievers [3]. The efforts within the OIF are aimed primarily towards Ethernet switching applications where link distances within a data center can range up to 2000m although the vast majority of the links are <<100m. A one-size fits all mentality is driving the co-packaging specifications towards single mode fiber only. It is also driving specifications for external lasers and socketed (not soldered) electrical interfaces. But within the High Peformance Computer space and now for AI training machines, link distances for CPU to xPU connections are typically <<50m, a distance that can be easily covered by multimode fiber. The drawers for these systems tend to be packed full, so space for external lasers is not readily available and the package laminate sizes tend to be smaller so area for transceiver sockets is not so large. This application space tends to use the cheapest available technology and for links of just a few meters, copper cables are ubiquitous. It is within this latter application space that we are developing a high speed, low energy, low cost optical transceiver for co-packaging which we call MOTION for Multiple wavelength Optical Transceiver Integrated On Node [4]. A great example of a similar multiwavelength VCSEL-based co-packaged optical transceiver effort can be found in [5]

In this paper, we focus on the characteristics of the 16 channel transmitter and in particular of the switching of the spare VCSELs which are included to increase reliability. We show all channels running at 50 Gb/s NRZ and a spare switching time of < 100ns.

MOTION Transceiver

The MOTION optical transceiver is built upon a glass substrate which serves as both the electrical and optical package. Figure 1 shows a picture of the glass substrate after the two ICs (separate 16 Ch. receiver and transmitter), VCSELs and Photodiodes have been flip chip soldered to it. Figure 2 shows a completed optical transceiver with heat spreader and optical fiber coupling elements on top and solderable organic interposer on the bottom. The solderable approach is taken because it consumes a smaller footprint on the package surface and has better signal integrity properties compared with sockets. Soldering is also viewed as being lower in cost than sockets. Few others in the co-packaging field are pursuing a soldered optical package but one notable exception can be found in [6].

The ICs are fabricated in a 55nm BiCMOS technology and require 2 supplies: 1.8v and 3.3v. Due to the nature of co-packaging in which these transceivers are placed within a few cm's of the data IC, these ICs do not contain retiming or CDR functions. They are fully dc coupled with CMOS compatible electrical interfaces. Each IC is 1.64 x 4.63 mm. There is a 16 channel PRBS generator in the Tx and a corresponding error detector in the Rx for testing purposes. The VCSELs operate in the 940nm range and the photodiodes can operate from 800-1100nm.

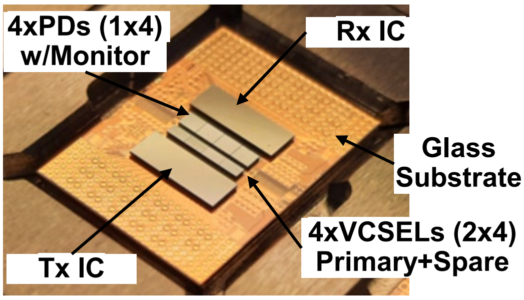

Fig. 1: Core components of the MOTION Transceiver

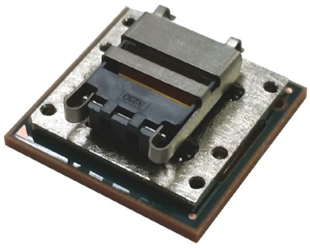

Fig. 2: Fully assembled 16+16 channel MOTION transceiver.

VCSEL Reliability and Sparing

In the co-packaging application, there is a concern for the overall reliability of the optical transceiver since it is placed very close to the main application IC which is very hot. In optical transceivers, the least reliable component is the laser. To address reliability concerns, sparing is often used for the laser. In our particular case, we have implemented 2:1 sparing, meaning that each channel has one primary laser and one spare. Both the primary and the spare laser can be efficiently coupled into the same fiber so no additional fibers are used. In a reliability simulation, the use of a spare laser showed almost a 1000x improvement in reliability over a 10 year period with the assumption that the spare was a 'hot' spare. In our implementation, the spare and it's driving circuitry are powered down making the spare closer to a 'cold' spare.

Figure 3 shows a die photo of the four channel VCSEL array which is arranged in two 1x4 rows, one for the Primary and the other for the Spare. The separation between rows is 285um.

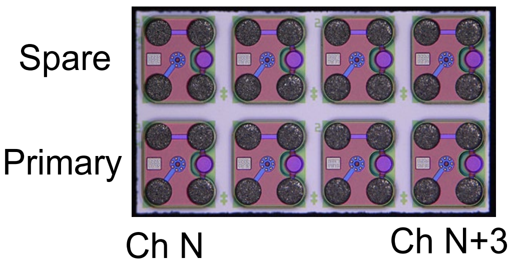

Fig. 3: Four channel VCSEL array showing Primary and Spare VCSELs

High Speed Characteristics

Figure 4 shows the transmitter's eye diagrams with all 16 channels running at 50 Gb/s NRZ using the primary VCSEL. The total power consumption is 2.23W which is equivalent to an energy of 2.7pJ/bit The average bias current is 9.6mA with a range from 7.3 to 12.4mA and the average modulation current is 8.3mA with a range from 6 to 9.1mA. The driver IC has three taps, main, FFE1 and FFE2. When the primary VCSEL is driven, FFE1 is turned on slightly (~10% of it's range) while FFE2 is either off or set to about 3% of it's range. The average extinction ratio is 1.78 with a range from 1.63 to 2.02. The average fiber coupled power is 2.91mW with a range from 1.64 to 3.35mW but it should be noted that this range includes variations in the package coupling elements as well as in the fiber ferrule.

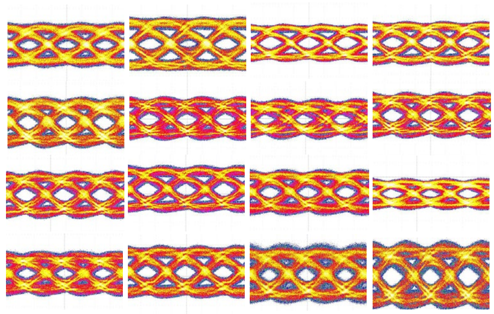

Fig. 4: Primary Channel Eye diagrams at 50 Gb/s/ch.

Figure 5 shows the eye diagrams from the spare VCSELs operating at 50 Gb/s. In this particular transmitter, one of the spare channels did not produce an eye for an unknown reason although optical power was present. It was found that the bias, modulation, and FFE settings needed to be slightly higher for the spare than for the primary channels. This is presumably due to the extra electrical path length connecting to the spares. The average bias was 0.8mA higher and the average modulation was 0.7mA higher. The biggest difference was in the FFE settings which were both increased to about 40% of their range. The average extinction ratio for the spares was 1.77.

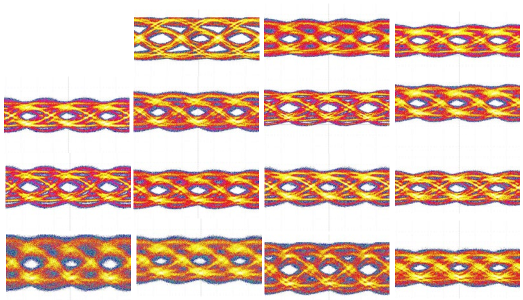

Fig. 5: Spare Channel Eye diagrams at 50 Gb/s/ch.

Fast VCSEL Sparing

Using 2:1 sparing is currently unique for parallel optical transceivers. It is of interest to investigate how quickly the spare can be switched into service. In this transceiver, the selection of primary and spare is set by a bit in a register that is accessed through the serial interface. By using a real time scope, with high speed data running at 20 Gb/s (for ease of triggering purposed), the switching between primary and spare can be captured. Figure 6 shows this capture. The top portion shows an upwards transient in the optical output during the switch from primary to sparing. The bottom portion shows the high speed eye diagram ~100ns later when it has settled about it's threshold. For this particular channel, the spare output power is slightly larger than the primary. In this circuit design with an emphasis on low energy usage, the spare circuitry was completely powered down. Some of the transients and delay are associated with turning on these circuits. It is possible to further reduce this switching time but at the expense of more power.

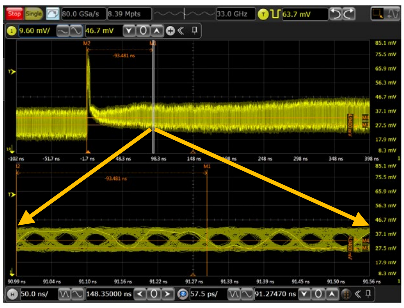

Fig. 6: Optical waveform showing sub 100ns Primary to Spare VCSEL switching. Top shows a 500ns view of the switching transient, Bottom is an expanded view ~100ns later when the eye is open again.

Packaging Feasibility study

Figure 7 shows a processor-like organic laminate module in various stages of assembly. The left side shows a laminate with a large IC in the center and 5 MOTION transceivers soldered around it. The center portion of figure 5 shows this same module with the heat spreader attached. The right portion of figure shows the module after the fiber strain reliefs and fibers have been inserted. These modules are assembled in preparation for a series of packaging feasibility studies which will include: Deep Thermal Cycling, Accelerated Thermal cycling, Thermal Aging, Temperature & Humidity, Temperature, Humidity and Bias, Power Cycling, Low Temperature Storage, and Shock & Vibe. These evaluations are being performed within the IBM Systems packaging team.

Conclusions

We have shown the characteristics of a 800 Gb/s, 16 channel transmitter which is part of co-packaged optical transceiver. All 16 primary channels operate at 50 Gb/s with an energy efficiency of 2.7pJ/bit including the laser. A unique characteristic of this transceiver is the 2:1 laser sparing. We have shown 50 Gb/s operation from the spare channels and characterized the speed of switching between primary and spare to be < 100ns. Additional results from the package feasibility studies will be available at the conference.

Acknowledgements

The authors acknowledge contributions from IBM Research (C. Baks, A. Benner, R. Budd, T. Dickson, F. Doany, W. Lee, M. Taubenblatt, P. Stark, H. Ainspan, Z. Toprak Deniz, S. Dhawan, T. Dickson, N. Dupuis, P. Francese, B. Sadhu, M. Kossel, T. Morf, M. Brändli, M. Cochet, C. Ozdag, A. Watanabe, H. Rahmani), IBM Systems (B. Meiswinkel, C. Muzzy, E. Steiner, D. Smith, T. Saunders, G. Pomerantz, J. Coffin, K. Marston, K. Smith, T. Ahmed, L. Rapp, Y.Yao, T. Wassick, M. Warbrick, T. Lombardi, B. Singh, C. Walker, S. Iruvanti, D. Yannitty, P. Ramaglia, T. Weiss, M. Interrante, J. Sorbello, C. Arvin, M. Stalter, A.

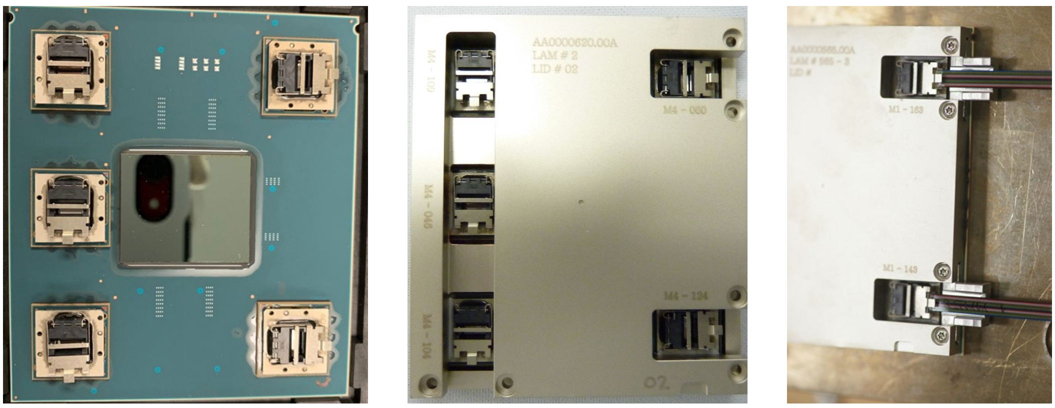

Fig. 7: (left) A processor-like module with 5 co-packaged optical transceivers before heatsink attach, (Center) Same as left but with heatsink attached, (Right) Same as Center but with strain relief and fiber cables attached.

Perez, P. Torbet, T. Olowofela, J. Bunt, M. Fisher, T. Childress, J. Mingo, C. Savoy, S. Ruiz, D.Kohler, R. Seifts, R. Olson, H. Polgrean, J. Rowland, C. Thomas, E. Kastberg, A. Schetter, D. Babcock, A. Greenberg, D. Lord, R. Rodriguez, C. Taylor, P. Minier, P. McInnes, S. Whitehead, R. Laning, D. Dreps, M. Hoffmeyer, J. Eagle, K. O'Connell, S. Canfield, S. Chun, R. Frota, K. Akasofu, C. Grosskopf, A. Tiano, T. Sass, E. Mallery, C. Setzer, J. Ross, K. Lange), IBM Bromont (P. Ducharme, S. Desputeau, A. Janta-Polczynski, C. Dufort), and II-VI Finisar(D. Case, P. Chen, J. Glover, C. Kocot, T. Nguyen, S. Pandy, S Quadery, K. Szczerba, S. Pandey, H. Hayashigatani). The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0000846. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

References

[1] ECOC 2021 Workshop, "Co-Packaging: How many fibers is too many?," ECOC 2021 Mo1C1-WS, Bordeaux, France, 2021.

[2] OFC 2022 Is Paradigm Shift from Pluggable Optics to Co-packaged Optics Inevitable in the Next Generation of Datacenters?," OFC 2022 Sunday workshops, San Diego, CA, USA, 2022.

[3] Optical Internetworking Forum (OIF) Co-Packaging Framework IA study https://www.oiforum.com/technical-work/hot-topics/co-packaging/

[4] D. Kuchta et al., "Multi-Wavelength Optical Transceivers Integrated on Node (MOTION)," 2019 Optical Fiber Communications Conference and Exhibition (OFC), 2019, pp. 1-3.

[5] M. Tan, "A CWDM Co-packaged optical module for short reach Data Center links," ECOC 2021 Mo1C1-WS, Bordeaux, France, 2021.

[6] K. Muth, "There can not be enough fiber! Co-packaged Optical I/O with Tomahawk Switch ," ECOC 2021 Mo1C1-WS, Bordeaux, France, 2021