Evolution of Optical Component Technologies for Access and Metro Networks

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Abstract: *Progress and innovation in a number of technologies including optoelectronic integration are leading to components for highly cost effective wavelength agile 40Gbps transport and will increasingly start to shape the next generations of broadband access and access – metro convergence.*

Introduction

In this paper we present key elements of the component development strategy within Oclaro to meet the changes being driven in network architectures to meet ever increasing bandwidth demands and cost expectations. Decisions on component and technology development have to anticipate and enable these changes, yet have to remain focused and relatively narrow from an affordability perspective. In the next five years we will see major changes in the traditional core, metro and access areas of the network and considerable convergence between them. Three major themes are optoelectronic integration – which is the foundation for cost reduction and scalability; tunability – which is now becoming all pervasive and will move to dominate most aspects of transmission, including the access edge, provided costs become sufficiently low. The third is in achieving high speed transport - 40 and 100Gbps at cost points which will drive and accelerate network evolution. There are common themes and related technologies linking these, which are outlined in the paper.

Network Evolution

It is the challenge of the optical component companies to enable the continuing exponential demand for bandwidth at ever decreasing cost per managed bit. Provided the technologies can be ahead of the curve and we execute efficiently, the component companies can be profitable, as volume will increase ahead of pricing, giving the vital growth in the business, further fuelling technology investment.

Two key trends which are clear in network evolution are the emergence of the Intelligent Photonic Core, enabled by reconfigurable optical add-drop multiplexers (ROADMs) and the growth and deployment of Optical Access networks, including PON and Point to Point. Both these are to some extent in their infancy, with the agile core being somewhat gated by ROADM cost and maturity. Fibre access rollout is now proceeding at an ever increasing pace and focus is shifting to ensure that the fibre infrastructure investment will be truly future proof, allowing for downstream evolution to beyond Gbps rates per subscriber and efficient backhaul/ access/ metro convergence.

Core network deployment is increasingly moving to 40 and eventually to 100Gbps on each wavelength, with 50GHz grid. At the optical layer this presents the ‘greenest’ solution, with ROADM and optical bypass networking enabling effectively dissipation free routing even at these higher bit rates. Full band tunability is an essential element working with the ROADM architecture, not only simplifying the supply chain and inventory but increasingly enabling the full flexibility of an optically agile network.

Cost Effective 40Gbps Transport

Current estimates of 40Gbps terminal costs are around 7X those of 10Gbps; it will cost require parity (4x) or even less to drive the deployment to conclusion. 100Gbps will be similar – these cost imperatives will not be reached simply by volume; new technologies and assembly methods are essential.

We have focused on the development of DQPSK coding for 40Gbps, as a concensus is building that this represents a sweet spot in the trade off between performance and complexity. Key advantages of DQPSK are resilience to chromatic and polarization-mode dispersion, together with reduced spectral width for compatibility with 50GHz DWDM spacing and the use of ROADMs. DQPSK is also advantageous compared to OOK in terms of OSNR performance. The use of RZ pulse shaping combined with DQPSK improves the nonlinear resilience of DQPSK for long-haul transmission, and provides almost equivalent OSNR performance to binary DPSK. To enable wide application of this approach, however, integration of optical functionality is required to provide high performance, compact size and cost effective manufacturing. This has been primarily achieved through high levels of optoelectronic integration on an InP platform, as illustrated in the figure below:

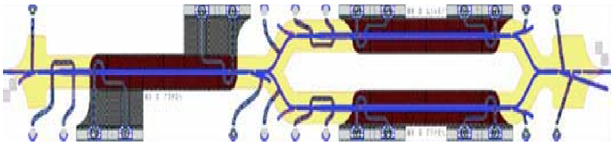

Figure 1 –InP RZ DQPSK modulator

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This chip include all the modulator elements for the provision and control of the RZ DQPSK format, can operate over either full C or L band and is in a minimal footprint that allows industry standard co-packaging with a full band tunable laser. The modulator chip has an overall length of only 7mm and includes the RZ pulse carver, the dual I/Q modulator configuration for DQPSK coding together will monitoring detectors and phase adjusters for set up. Figure 2(a) below shows a full band DQPSK transmitter incorporating the Oclaro DSDBR monolithic tunable laser. The assembly methods and layout are essentially identical to that used for our 10Gbps products, the only differences being in the modulator test methods.

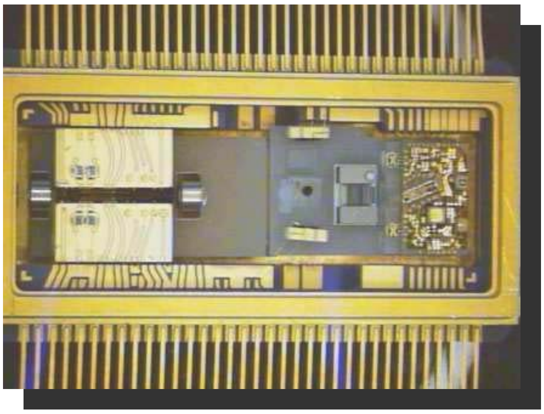

Fig 2(a). 40Gbps DQPSK transmitter

Fig, 2(b) Transmitter integrated into the TTA format

The receive end of the RZ-DQPSK transponder presents cost and technology challenges at least equal to that of the transmitter. The optical receiver requires the regeneration of the I and Q channels through, for instance, dual delay and add interferometers driving balanced detectors. Optical phase must be adjustable and controlled to give the correct eye opening. In our receiver we integrate the optical hybrid, phase controllers and the balanced detectors onto a monolithic InP chip, using processes similar to that used for the modulator. The one bit delay is implemented in simple micro-optics, thereby easing the requirements on polarisation. Figure 3 shows a prototype integrated receiver, incorporating the micro-optic delay and the InP receive chip. An additional aspect of cost reduction is the development of full surface mount technology for transponder assembly, where we have been working closely with the suppliers of the CDR and driver circuits to take this next step. Currently we are sampling transponders with discrete receivers and anticipate shipping transponders with the integrated unit early in 2010.

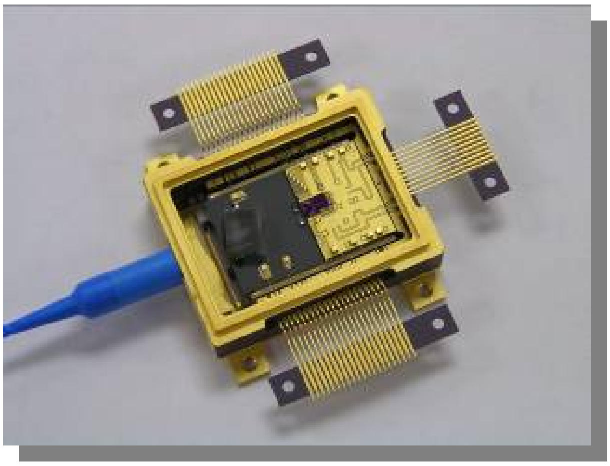

Figure 3 – Integrated DQPSK receiver

We believe with this level of complementary integration in both the receiver and transmitter, together with the surface mount electronics, 40Gbps transponders become manufacturable for the first time at price points which will rapidly accelerate deployment.

Many of the component building blocks, such as the modulators, lasers and the InP receive circuits are also forward compatible with the emerging coherent polarisation multiplexed QPSK standard for 100Gbps transport.

Tunability – The Next Steps

The DSDBR monolithic tunable laser has proven to be a highly manufacturable device with class leading performance. It has been widely deployed in many 10 and 40Gbps systems, with estimated field failure rates now approaching 10FIT. In addition to high temperature, high current accelerated reliability qualification, devices have been operated continuously at room temperature under open loop conditions to further confirm long term frequency stability. Figure 4 below shows devices operating continuously for five years, with open loop (not using the locker) frequency shifts under 5GHz. This is a small fraction of the available ‘mode width’ showing that mode hopping will never occur in these devices under normal operational life.

The device performance is primarily dictated by the quality of the gratings in the DSDBR structure; with the control and reproducibility afforded by dedicated e-beam writing and full wafer stepper based batch processing exceedingly high yields are achieved.

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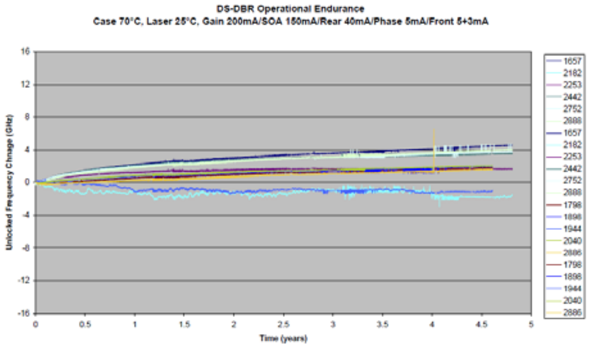

Figure 4. Long term unaccelerated frequency stability of DSDBR lasers

Figure 5 shows an on-wafer test map, wherein the performance and tuning quality can be assessed as soon as the wafer completes processing. In this instance, more than 99% yield of devices is achieved. These devices require three stages of epitaxy for their fabrication. The data demonstrate that process yield with multiple epitaxial steps, which we believe is key to performance optimized monolithic integration, is no longer a problem or a limitation.

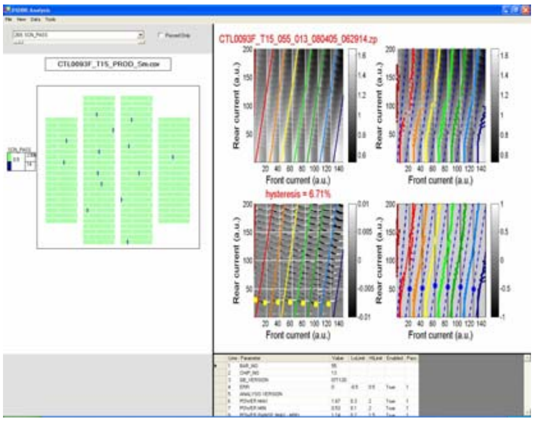

Figure 5. On wafer mapping and testing of DSDBR tunable lasers

The DSDBR design is also showing itself to be very capable of enhancement and as a building block for forward integration. As an example the plot below shows a full band DSDBR laser fabricated using the AlGaInAs material system optimized for high temperature semi-cooled or coolerless operation. This example is at a 70C heatsink temperature whereas 50C is seen as the optimum carrier temperature to minimize total dissipation for semi-cooled operation. The above demonstrates that the DSDBR design has performance in hand to meet these requirements.

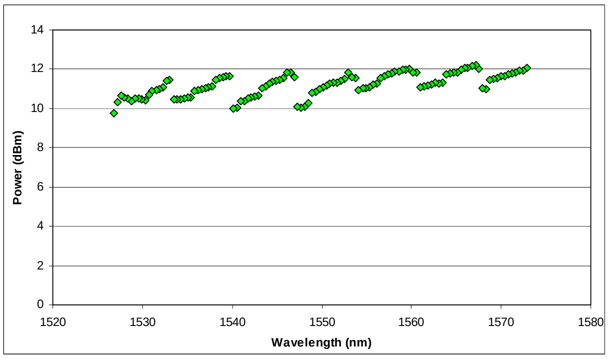

Figure 6 – Operation of Al(Q) DSDBR laser at 70C

Integration for cost and footprint reduction

Figure 7 below shows a monolithic tunable laser – modulator chip for 10Gbps operation, being developed for very small form factor XFP applications.

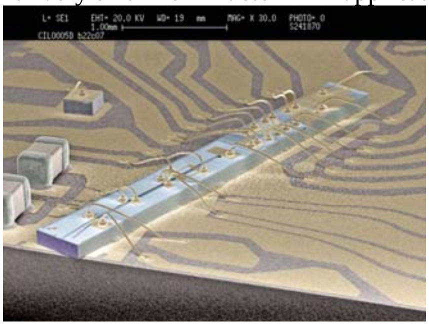

Figure 7. Integrated DSDBR – Modulator Chip for XFP and Tunable TOSA applications.

The above design essentially combines the process stages of the tunable laser with those for the modulator platform. Up to six stages of epitaxy are required, where a monolithic spot size converter is included to simplify packaging. By adopting this multi-epitaxy 'engineering' approach the performance and reliability understanding of the constituent elements can be essentially retained as we move into these more highly integrated devices. This enables us to rely on a much more flexible platform based reliability and qualification approach.

Tunability and Access Evolution

Over the next few years the exponential growth in access bandwidth is likely to continue. To date, this trend has been enabled by the widespread adoption of broadband access services, notably xDSL, with fibre to the home becoming widely available in Korea, Japan, USA and some European countries. Several studies and projections suggest that in order to sustain such growth in capacity, 10Gbit/s home terminals may be required as soon as 10-12 years from now. It is accordingly vital that the fibre infrastructure which will need to be installed in the next few years is capable of being fully scalable in capacity to each subscriber, such that the capacity, optical infrastructure and cost/ flexibility opportunities for this effective access – metro - backhaul convergence can be maximized and made ‘future proof’.

Systems Architectures and WDM-PON

No architecture yet deployed achieves the necessary combination of cost, scalability and flexibility. A key decision is the position of the aggregation point within the network. By running essentially passive fibre connections from the user to central offices that could be 100-150km away, large cost and energy savings are seen to be possible [1]. The simplest architecture conceptually is point-to-point, with a physical fibre for each connection. This choice has been selected for a number of fibre-to-the-home (FTTH) deployments. Such a solution is viable where the cost of fibre deployment is not prohibitive and where the aggregation point is relatively close to the user. More typically, and particularly in the case of ‘long-reach’ access systems, a ‘virtual point-to-point’ system is preferable. Wavelength division multiplexing is the key to the hardware reduction that is required, hence the birth of the ‘WDM-passive optical network’ or WDM-PON. Such systems can provide the economically advantageous long reach operation that is desired, either by combining WDM with time division multiplexing (WDM-TDM) [2] or by allocating each user a full wavelength channel [3].

To be economically viable, it is necessary that user terminals in a WDM network are all identical, i.e. ’colourless’ – otherwise inventory management costs and deployment issues will be excessive. Various solutions to this problem have been proposed, including for example systems based on injection-locked lasers at the user site and on reflective modulation. These systems, whilst doubtless effective, pose significant challenges that limit overall system performance and scalability. In general there has been a perception in the industry that solutions based on tunable laser technology will be too expensive for widespread deployment in home terminals. We believe that it is now time to question this paradigm; a ‘colourless’ tunable ONU would give maximum flexibility for performance, reach and convergence. Tunable chip technology is now clearly at the point where chip cost as such should no longer be an issue; the real questions are in scalable packaging as well as minimizing test and power consumption. At OCLARO in the UK - in an initiative driven by the Technology Strategy Board (TSB) linked to the EC Framework programme and Photonics 21 - we are studying with a number of partners candidate components and architectures to demonstrate that it is now feasible to plan access evolution based on tunable ONU development. One candidate architecture is shown in Figure 8; this architecture includes a colourless user terminal (ONU) based on a tunable laser. It will be seen that he ONU is connected to the network by a WDM which may take the form of a cyclic mux/demux (e.g. based on arrayed waveguide gratings, AWG). Such a system should be effective and resilient, since the multiplexer provides a low loss path for each allocated wavelength, while blocking any wavelengths that are out of band.

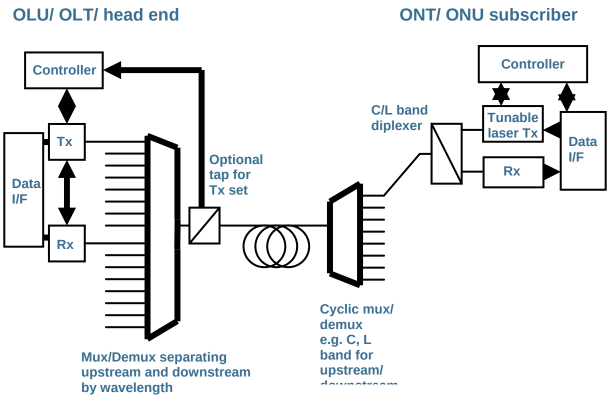

Figure 8. WDM-PON access system architecture employing tunable laser in a ’colourless’ optical network unit (ONU).

The challenges in implementing such architectures have now moved on from the hitherto prohibitive costs of tunable components; control schemes to minimize test and calibration, scalable future proof architectures and packaging challenges will need to be addressed.

Conclusions

This paper has focused on some strategic directions and changes which are helping to enable the next generation of networks and to help drive access metro convergence. To cope with the ever increasing demand for bandwidth at ever lower cost per managed bit we need component technologies that are faster, more transparent, and increasingly ‘green’ in their operation. Technologies to drive down the implementation cost of 40Gbps and higher speed transport as well as to enable future scalable access using tunable components have been presented. In all these cases a high yield optoelectronic integration process is required; it is clear that InP monolithic integration can meet many of these requirements.

References

[1] R.P. Davey *et al.*, “Long Reach Passive Optical Networks”, J. Lightwave Technol., **27**(3), pp. 273-291 (2009).

[2] G. Talli and P.D. Townsend, “Hybrid DWDM-TDM Long Reach PON for Next-Generation Optical Access”, J. Lightwave Technol., **24**(7), pp. 2827-2834 (2006).

[3] S.-M. Lee *et al.*, “Demonstration of a long-reach DWDM-PON for Consolidation of Metro and Access Networks”, J. Lightwave Technol. **25**, pp. 271-6 (2007). OWH6, OFC 2007.