Semiconductor laser sources for datacom and telecom applications: recent trends

Marina Meliga

Agilent Technologies, marina_meliga@agilent.com

A brief review of current options for semiconductor laser sources for different network segments: LAN (Local Area Network), MAN (Metropolitan Area Network) and WAN (Wide Area Network).

INTRODUCTION

Despite the current market downturn, the bandwidth demand is still increasing. Bit rates of 2.5 Gb/s, 10 Gb/s and 40 Gb/s over many kilometres of optical fibres are a reality. The driving force for this current improvement is due to increasing data traffic, not only in the WAN (Wide Area Network) and in the MAN (Metropolitan Area Network) and but also in the LAN (Local Area Network). This last one, generally for datacom applications, represents an exception in the general market downturn and, in the last period, it has grown at a good pace. A general picture of the datacom and telecom network is sketched in Fig. 1.

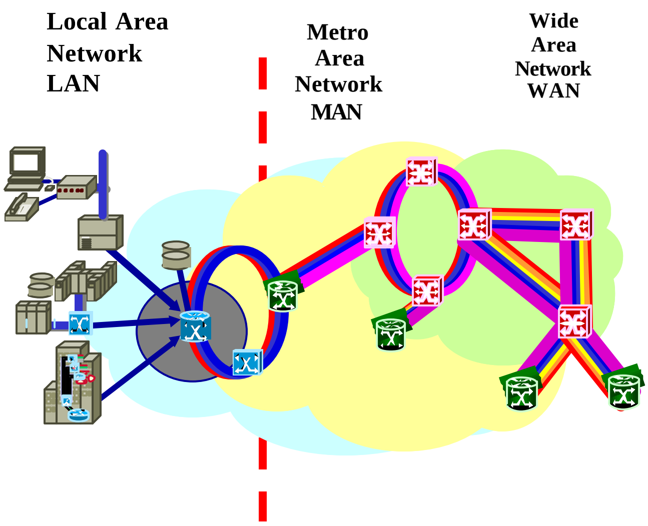

Fig. 1: Optical Network sketch

Different network applications mean different requirements for sources and optical components, but some general trends related to: the optimised active material sources (for LAN, MAN and WAN), high speed uncooled sources (mainly for LAN, but also for MAN) and tunable sources for WDM systems (used in MAN and WAN) are becoming more common for the different network segments. To meet that increasing demand, the optical laser sources changed dramatically during the past decades. Invented in the sixties, the semiconductor laser diodes has made practicable the development of optical fibre transmission systems and of the current "interconnected world" that everyone is experiencing daily when exchanging information with work colleagues or simply chatting on-line.

ACTIVE MATERIAL AND CONFINEMENT STRUCTURES FOR SEMIC ONDUCTOR LASER

From the pioneering work done by H.Kroemer and Z.Alferov, awarded, last year, with the Nobel price for the development of the double heterojunction (DH) laser diode both technology and device requirement have changed a lot.

After the initial AlGaAs/GaAs based sources, emitting near 850 nm wavelength grown on GaAs wafers, quaternary compounds InGaAsP alloys grown on InP have been soon introduced to get firstly the wavelengths around 1300 nm and then the wavelengths around 1550 nm, where the fibre attenuation exhibits the minimum value.

MQW (Multi Quantum Well) active structure represents another big change in the history of the semiconductor lasers. Suggested by R.Dingle and C.H.Henry at ATT Bell Labs in 1976 [1], MQW active layers, based on a few monolayers thick active material, had come to practice in early 90's, thanks to the maturity of epitaxial growth techniques. A (single) quantum well is formed when a thin layer (2-10 nm) of low bandgap material is sandwiched between high gap barriers. Often barriers and wells are repeated in the active structure to reach a cumulative effect, i.e. multi quantum well. For physicists MQW active layers represent one of the most intriguing and practical applications of quantum mechanics, for technologists MQW structures are the main reason for the development of sophisticated growth techniques with a perfect control of interfaces. Furthermore in MQW structures the general rule of maintaining a lattice matching between the substrate and the epi-layers can be overcome and can produce positive effects. In fact MQW structures and especially strained, non-lattice matched, MQW structures exhibit a differential gain that is several times higher than conventional (bulk) active layers. Differential gain $\delta g/\delta N$ is a measure of the dependence of the optical gain versus the density N of carriers injected and is a physical parameter which dominates the final static and dynamic laser performances.

For all 90's MQW active structures, based on InGaAsP or sometimes InGaAlAs quaternary materials, represent the best active for long wavelength lasers, obtaining high modulation bandwidth (up to 30 GHz and beyond), very low threshold current (few mA or less), high optical power (tens of mW), suitable for long distance telecommunication system applications as well as for LAN Local Area Network.

For advanced long wavelength semiconductor lasers high modulation bandwidth is still a must but high operation temperature becomes more and more important.

The physical parameter describing the dependence of the threshold current from temperature is called T_0. For advanced devices T_0 must be increased to values higher than 100 K compared to the normally reported 50-60 K for the InGaAsP alloys.

Optimised high T_0 active materials in the range of 1300nm could be used both for conventional edge emitter lasers and for Vertical Cavity Surface Emitting Lasers, VCSELs. VCSELs represent a new classes of devices in which the emission is provided through the surface in vertical direction. VCSELs represent also a further step toward reduction of the cost. Since the emission is vertical and the output mode is nearly circular due to the fabrication technology a parallel approach is possible enabling the realisation of VCSEL arrays and moreover a testing of the device prior the final processing.

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HIGH SPEED UNCOOLED SOURCES

In the last period there is an increased demand for cheaper lasers for fibre optic transmission in emerging high-data–rate Gigabit Ethernet modules.
10 Gigabit Ethernet systems, [2] are becoming more and more important in LAN and in the next future also in MAN. An uncooled DFB laser directly modulated at 10 Gb/s, emitting at 1300 nm is a key element for these network applications and can be used in optical transceivers in order to reduce cost, size and power consumption.
In fact for cost reduction Gigabit Ethernet modules are uncooled and so lasers must work at very high operation temperature (80 or 90 C are a reasonable guess) but with no significant reduction of device performances.
It has been frequently indicated that the use of InGaAsP/InP active layers has been the cause of poor temperature characteristics of lasers emitting at 1300nm. So in recent years, significant effort has been reported in the literature to find alternative active MQW layers with improved temperature performance. AlGaInAs was considered to be the best candidate, and 10 and 12.5 Gb/s operation up to 85C has been demonstrated [3,4].

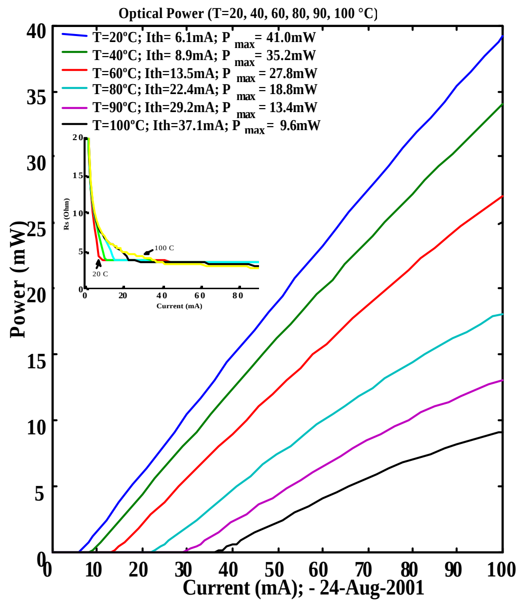

Fig. 2 L-I characteristics of Agilent uncooled DFB for GbE applications

In Agilent we have demonstrate that high temperature performance can also be obtained by using Phosphorus-based MQW active structure and we have reported what, we believe, is the current state of art for uncooled DFBs emitting at 1300 nm. The DFBs have been obtained by combining an optimised active region based on well assessed InGaAsP strained MQW and a low parasitic lateral confinement region. The DFBs work up to 100 °C (substrate base temperature, about 110 active stripe temperature), see Fig. 2, with perfectly open eye diagrams (showing an extinction ratio of 5 dB), and with Bit Error Rate over 10 km without error floor, see Fig. 3. Up to 90 °C our DFBs show threshold current as low as 29 mA, optical power as high as 13 mW and meet perfectly 10 Gb scaled Ethernet mask with extinction ratio > 6 dB.

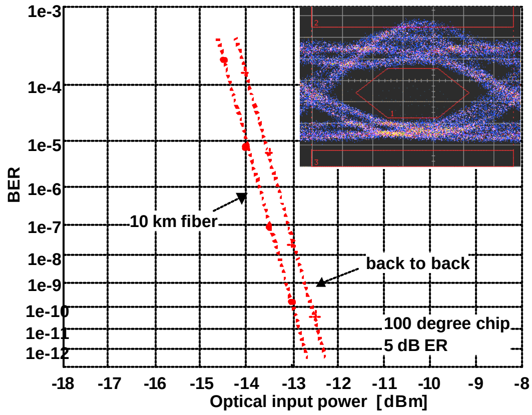

Fig. 3 Bit Error Rate back to back and over 10 km at 100 C, by using uncooled DFB laser.

WDM SYSTEM AND TUNAB LE SOURCES

In WAN and MAN applications, photonic devices, performing in the low-loss spectral band of about 1550 nm have enabled more than a single wavelength in the same fibre.

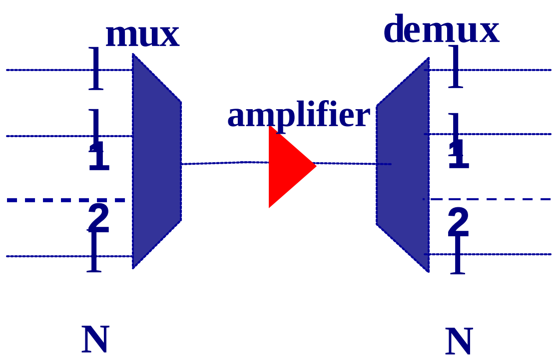

Fig.4 WDM system sketch

Having put a number of wavelengths, see Fig. 4, in the same fibre, the total bandwidth per fiber is equal to the bandwidth of each laser multiplied by the number of the lasers. This represents the WDM (Wavelength Division Multiplexing) concept. WDM technology is flexible and can be used to increase dramatically the bandwidth of the system, reducing degree of complexity of the system and the total cost , if compared with other possible solutions: TDM (Time Division Multiplexing) and SDM (Space Division Multiplexing). So WDM in carrier networks is resulting in massive increases in the capacity of carrier backbones, but it is also raising a whole set of new problems. One of them is that every WDM channel needs its own laser that has to be configured for a specific wavelength. To make matters worse, carriers have to keep spares readily to hand – and those also need to be wavelength specific. This means huge inventories of spare lasers both for customers and manufacturing companies

Until now, DFBs have been used by changing the operating temperature and so the emitted wavelength. But thermal tuning can give no more than 2-3 nm of wavelength variation, so again many spare components are needed.

A new generation of tunable lasers, now starting to appear, promises to reduce these costs considerably. They are capable of being tuned over a much wider range of wavelengths. In some cases, in fact, they can be tuned to any of the wavelengths in common use in the network. As a result, one next-generation tunable laser can serve as a spare for *any* laser, allowing a dramatic inventory reduction.

In addition some of these tunable lasers are being packaged with other devices to create subsystems that help vendors get WDM equipment to market faster. Tuneable lasers are the key WDM technology block, with fast space switching, low cost MUX/DEMUX and wavelength stabilisation technologies also being important. Tuneable lasers would enable fabrication of re-configurable optical add-drop terminals which would make WDM networks much more flexible. There are two main families of tuneable lasers: Edge emitters based on variants of DBR lasers [5] and Vertical emitters based on VCSELs [6] with MEMS tuneable mirrors. The former promises more power whereas the latter could be easier to control. The technology for both is at a similar state of maturity. For the edge emitting devices control is complex with several currents changing both wavelength and output power. Most devices will be micro-processor controlled and require extensive characterisation. There are as yet no evidence of technologies capable of giving uncooled WDM capability, however this is an area of investigation. This would enable even lower cost systems and would be a market leading product.
Several different schemes have been reported for the fabrication of tuneable lasers. But there are a number of performance compromises and some difficulties common to all approaches:

- Performance trade-offs: how many channels can be accessed vs power available vs dispersion performance.
- Manufacturability varies from minor modifications to existing technological approaches through to devices really needing fundamental new materials science.
- Packaging because wavelength stability is key, has stringent demands on thermal management and stability.
- Testing and characterisation of tuneable lasers is typically complex and time consuming, with high

confidence in the stability of the measurements being essential.

- Control systems - stability and predictability

Currently medium tuning DBRs (Distributed Bragg Reflector) can represent a good trade off in terms of device performances and manufacturability. Typically DBR lasers have around 10nm tuning, 3 sections which require control currents, are capable of high power (c.10-30mW), but the tuning range typically is about 10-15 nm, fabrication is and are easy to make.

CONCLUSIONS

In this paper a brief review of current options for semiconductor laser sources for different network segments: LAN, MAN, and WAN has been reported.

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