OE – VCSEL based WDM modules: focus on manufacturing

Peter Guilfoyle*, Mitch Harris, Dhiraj Kumar, Dave Peters, and Duane Louderback
OptiComp Corporation, 183 Hwy. 50, P.O. Box 10779, Zephyr Cove, NV, 89448

ABSTRACT

OptiComp's WDM optoelectronic transceiver module includes a transmitter optical sub-assembly that is comprised of an array of WDM VCSELs directly coupled into an optical multiplexer, the receiver optical sub-assembly which optically demultiplexes the incoming light for photodetection by PIN photodiodes, and an embedded digital diagnostic monitoring interface that enables real-time control of the transceiver and monitoring of the operation status. The transceiver module package offers scalable, high-speed, high-density interconnects for demanding aerospace and space applications. The highly integrated device designs coupled with the modular approach reduces assembly time, increases yield and offers scalability in upgrading individual transceiver components at both the device-level and sub-assembly level without requiring a change in device design, fabrication process, or manufacturing qualifications.

Keywords: Optoelectronic transceiver, VCSEL, WDM, space, avionics, optical networks

1. INTRODUCTION

A significant challenge of optoelectronics for aerospace and defense applications is the tradeoff between reliability and cost[1] due to the need to assemble and qualify many individual components during the manufacturing process. Optoelectronic transceiver modules allow for improved robustness and manufacturing throughput due to the discrete nature of the individual modules for the transmitter, receiver and corresponding electronic controllers. The wavelength-division multiplexing (WDM) transceiver module discussed in this work incorporates vertical-cavity surface-emitting lasers (VCSELs) and high speed photodiodes in transmitter and receiver modules to achieve a rugged, compact, high-speed transceiver with low power consumption. The four-channel module operates at an aggregated 40Gbps and the design is highly-scalable without a significant increase in manufacturing complexity.

The modular approach to the manufacturing of the transceiver allows for higher yield since the components can be tested at the device, sub-assembly, and package levels. For both the VCSELs and photodetectors, all devices are tested at the wafer level prior to bonding onto the submount. This ensures that only the devices meeting the strict conformance requirements are bonded onto the submount arrays. The sub-assemblies can then also be tested individually to ensure successful bonding and operational characteristics prior to mounting onto the transmitter or receiver carrier.

2. DEVICE COMPONENTS

The primary device components of the transceiver assemblies are the VCSELs, photodetectors, and optical mounting benches. The highly integrated device designs used in the modules reduce the number of components that need to be assembled during the manufacturing process, which also improves the overall yield and reduces the assembly time. The components of the sub-assemblies can be fabricated in a parallel manner making efficient use of the fabrication facilities and allows for testing of components as they become available.

*peter@opticomp.com; phone: 775-588-4176; fax: 775-588-1348; www.opticomp.com

Enabling Photonics Technologies for Defense, Security, and Aerospace Applications V,
edited by Michael J. Hayduk, Peter J. Delfyett Jr., Andrew R. Pirich, Eric J. Donkor, Proc. of SPIE Vol. 7339,
733907 · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.820927

2.1 Vertical cavity surface emitting lasers

The high performance multimode VCSELs designed for this application are fabricated from a high-quality epitaxial growth having a multi-quantum well structure between highly-reflective DBRs grown on a gallium arsenide (GaAs) wafer. The range of wavelengths necessary for WDM is achieved by varying the material properties during the epitaxial growth; however, the fabrication process for the VCSELs of various wavelengths is unchanged. The VCSELs, shown in Fig. 1, have a small optical aperture which allows for high output power and low threshold currents in a very compact device that is able to operate over a large temperature range. The manufacturing process for the device components follows many Telecordia, MIL-SPEC and ISO standards in order to achieve high fabrication yields and ensure operational reliability. A representative VCSEL wafer recently fabricated by Opticomp Corp. had a 94.9% overall yield on wafer-level LIV testing with 98% having an output power greater than 5mW at 15mA, as illustrated in Fig. 2.

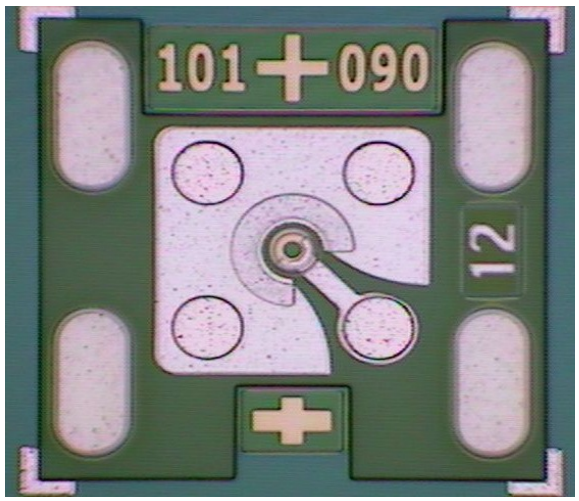

Fig. 1. VCSEL die fabricated on a GaAs wafer in OptiComp Corp. manufacturing facility. This device will be bonded to an optical mounting bench in the transceiver module.

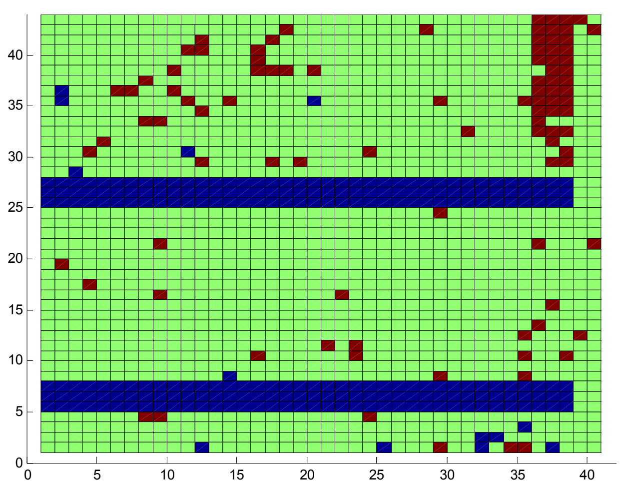

Fig. 2. Fabrication of VCSELs is a high yield process with nearly 95% passing all wafer-level LIV conformance, shown in green, versus those not passing (shown in red).

2.2 PIN photodiodes

The photodetectors are high-speed PIN photodiodes designed for operation over a large temperature range in order to eliminate the need for active cooling. The PIN photodiode is a robust, compact design that can be fabricated in a planar structure which improves the manufacturability, reliability, and ease of assembly. The mesa-etched InGaAs PIN photodiodes, shown in Fig. 3, are designed to operate at 10Gbps and have a responsivity greater than 0.65 A/W for the entire range of VCSEL wavelengths included in the transmitter module. Fig. 4 illustrates the eye diagram of a photodiode at 10Gbps operation of an Opticomp Corp. prototype WDM transceiver module.

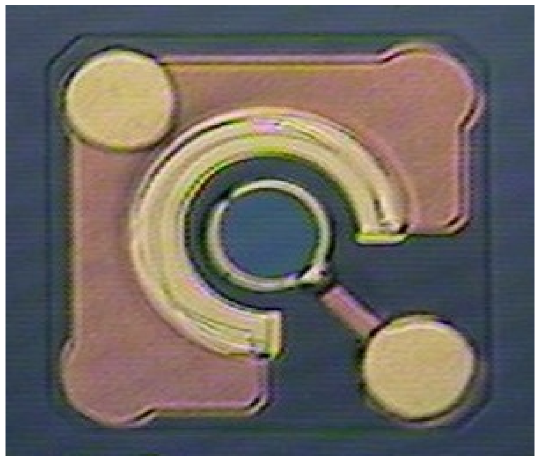

Fig. 3. PIN photodiode fabricated at OptiComp Corp. that can be bonded to an optical bench for a vertical submount in the receiver module.

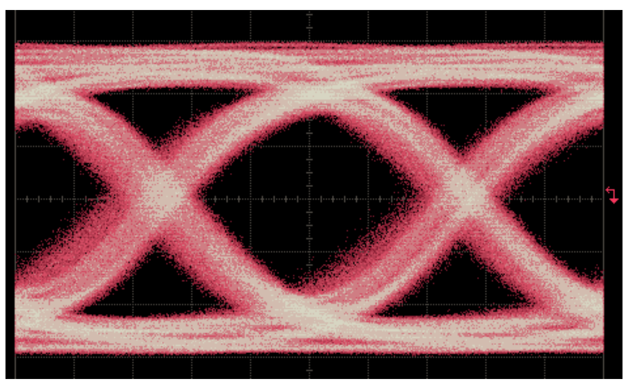

Fig. 4. Eye diagram of 10Gbps operation of an OptiComp Corp. prototype WDM transceiver module.

3. Transceiver Module Components

The transceiver will be housed in a hermetically sealed column grid array (CGA) ceramic package, with a dual fiber snout optical interface as illustrated in Fig. 5. The column grid array ceramic package offers a high-speed, high-density electrical interface for demanding aerospace and space applications. The solder columns, as compared to solder balls, provide a flexible interconnect that improves the thermal performance characteristics of the package solder joints by increasing heat dissipation and reducing thermal expansions issues. The package interior features two modular assemblies, the transmitter optical sub-assembly (TOSA) and the receiver optical sub-assembly (ROSA). The two optical sub-assemblies will be assembled and tested independently prior to being integrated onto the common optical board. Therefore, the modular approach ultimately increases assembly yield and offers high flexibility in upgrading individual transceiver components at both the device-level and sub-assembly level without requiring a change in device design, fabrication process or manufacturing qualifications.

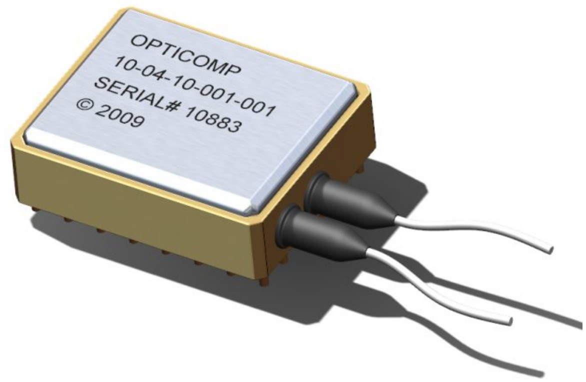

Fig. 5. Schematic of column grid array ceramic transceiver package.

Scalability is an additional benefit to the modular WDM transceiver approach. Specifically, the number of channels per module can be increased from 4 channels to 12 channels by substituting the optical benches that hold the respective VCSEL and photodetector arrays, carriers, mounts, driver chips, and the polymer waveguide, but the assembly process for both the transmitter and receiver optical sub-assemblies remains the same. Furthermore, the laser diode driver (LDD) and transimpedance amplifiers/limiting amplifiers (TIA/LA) can be replaced with compatible die for upgraded modulation speeds from 2.5 Gbps up to 10 Gbps. Another key aspect of the transceiver design is its operating temperature range of 0–85 °C without the use of any temperature control mechanism; therefore, significantly reducing the size, weight, and power consumption.

3.1 Transmitter optical sub-assembly

The transmitter optical sub-assembly is comprised of an array of VCSELs that are directly coupled into a waveguide optical multiplexer. Each VCSEL emission is coupled into an individual input waveguide and the waveguide multiplexer combines the individual signals into a common output waveguide that is directly coupled into a multimode fiber. The devices are mounted vertically with respect to the carrier plane by means of a vertical sub-mount, eliminating the need of an optical turning mirror.

The vertical sub-mount provides an electrical bridge between the VCSELs mounted on the vertical sub-mount and the laser diode driver that is die attached to the TOSA carrier board. An optical window, illustrated in 6, is laser drilled out of the transmitter vertical sub-mount to allow the waveguide multiplexer to pass through for direct coupling of the VCSEL emission.

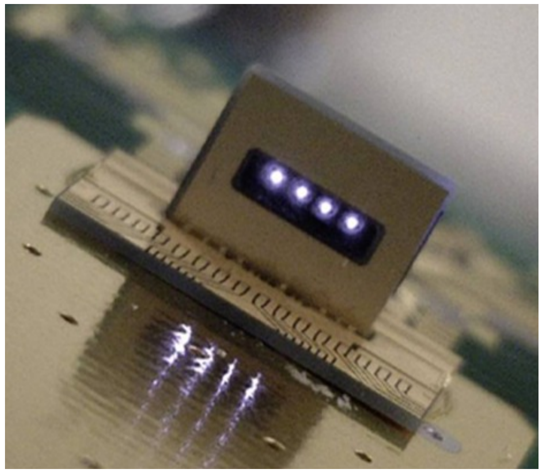

Fig. 6. Prototype transmitter sub-assembly with four VCSELs mounted on vertical submount.

The transmitter optical sub-assembly also incorporates monitor photodiodes that provide individual VCSEL emission power feedback to the microcontroller unit (MCU). The MCU, in turn, continually adjusts the VCSEL's drive current in order to achieve the target optical output power and allows for operation over a large range of temperatures, as illustrated in 7. This adjustment capability, as well as the coarse WDM design of the transceiver, enables low-cost, robust operation over much wider temperature ranges than can be achieved with single-mode, DWDM approaches[2].

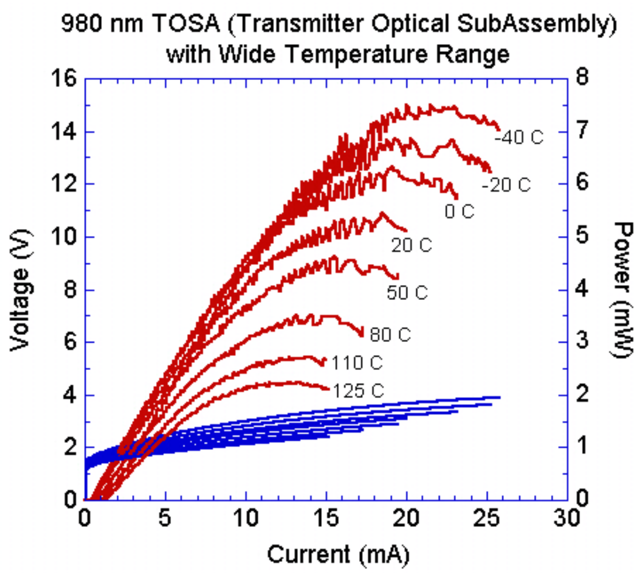

Fig. 7. Excellent operational characteristics of VCSELs over a wide temperature range eliminates the need for active cooling of the transceiver module.

3.2 Receiver optical sub-assembly

The receiver optical sub-assembly optically demultiplexes the incoming light corresponding to the individual wavelengths for photodetection by the PIN photodiodes. The demultiplexed beams propagate parallel to the carrier board and the photodetectors are mounted vertical to the propagation plane by means of the vertical optical bench sub-mount. Fig. 8 displays the emission spectrum of a 1x8 transmitter sub-assembly prototype module of after propagating through the demultiplexer and array of high-speed photodetectors.

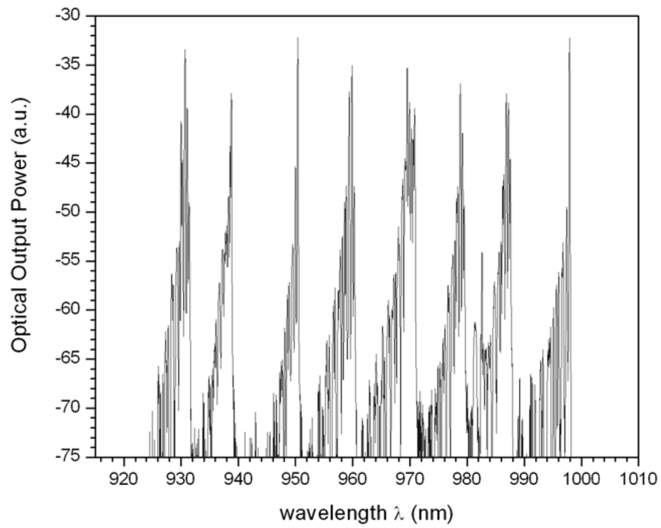

Fig.8. Channel outputs of VCSELs mounted on optical benches as observed in a prototype transceiver module.

3.3 Embedded DDMI

The embedded digital diagnostic monitoring interface (DDMI) of the transceiver enables the management and control of the transceiver functions through an I^2C interface. Therefore, the DDMI facilitates real-time module operation status and control of the transceiver. The DDMI schematic, illustrated in Fig. 6, describes a predefined control interface for a specific transceiver type. It is used to monitor transceiver operation, manage faults, and configure the transceiver for different network physical layers. The MCU, which manages the functions of the control and monitoring circuit, will interface to an analog to digital converter with several multiplexed inputs. Operational amplifiers, implemented in quad-amp packages, are used to convert the electrical power, generated when laser light is incident on the monitor photodetectors, into voltage ranges that are readable by the analog inputs. This analog data is used to optimize the VCSEL output power. Also, analog signals from the VCSEL and detector IC's are scanned for added diagnostics, monitoring, and fault detection.

External connections to the system are made through an integrated I^2C port on the MCU. This external I^2C connection conforms to the I^2C 2.1 Specification. The 2-wire serial connection (non-I^2C conformant) to the transceiver ICs is made with general purpose I/O on the MCU and protocol implementation is achieved in the MCU application code. The computer running the Control Center software communicates with the transceiver's MCU through a standard 2-wire I^2C interface device. Data retrieved from the MCU is graphically displayed by the user interface (UI), shown in Fig. 7, and control changes made in the UI software are sent to the MCU. All control changes made by the user in the UI are first verified by the MCU before any modifications to the transceiver's operating parameters are made.

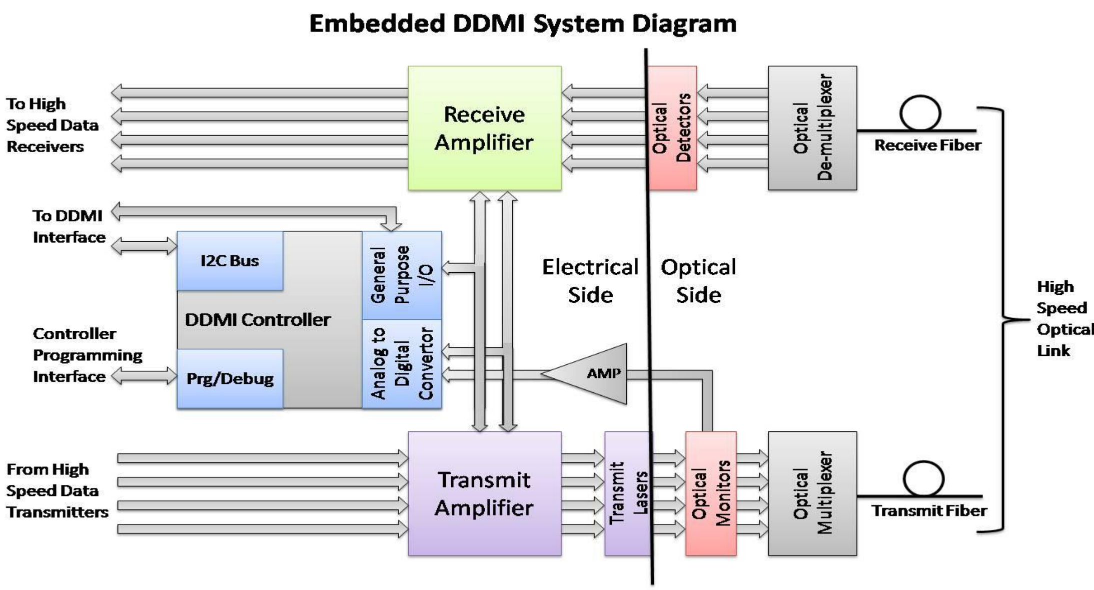

Fig. 6. DDMI system block diagram illustrating the various component of the transceiver module.

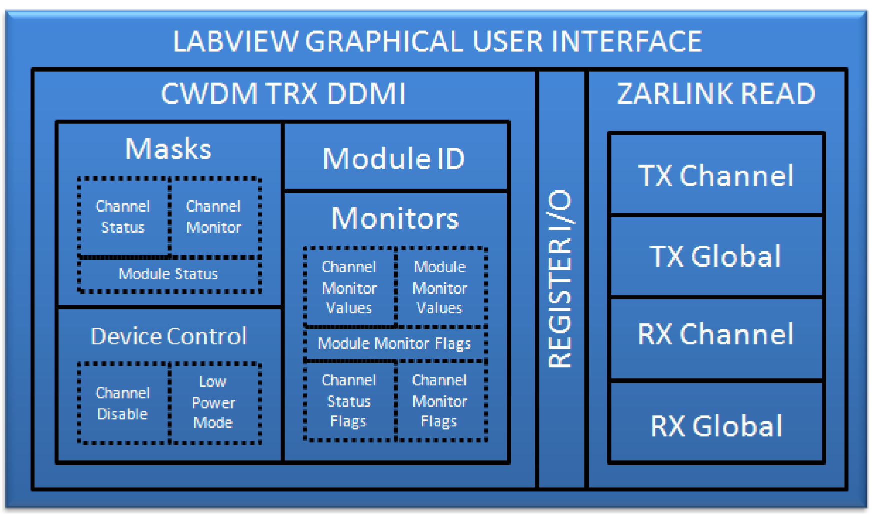

Fig. 7. LabView user interface architecture used for module development.

3.3.1 Processing Firmware

The firmware will continuously monitor transceiver operations and update the transceiver DDMI tables with monitoring data and fault interrupt flags. One global interrupt signal, available as a discrete hardware pin will trigger when any of the several other interrupt flags are asserted by the firmware. When the global interrupt is asserted it is the responsibility of the host network management system to read the DDMI tables from the OptiComp transceiver to determine which specific interrupt flag(s) are asserted. The firmware also supports interrupt masks to disable selected interrupts. Additional controls are available to the remote network management system. The ability to disable transmitter and receiver channels, adjust power levels, select alternate data rates, execute module 'applications' and disable transmit and receive squelch are implemented in the firmware.

Another function of the firmware is to monitor and adjust the VCSEL power for optimal operation. The photodiode output is scaled by an operational amplifier circuit, converted to digital, and made available to the firmware. The firmware compares the VCSEL output to predetermined operating limits and if adjustment is needed the firmware signals the VCSEL driver IC to increase or decrease the power supplied to the VCSEL.

3.3.2 DDMI Tables

The DDMI tables contain the data shared between the OptiComp transceiver and the network management system. The tables contain monitoring information for real-time diagnostics including analog values of module temperature, supply voltage, and receiver and transmitter power. Mask-able interrupts are also included to provide instant indication of faults including both alarms and warnings to indicate when a fault is critical, near critical, or a deteriorating condition. Examples of interrupts include:

- Loss of Signal (LOS) on Transmitter and Receiver
- General Transmitter Fault
- Temperature High and Low Warnings and Alarms
- Supply Voltage High and Low Warnings and Alarms
- Receiver Power High and Low Warnings and Alarms for each channel
- Transmitter Bias Current High and Low Warnings and Alarms for each channel

Identification information is stored in the DDMI tables to indicate to the network management system the capabilities of the OptiComp transceiver as well as manufacturer name, revision level, part number, and serial number.

4. Conclusion

The modular approach to the fabrication and assembly of the optoelectronic transceiver results in a lower cost, high yield manufacturing process by allowing for testing and qualification of components at multiple stages of production. The individual device components are designed to be compact, robust, and highly integrated allowing for reliable operation in the rugged environments encountered in defense and aerospace applications. The DDMI provides an accessible interface to the network management system for setup, control, and monitoring of the transceiver module providing stable operation over the large temperature ranges expected in extreme applications. The sub-assemblies are all readily scalable to a larger number of channels (fibers and/or wavelengths) for higher speeds by simply changing the submounts of the modules without a need change the system design or process qualifications making this a viable approach to highly reliable WDM transceiver manufacturing.

5. Acknowledgements

This work was supported in part by the Air Force Research Labs (AFRL).

References

[1] Aronsom, L. B., Lemoff, B. E., Buckman, L. A., and Dolfi, D. W., “Low-Cost Multimode WDM for Local Area Networks Up to 10 Gb/s,” IEEE Photon. Technol. Lett., 10(10), 1489-1491 (1998).

[2] Nagarajan, R., Kato, M., Joyner, C. H., Schneider, R. P., Back, J., Dentai, A. G., Desikan, T., Dominic, V. G., Evans, P. W., Kauffman, M., Lambert, D. J. H., Hurtt, S. K., Mathur, A., Mitchell, M. L., Missey, M. J., Murthy, S., Nilsson, A. C., Peters, F. H., Pleumeekers, J. L., Salvatore, R. A., Taylor, R. B., Van Leeuwen, M. F., Webjorn, J., Ziari, M., Grubb, S. G., Perkins, D., Reffle, M., Mehuys, D. G., Kish, F. A., and Welch, D. F., “Wide Temperature (25-85C)/Coolerless Operation of 100Gbit/s DWDM Photonic Integrated Circuit,” Electron. Lett., 41(10), 612-613 (2005).