Implementation of Future Generation Agile Gigabits Passive Optical Network

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Abstract

This paper reviews the progress of the passive optical network, and discusses a viable means for the realisation of future generation agile gigabits passive optical networks, (GPONs) by the use of low cost narrow band tunable lasers and arrayed waveguide gratings (AWGs). It projectes a two-stage strategy for the realisation of future generation agile GPONs, i.e., the near-term Time and Wavelength Division Multiplexed Gigabits Passive Optical Networks (TWDM-GPONs) and the ultimate Wavelength Division Multiplexed Gigabits Passive Optical Networks (WDM-GPONs). It also presents typical practical designs of narrow band tunable lasers and arrayed waveguide gratings (AWGs) for the agile GPONs.

Keywords

Passive Optical Networks; Tunable Laser; Arrayed Waveguide Gratings; Agile Gigabits Passive Optical Network; Time and Wavelength Division Multiplexed Gigabits Passive Optical Networks; Wavelength Division Multiplexed Gigabits Passive Optical Networks

Introduction

The passive optical network (PON) operation was originally developed in the 1980s as a cost-effective method of sharing optical fibre infrastructures for narrowband telephony (TPON) to business premises. It has now evolved into an interactive broadband network. Applications have evolved from basic passive optical networks (PONs) to broadband passive optical networks (BPONs) and ethernet passive optical networks (EPONs), and now gigabit passive optical networks (GPONs), all based on Time Division Multiplexing Access (TDMA). Network providers are now faced with the challenges of developing new business models through the innovative upgrading of existing network infrastructures to meet the ever growing bandwidth demands.

Future generation agile GPONs, featuring dynamic allocation, alteration and management of operating wavelengths, are capable of deliverying triple-play service (TPS), which are believed to be promising business models for the network provider. For the TPS applications, voice, data and video services can be integrated in the form of TPS, and delivered through a single optical fibre network. Consequently, an internet function will change from its original web browsing to the online watching of high definition (HD) TV/film, the downloading of HD film/TV and music, the transferring of high pixel images/pictures/photos, the provision of multi-access web-conferences, and the delivery of distance medical and educational services. Key technologies for the implementation of future generation agile GPONs mainly relate to two innovative optical components: tunable lasers and arrayed waveguide gratings (AWGs). This paper suggests a two-stage strategy for the realisation of future generation agile GPONs by employing low cost narrow band tunable lasers and AWGs. Typical designs of these critical components for the agile GPONs are also presented.

Implementation of Near-term TWDM-GPONs and Ultimate WDM-GPONs

A currently widely used typical GPON transmits downstream at 1.49 μm with a bit rate of 2.5 Gb/s, and upstream at 1.3 μm with a bit rate of 1.25 Gb/s; optical power budgets allow the transmission distance to span 20 km when 32 customers are connected to the GPON. The 10G-PON (10GE-PON or XG-PON) is currently at the trial stage. All these TDM-PONs have only one wavelength for downstream data and one for upstream data, to share amongst all of the users, which limits the average bandwidth per user to a few tens of Mbit/s. As a result, all of the above foreseen GPONs still suffer from an unsolved last mile network access bottleneck, defer numerous vital bandwidth-hunger applications, and prevent the deployment of new services and the development of new applications.

Recently, Full Service Access Network (FSAN) has carried out investigations into future GPONs beyond 10Gb/s, known as the next generation PON stage 2

(NG-PON2). TWDM-PON is favoured by most global vendors at present as the successor to the 10Gb/s, which acts as the first move on the long road towards agile GPONs implementation.

Near-term TWDM-GPON

TWDM-PON is essentially a hybrid access system, which stacks multiple XG-PONs by implementing multiple pairs of wavelengths. As an illustration, when four pairs of wavelengths are used, four XG-PONs can be stacked to achieve an aggregated rate of 40 Gb/s in the downstream and 10 Gb/s in the upstream. This is a near-term compromise solution with which to solve the problem of the network access bottleneck. It shares the optical channels that operate in different wavelength pairs, representing the most cost-effective way at present to expand bandwidth at minimal cost. Since a limited number of wavelengths is required for this scheme, narrow band tunable lasers become the best cost-effective choice for the implementation of this.

A hybrid solution is to use a coarse WDM demultiplexer (an AWG with a high free spectral range) followed by passive splitters. In this way, the network can be partially reconfigured while the required power budget is reduced. An example of hybrid TWMD-GPON configuration is shown in Fig.1

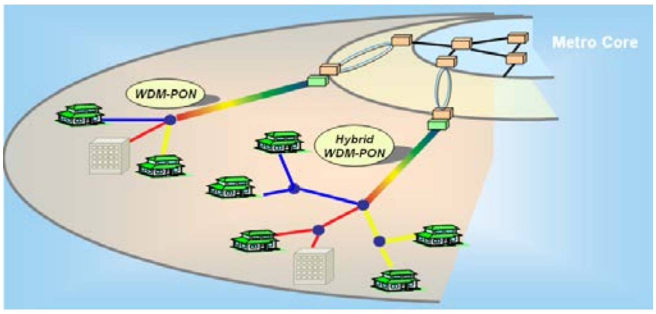

FIGURE 1: ILLUSTRATION OF A HYBRID TWDM GPON

Ultimate WDM-GPON

Wavelength Division Multiplexing (WDM) technology promises an ideal solution to extend the capacity of TDM-PONs without drastically changing the fiber infrastructure. An optical access network, including Fiber To The Home/Curb /Node (FTTHx), has long been the desired ultimate solution to the last mile problem. The straightforward way to implement this standard WDM-PON is to replace the 1×32 optical power splitter in the distribution node of a traditional TDM-PON with a 32-wavelength (de)multiplexer, typically a 1×32 arrayed waveguide gratings (AWGs) device. Subsequently, tunable lasers covering the tuning range of the WDM-PON will be required. Some other alternatives to the tunable laser have been explored to reduce the implementation costs of WDM-PONs. The WDM-PON will be able to address the huge bandwidth demands from various applications, such as high-definition TV, IPTV, video-on-demand, 3D video, wireless traffic backhauling, which will be the ultimate step towards the future all-optical network.

To avoid the initial huge cost of employing the full C-band widely tunable laser in the WDM-PON, a set of narrow band tunable lasers, each with an individual tuning range of 8-10 nm and combing tuning range covering the full C-band can initially be introduced.

Design of Narrow Band Tunable Lasers

Tunable lasers have already been used in some networks for several years, starting with devices with a small tuning range, but moving towards full-band tuning. The main initial driver for tunability has been inventory management and flexibility. Using a universal transceiver card has a number of obvious advantages for an operator: 1) no wavelength planning is required before ordering; 2) simplified logistics; 3) significantly reduced spares costs; 4) it allows automated provisioning. The features and attributes of tunable lasers are: 1) The wavelength is tunable, and can be set to work at any operating channel within its tuning range on demand. This allows the network provider to have tremendous flexibility in its operation of an optical network; 2) A single tunable laser can provide spares backup for many operating channels, and thereby greatly reduce the management cost of the inventory; 3) The tunable laser features wavelength agile tunability. It can meet the need for flexible expansion of future optical networks to add additional channels dynamically and quickly, on demand.

A general narrow band tunable laser structure is illustrated in Figure 2(a), together with the tuning principle illustrated in Figure 2(b). This device has been designed by the author and reported previously.

A typical gain region vertical modal profile and refractive index profile of the tunable laser is shown in Figure 3. Simulation and design suggest that a 20-degree angle is needed for the the interface between the gain region and the tuning region. A top view of this interface is illustrated in Figure 4. This angle is used to minimise the interface reflection which is a typical fabrication issue as illustrated in Figure 5.

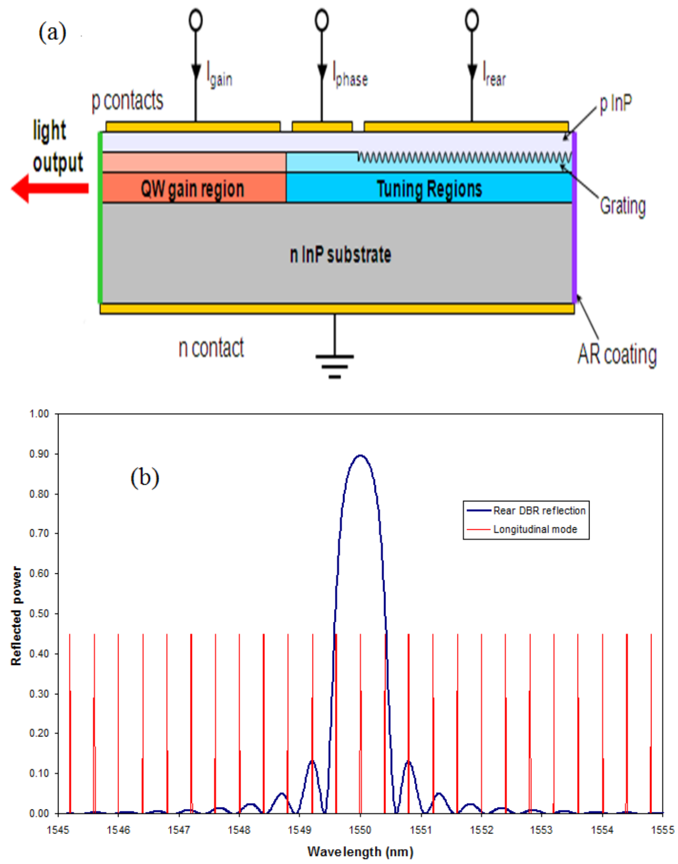

FIGURE 2: ILLUSTRATIONS OF (a) A NARROW BAND TUNABLE LASER STRUCTURE; (b) THE TUNING PRINCIPLE

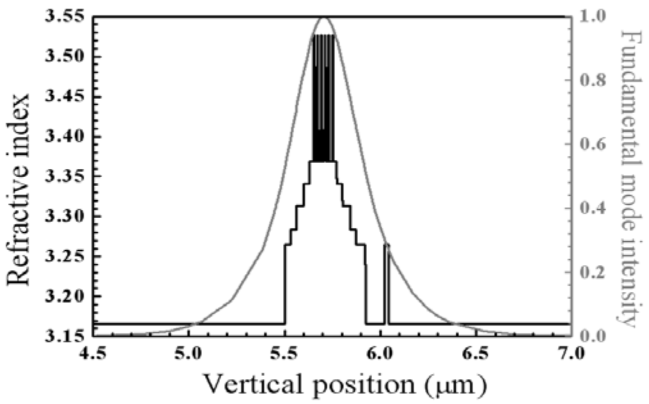

FIGURE 3: A TYPICAL OPTIMISED GAIN REGION: VERTICAL MODEL PROFILE AND REFRACTIVE INDEX PROFILE.

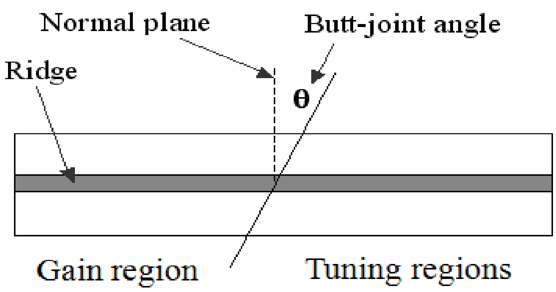

FIGURE 4: TOP VIEW OF THE INTERFACE ANGLE BETWEEN THE GAIN REGION AND THE TUNING REGIONS OF A NARROW BAND TUNABLE LASER.

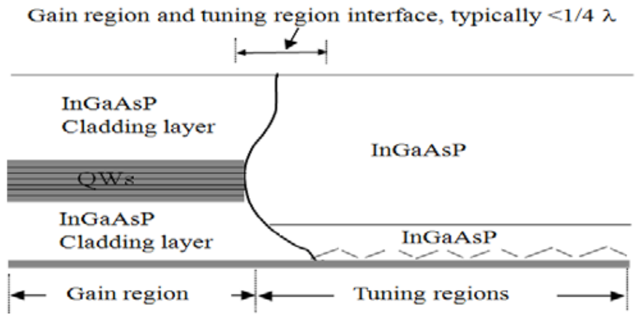

FIGURE 5: SCHEMATIC ILLUSTRATION OF A TYPICAL FABRICATED NARROW BAND TUNABLE LASER WITH AN UNDESIRABLE GAIN REGION AND TUNING REGION INTERFACE.

Design of Arrayed Waveguide Gratings

Two versions of 1×32 AWG devices have been designed with free space range (FSR) values of 25.6 nm and 50.4 nm, respectively. The input waveguide is in the middle without position shift. The main design parameters are: channel spacing of 50 GHz, i.e. 0.4 nm; channel bandwidth of 25 GHz; core/cladding index difference Δn=1.5%; C-band operation. The simulated AWG transmittance maps are shown in Figure 6 (a) and (b) for the above two devices respectively, together with the International Telecommunication Union (ITU) grid channels (50 GHz spacing), shown in green.

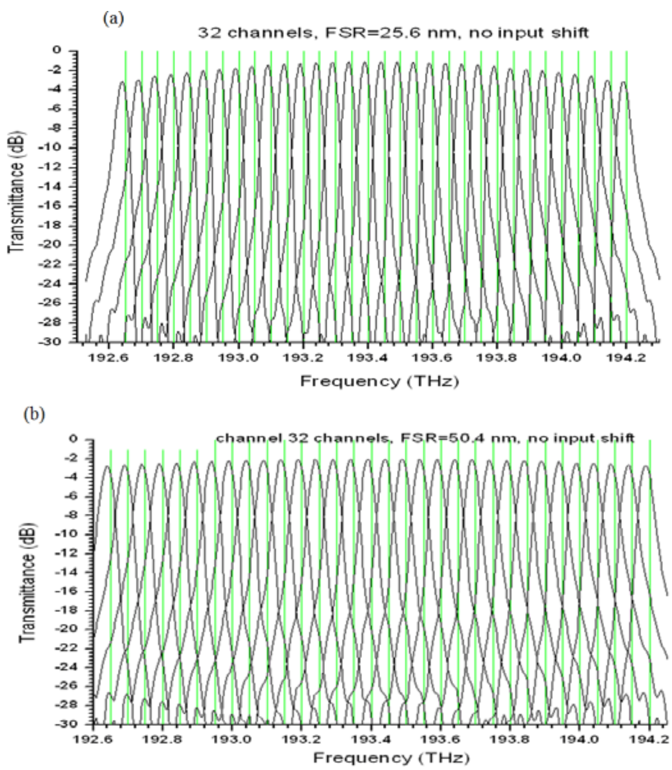

FIGURE 6: AWG TRANSMITTANCE MAPS: (a) FSR OF 25.6 NM, AND (b) FSR OF 50.4 NM, TOGETHER WITH THE INTERNATIONAL TELECOMMUNICATION UNION (ITU) GRID CHANNELS (50 GHZ SPACING) IN GREEN.

By adjusting the position of the input waveguide relative to its original center position, the AWG output channels on the transmittance maps can be shifted and aligned to the ITU grid channels, as illustrated in Figure 7.

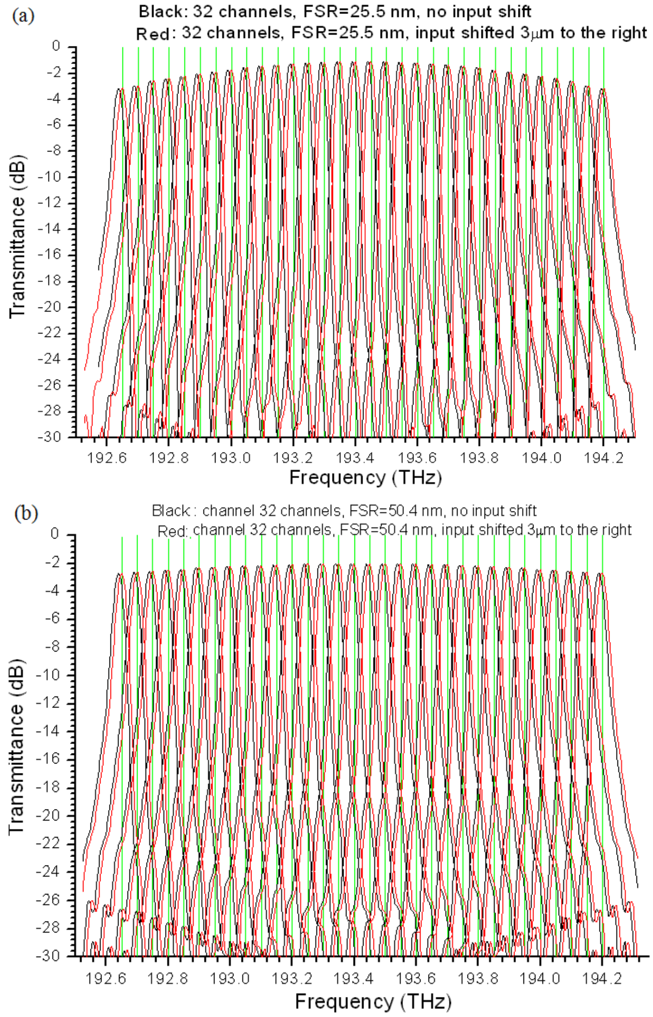

FIGURE 7: ADJUSTED AWG TRANSMITTANCE MAPS IN RED, WHICH ARE ALIGNED TO THE ITU GRID CHANNELS, BY SHIFTING THE INPUT WAVEGUIDE POSITION OF 3 NM TO THE RIGHT WITH REFERENCE TO ITS ORIGINAL CENTER POSITION: (a) FSR OF 25.6 NM, AND (b) FSR OF 50.4 NM, TOGETHER WITH THE INTERNATIONAL TELECOMMUNICATION UNION (ITU) GRID CHANNELS (50 GHZ SPACING) IN GREEN, AND THE UNADJUSTED AWG TRANSMITTANCE MAPS IN BLACK.

Conclusions

Worldwide implementations of future generation agile GPON is on the way and the trend is inevitable towards ultimate WDM-GPON. The major obstacles are the costs related to the optical components and the alteration of the existing infrastructures. Near-term hybrid TWDM-GPONs may play an important role, while the ultimate choice will be full WDM-GPONs, with variants of WDM implementation approaches.

REFERENCES

D. Lavery, R. Maher, D.S.Millar, et. al. , "Digital Coherent Receivers for Long-Reach Optical Access Networks", J. Lightw.Technol., vol. 31, no. 4, 2013, pp.609-620.

E. Wong, "Next-Generation Broadband Access Networks and Technologies", J. lightw.Technol., vol. 30, no. 4, 2012, pp.597-608.

G. Kramer, M. D. Andrade, R. Roy, and P. Chowdhury, "Evolution of Optical Access Networks: Architectures and Capacity upgrades", Proceedings of the IEEE, vol. 100, no. 5, 2012, pp.1188-1196.

Http://www.fsanweb.com

K. Prince, T. B. Gibbon, R. Rodes, et. al, "GigaWaM-Next-Generation WDM-PON Enabling Gigabit Per-User Data Bandwidth", J. lightw.Technol., vol. 30, no. 10, 2013, pp.1444-1454.

L. H. Spiekman, "Active Devices in Passive Optical Networks", J. Lightw.Technol., vol. 31, no. 4, 2013, pp. 488-497.

M. J. O'Mahony, C. Politi, D. Klonidis, et. al. , "Future Optical Networks",J. Lightw.Technol., vol. 24, no. 12, 2006, pp.4684-4696.

P. Ossieur, C. Antony, A. Clarke, et. al., "A 135-km 8192-split carrier distributed DWDM-TDMA PON with 2 32 10 Gb/s capacity", J. Lightw. Technol., vol. 29, no. 4, 2011 pp. 463–474.

P. Ossieur, C. Antony, A. Naughton, et. al. , "Demonstration of a 32 ⊚ 512 split, 100 km reach, 2 32 10 Gb/s hybrid DWDM-TDMA PON using tunable external cavity lasers in the ONUs", J. Lightw. Technol., vol. 29, no. 24, 2011, pp. 3705–3718.

Y. Luo, M. Sui, and F. Effenberger, "Wavelength Management in Time and Wavelength Division Multiplexed Passive Optical Networks (TWDM-PONs)," Globecome 2012 – Optical Networks and Systems Symposium, pp. 2971-2976.

Y. Ma, Y. Qian, G.Peng, et. al,"Demonstration of a 40Gb/s Time and Wavelength Division Passive Optical Network Prototype System," OFC/NFOEC'2012 post dealine paper, March 2012.

Y. Zhang, "Design of ultra-high power multi-section tunable laser", IEEE J. Sele. Topics in Quantum Elec., Vol. 12, No.4, July/August, pp.760-766, 2006.

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