Technology Options for Future WDM-PON Access Systems

Michael J. Wale
Oclaro, Caswell, Towcester, Northamptonshire, NN12 8EQ, UK
Phone: +(44) 1327 356560, Fax: +(44) 1327 356389, Email: Mike.Wale@oclaro.com

Abstract
Economic implementation of broadband access networks that are truly scalable in capacity will require significant changes in technology. We examine options for colourless terminals in WDM-PON systems and propose some promising solutions.

Introduction
Internet traffic worldwide has experienced remarkably rapid growth over the last decade: numerous studies indicate growth rates of 50-60% per year [1], driven by new services such as peer-to-peer file sharing, social networking and game playing, as well as conventional entertainment. Personal internet use is increasing rapidly and will dominate future growth [2]. These trends have been enabled by the widespread adoption of broadband access technology, notably xDSL, with fibre to the home (FTTH) now widely available in Korea, Japan, USA and some European countries [3]. Empirical data show a rise in residential access data rates of 42% annually, or a factor of four in 4 years [4]. It is accordingly vital that new infrastructure is capable of being fully scalable in capacity to each subscriber, since this infrastructure represents a 'once in a lifetime' capital investment.

Systems Architectures and WDM-PON
No architecture yet deployed achieves the necessary 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 [5]. 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, for example in Sweden and The Netherlands [6,7]. 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 [8]. Such systems can provide the economically advantageous long reach operation that is desired, either by combining WDM with time division multiplexing (WDM-TDM) [9] or by allocating each user a full wavelength channel [10].

To be economically viable, it is vital that user terminals in a WDM network are all identical, i.e. 'colourless' – inventory management and deployment issues will otherwise dominate installation costs. Various solutions to this problem have been proposed, including systems based on injection-locked lasers at the user site [10] and on reflective modulation [11]. These systems, whilst doubtless effective, pose significant challenges that limit overall system performance and cost-effectiveness. 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 aim to demonstrate that advances in tunable laser technology and manufacture are rapidly establishing a situation where this need no longer be the case.

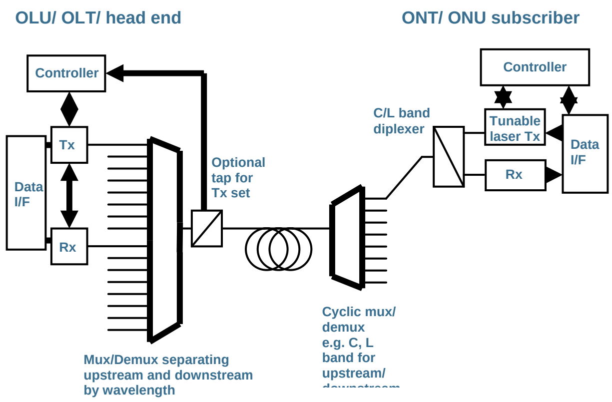

Figure 1. WDM-PON access system architecture employing tunable laser in a 'colourless' optical network unit (ONU).

Figure 1 shows a WDM-PON architecture including a colourless user terminal (ONU) based on a tunable laser. It will be seen that the 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 is effective and resilient, since the multiplexer provides a low loss path for each allocated wavelength, while blocking any wavelengths that are out of band. Such an architecture offers new possibilities for implementation of colourless ONUs.

Monolithic tunable lasers are now widely deployed in metro and long-haul networks, owing to their high performance and cost-effectiveness. The Digital Super-mode Distributed Bragg Reflector (DSDBR) design [12] is in volume production and is a suitable basis for studies of access scenarios. A wafer map showing the yield of full-specification devices, shown in Figure 2, reveals that very high yields (>99%) are now achievable. Coupled with high manufacturing volumes on a 3” InP line, chip cost is no longer an issue for tunable laser deployment.

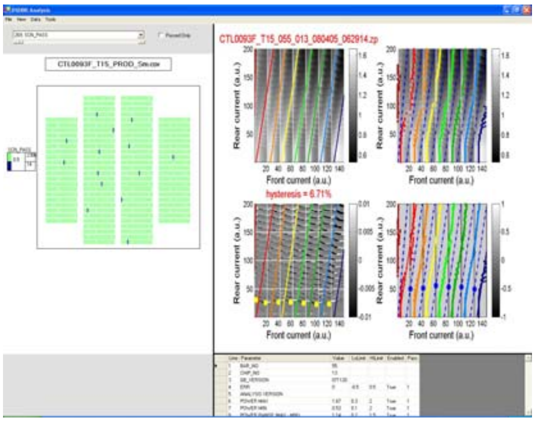

Figure 2. On-wafer test map for 3” DSDBR tunable laser wafer showing 14 marginal fails out of 2400 devices (>99% yield).

With chip costs no longer an important driver, focus must now be on packaging, test and calibration. In particular, new ways of thinking are required to circumvent the need for absolute frequency stability, which drives significant cost. It is possible that a system or network-level solution will provide the basis for large cost savings, noting that frequency error will only result in a single channel impairment, not a threat to the network as a whole.

Developments are presently underway to enhance the performance and functionality of the DSBDR laser, including implementation in the AlGaInAs/InP material system, which will allow higher temperature operation, with correspondingly reduced cooling requirements [13] and the monolithic integration of a Mach-Zehnder modulator similar to those presently used in metro-network 10Gbit/s systems [14]. A prototype integrated DSDBR-MZ chip is shown in figure 3.

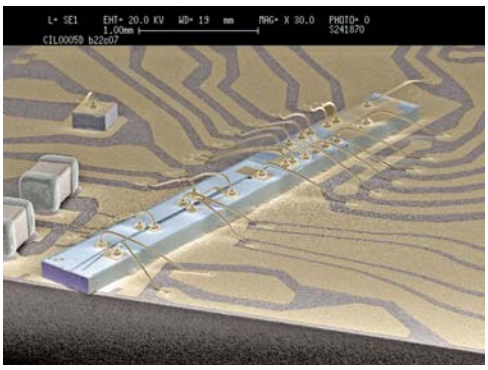

Fig. 3. Integrated DSDBR tunable laser-Mach Zehnder modulator in InP for 10Gbit/s transmission.

We anticipate also that the widespread availability of digital signal processing will provide new opportunities to exploit photonic technology. These developments, together with radical thinking in systems design, are likely to make tunable laser-based solutions compelling for next-generation WDM PON systems.

Conclusions

Internet growth is demanding the introduction of highly scalable and flexible systems architectures such as WDM-PON, with attendant demands for high performance, ‘colourless’ terminals. Tunable laser-based ONUs appear viable with current device technology, given appropriate component/systems architectures. Photonic integration is vital for cost-effective manufacture of both OLT and ONU. Low cost packaging approaches need to be evolved. The principal enabler is volume: ‘high technology’ 1-10Gbit/s access solutions can then be highly cost effective.

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