DEVICES AND COMPONENTS FOR LIGHTWAVE TRANSMISSION SYSTEMS

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ABSTRACT

Device and component developments for future broadband networks are reviewed. High speed (~10Gb/s) operation is pursued both for optical and electrical devices. Wavelength control and narrow-spectrum operation are the key issues for coherent systems. High-reliability low-cost devices are also developed for subscriber systems.

LIGHT SOURCES FOR HIGH BITRATE TRANSMISSION SYSTEMS

Semiconductor lasers with grating feedback, i.e. distributed feedback (DFB) and distributed Bragg reflector (DBR) lasers, are the most popular single mode lasers for high bitrate systems. The fundamental feasibility of sucn lasers was demonstrated a decade ago in the short wavelength region using GaAlAs. Then the technology was adapted to the long wavelength region (1.3~1.6μm) where the lightwave transmission systems have been widely developed.

A DFB laser has a grating with a period of half a wavelength along the laser active region. The grating is fabricated on an InP substrate by holographic exposure or other methods. Buried heterostructure or similar structures are used for low thereshold, transverse mode stabilized operation.

By these technologies, DFB lasers operate with a threshold current of 15~20mA and a differential efficiency of 0.15~0.25mW/mA, which are very comparable with those of Fabry-Perot type lasers.

Ironically, efforts are still necessary to guarantee single longitudinal mode operation. DFB lasers with a simple symmetrical structure are known to have two lowest-threshold modes just outside the stopband of the grating filter. Corresponding to this fact, two mode operation is often observed in DFB lasers. Also their longitudinal mode behavior is much susceptable to the optical feedback from the both ends of the waveguide. Such mode competition becomes a serious problem under high bitrate operation. Recent study shows that a gain difference of more than $5cm^{-1}$ is necessary between the oscillating mode and adjacent modes for dynamically single mode operations.

The introduction of a $\lambda/4$ shifted grating is a solution to increase the yield of single mode operation.[1] The phase of the grating is half a period shifted in the middle of the laser, resultng in a dominant resonance mode at the center of the stopband. The new lasers operate in the single mode and prove to be more stable against the external feedback. The long term reliablity of the modal behavior is now under detailed study.

The DFB lasers are successfully used in high bitrate (1-2Gb/s), long haul (20-50

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km) systems where mode competition seriously deteriorates the system performances. Laser packages containing an InGaAsP DFB laser (1.3μm, 1.55μm), an optical isolator, and a GaAs driver IC are available for system applications. They launch an optical power of ~1mW into a fiber under modulations up to 4Gb/s. The isolator is composed of polarizers, YIG Faraday rotators, and cylindrical magnets. By using two isolators in series, an isolation loss of more than 60dB was obtained in the temperature range of -20℃ to 80℃. The GaAs driver IC is composed of GaAs MESFETs with a 0.8μm long gate and a transconductance of 260mS/mm. It is fabricated by ion implantation and self-aligned process using a WSix metal gate.[2)]

Laser operation at higher bitrates (6-10Gb/s) are the current interest.[3)] The direct modulation bandwidth of a semiconductor laser is limited by two factors;

(1) parasitic capacitance in parallel to the active region,

(2) relaxation oscillation of a laser.

In the buried heterostructure, the capacitance at the interface between the burying InP layer and the substrate is the main origin of the parasitic capacitance relevant to the frequency limitation. The capacitance is well reduced by mesa etching and the use of PIQ or other insulating materials as a refill.[4)]

The intrinsic limit of modulation bandwidth is caused by the relaxation oscillation in semiconductor lasers.

The relaxation oscillation frequency fr is given by

$$fr = \frac{1}{2\pi}\sqrt{\frac{P_0 G}{\tau p}} \qquad (1)$$

where P_0 is the optical power density normilized by the photon energy, G is the differential gain and τp is the photon life time in the laser cavity. Simple ways of increasing fr are to make a laser cavity short and to decrease the photon life time. Another approach is to increase the differential gain G by optimizing the laser structure. Recently a relaxation oscillation frequency up to 30GHz has been demonstrated in modulation-doped multi quantum well (MQW) GaAlAs lasers.[5)] This is about five times higher than that of conventional double heterostructure lasers at the same output powers. The injected carriers are more effectively used for laser oscillation because of the two dimensionality of the electron and hole gases. Also the selective doping of Be in the barrier layers realizes high hole concentration in the well. The new laser structure opens the possibility of ultra-high-bitrate (>10Gb/s) operation of semiconductor lasers.

LIGHT SOURCES FOR COHERENT SYSTEMS

The linewidth of a DFB laser is typically 10-30MHz. Narrow linewidth (~10MHz) lasers are selected for FSK (or ASK) experiments. The further reduction of the linewidth has been pursued by combining a laser with an external cavity. The theoretical prediction of the linewidth of such a composite laser cavity is given by

$$\Delta f = \frac{\Delta f_0}{\left(1 + \frac{\tau e}{\tau p}\sqrt{\eta}\right)^2} \qquad (2)$$

under the in-phase condition, where Δf_0 is the linewidth of a laser without the external cavity, τe and τp are the round trip time in the external cavity and the photon life time, respectively, and η is the power feedback ratio.[6)] Assuming η=0.04, τp=2.5ps, and τe=50ps, we obtain a linewidth reduction factor of 25. The round trip time of 50ps roughly corresponds to an external cavily length of 0.5cm (fiber cavity) or 0.2cm (InP waveguide cavity).

Using a fiber cavity which was attached to a laser facet, a linewidth of 75kHz was obtained.[7] A monolithic integration of a laser and a semiconductor waveguide cavity on a single chip was also reported to give a linewidth of 600kHz.[8]

The Eq.(2) is valid when the reflected light is in phase with the light in the laser. The phase of the reflected light should be controlled by changing the refractive index of the external cavity by current injection or other methods.

Frequency tuning is another key technology for light sources in coherent communications. This has been achieved by changing the refractive index of the Bragg reflector in DBR lasers. Using three terminal DBR lasers, a tuning over 3.1nm was demonstrated.[9]

LIGHT SOURCES FOR SUBSCRIBER SYSTEMS

Low-cost and high-reliability are key factors for selecting light sources for future subscriber systems. Because of a rather short transmission distance (<10km), the GaAlAs laser developed for optical pick-ups is a possible candidate. Through a microlens window, an optical power of ~100μW is coupled into a single mode fiber. The same coupling scheme is also applicable to the InGaAsP laser package. However, the poor temperature characteristics of the InGaAsP lasers are still a barrier for them to be used without temperature control.

PHOTODETECTORS AND OEICs

InGaAs avalanche photodiodes (APDs) are widely used for high bitrate systems. A separate absorption and multiplication (SAM) structure and careful guardring process have realized a gain-band product of 30-70GHz, resulting in a receiver sensitivity of -35~-40dBm at 1.2Gb/s and ~-25dBm at 8Gb/s.[10]

Integration of a PIN photodiode and a low noise amplifier is an example of optoelectronic integrated circuits (OEICs). The reported receiver sensitivity of such OEICs is -18~-26dBm at 1-1.6Gb/s, which is about 15dB lower than those of APDs. The difference will become less in the future by further development of OEIC technology, especially by integrating submicron (~0.3μm) gate FETs with a photodiode.

OPTICAL INTEGRATED CIRCUITS

The optical components which are fabricated using discrete prisms, multi-layered filters, mechanical switches, etc. will be replaced by thin film devices. An effort in this direction is to develop a thin film multiplexer and demultiplexer for future wavelength division and multiplexing (WDM) systems. Recently a multi/demultiplexer with high stopband rejection was made using high-silica embedded channel waveguides.[11] By using three directional couplers of the same structure, a stopband rejection loss of more than 20dB was obtained over a bandwidth of 100nm for 1.3μm/1.55μm wavelengths. Such optical devices will be easily mass-produced in the near future.

Thin film optical switches of directional coupler type have been investigated for a long period using optical crystals ($LiNbO_3$, $LiTaO_3$, etc.) and semiconductors (GaAs, InP etc). In these devices the optical path is switched by the change of the refractive index of the waveguides. The index change is caused by the electrooptic effect. Since the index change is small ($<10^{-3}$), the coupling length is 5~10mm typically. Recently, an index change of $\sim10^{-2}$ was achieved by current injection to a waveguide. It is based on the fact that the accummuration of carriers changes the index (and also absorption coefficient) near the band edge significantly. The current injected region can be used as a reflection mirror. The advantage of this approach is the small size of the switching area ($\lesssim$200μm). A 4x4 optical switch of the injection type was demonstrated with an extinction ratio of 20dB and an insersion loss of ~20dB.[12] The rather high insersion loss was mainly due to the light absorption in the waveguide, which should be much reduced by structural and fabricational optimizations. Another advantage of semiconductor optical ICs is the capability of monolithic integration of both active and passive component. Lasers, amplifiers, optical switches, and photodiodes can be integrated rather easily, as demonstrated previously.[13]

REFERENCES

1) K. Utaka et al., IEEE J. Quantum Electron., QE-22, p.1042(1986).
2) N. Kotera et al., Technical Digest, 1987 GaAs IC Symposium, p.103(1987).
3) S. Fujita et al., Technical Digest, OFC 88, PD16(1988).
4) J. E. Bower et al., Electron. Lett., 21, p.1090(1985).
5) K. Uomi et al., Technical Digest, ECOC 87, vol-2, p.29(1987).
6) K. Kikuchi and T. Okoshi, Electron. Lett., 18, p.10(1982).
7) K. Y. Lio et al., Appl. Phys. Lett., 48, p.1039(1986).
8) Y. Matsui et al., Technical Digest, OFC 88, Th K7(1988).
9) S. Murata et al., Technical Digest, OFC/IOOC '87, WC3(1987).
10) B. L. Kasper and J. C. Compbell, IEEE J. Lightwave Tcchnology, LT-5, p.1351 (1987).
11) K. Imoto et al., Appl. Opt., 26, p.4214 (1987).
12) H. Inoue et al., IEEE Lightwave Technology, to be published.,
13) S. Sakano et al., Electron. Lett., 22, p.594(1986).