Compound Semiconductor Requirements for Fiber Optic Telecommunications

Mike Scott

Nortel Networks
3500 Carling Avenue, Nepean, Ontario, Canada, K2H8E9

Abstract

The explosive growth in network bandwidth requirements has led to a tremendous increase in the demand for high-speed fiber optic telecommunications equipment and demands for its continued bandwidth evolution. Typically fiber systems rely on InP based devices to provide the optoelectronic functions. This is due to their ability to source directly modulated light and to detect light in the 1.3 and 1.55 nm wavelength bands for fiber transmission. Key attributes are temporal and spectral purity and modulation bandwidth. For the electronics, in particular the very high speed analogue transmit and receive functions, GaAs based integrated circuits continue to be deployed for the highest speed leading edge systems. Key attributes are timing jitter and small and large signal amplification. In this paper I will discuss the particular III-V technology requirements for a 10 Gb/s high performance fiber system, and use this example to highlight some of the requirements of current and future systems.

1. Introduction

1.1 Fiber Transmission

The key components for a typical 10Gb/sec fiber transmission link are shown in Fig. 1. A determining factor for the various components is the desired transmission distance. This is affected by the optical attenuation and spectral dispersion properties of the fiber used. Fiber attenuation is minimum at 1.55um and its dispersion is zero at 1.3um. The advent of WDM and the availability of Erbium-doped fiber amplifiers (EDFAs) make the 1550nm band especially attractive.

Nortel Networks has manufacturing capability for InP based optical devices on 2 inch substrates, this choice being dictated by the non-availability of high quality substrates of larger diameters. These are now becoming available at both 3 and 4 inch. The high fragility of InP, compared even with GaAs, coupled with small substrate size and the non-availability of sophisticated automatic process equipment, presents a number of unique challenges in a manufacturing environment. Fortunately, the InP devices we require are currently used as discrete devices rather than large ICs, so the potential yield of a 2 inch- wafer can be extremely high.

We currently use both conducting and semi-insulating (Fe doped) substrates. In addition, for optimum performance, we frequently perform several re-growths on partially processed wafers, making in-house epitaxial growth (and by implication an extensive analysis capability) a necessity.

For high-speed electronics functions we have increasingly turned towards GaAs based devices, utilizing MESFETs at 2.4 GHz, and largely HBTs at 10 Gb/s. Nortel Networks has both capabilities in-house.

Components for fiber systems have stringent reliability requirements, typically only a few FITs. This is to meet 20 year in service needs. Reliability and performance dictate the choice of technology, rather than cost. Obviously as volumes increase, driving down unit cost becomes more important. Typically there is a five year period before increased bit-rate systems are introduced, but a new system does not imply redundancy of existing installed base, instead the existing equipment is used as tributaries to upgraded system.

2. Optical Devices

2.1 Lasers

DFB lasers are used for wavelength stability and narrow spectral width. Many wavelengths are required for WDM, and this is currently achieved by using a separate laser for each wavelength. Gratings and epitaxial overgrowth are required for optimum performance, requiring growth and process capabilities to be co-located. These somewhat complicated devices tend to be lower yield and higher cost.

2.2 Detectors

Both PIN and APD (avalanche photo-diode) detectors are used in fiber systems; APDs have improved sensitivity, but are gain-bandwidth product limited to rates lower than 10Gb/s.

2.3 Modulators

Although lasers can be modulated at high rates, external optical modulation is preferred for high speed, as there is less chirp and jitter during turn on and off. Several modulator options have been utilized, although Li3Nbo3 and InP based Mach-Zehnder or electroabsortion modulators are typically used.

2.4 Pump Lasers

GaAs based pump lasers operating at 980nm, or InP based at 1480nm, with output powers in excess of 120mW, are utilized to optically pump the Erbium Doped Fiber Amplifiers. Raman amplification is also being deployed to broaden the total optical bandwidth for DWDM systems; these use InP based pump lasers.

3 Electronics

Speed and reliability really dominate the choice of device. GaAs FETs used at 2.4 Gb/s, but at 10 Gb/s we needed PHEMTs or HBTs. As broadband power, analog, and digital functions are all required we adopted HBTs, GaAs based, as these are more mature than the InP devices. GaInP emitters rather than AlGaAs were developed, as these give superior performance and reliability.
Amplifiers need to have large bandwidth not just high frequency. OC-192 is coded as NRZ, therefore a string of ones looks like a low frequency, and a lot of information is contained at MHz levels. The Nortel Networks HBT process was described at the 1998 MANTECH conference. The first circuits went into production in 1995. To meet the demands of higher power applications we have also developed a new process, which offers a simplified higher yield fabrication and higher interconnect current densities, as well as higher breakdown voltages.

3.1 Modulator Driver

Modulators require high voltage drive levels. We currently manufacture 3V, 5V and 6V versions.

3.2 MUX

The Mux is a digital circuit, having approximately 1500 transistors, and is used to multiplex 8 incoming 1.25 Gb/s signals into a single 10 Gb/s stream.

3.3 Transimpedance Preamp

The PHEMT seems a more logical choice for low noise applications, however the noise performance of the HBT circuit proved to be adequate, and its high yield (in excess of 95% on a wafer) makes it very attractive. Its relatively small size (approximately 1mm square), means a large number of pre-amps can be obtained from a single wafer.

3.4 DEMUX

The demux is slightly larger than the MUX, and contains data recovery, as well as proprietary circuitry to monitor the received signal quality.

4 Future requirements

We foresee a migration to higher and higher data rates- 20, 40 or even 80 Gb/s will almost certainly be required, although there are some fiber penalties at the higher bit rates. We believe that InP based electronics (probably HBT) will be required as we move up in speed.
To fully utilize fiber bandwidth there will certainly be increased WDM, 160 wavelengths at 10Gb/s each are already available. We are very likely to see the adoption of tunable lasers to supply the wide range of wavelengths.
As higher speed Si and Si/Ge become more readily available they are likely to displace the GaAs based electronic devices, probably at higher levels of integration, and only if costs are reduced and reliability targets are met.

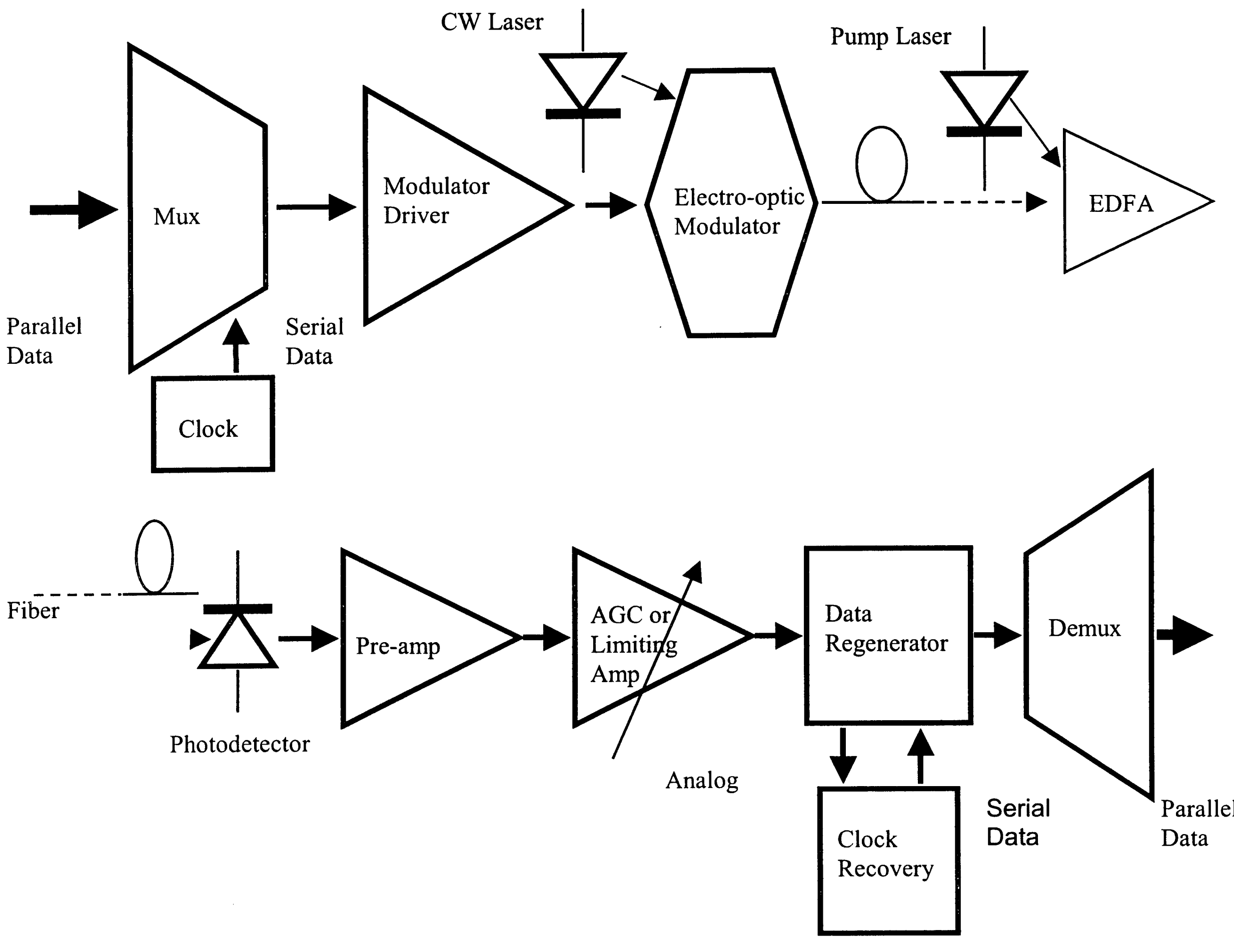

Fig.1 Fiber link showing high-speed components.