AD-A271 985

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

...is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, ...ing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this ...ing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ...id to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Finalr Report 15 Mar 91 - 14 Nov 92

4. TITLE AND SUBTITLE
Workshop on high speed/high frequency optoelectronics

5. FUNDING NUMBERS
2301/A1

2

6. AUTHOR(S)
Dr Charles Freiman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
United Engineering Trustees Inc
345 East 47th Street
New York NY 10017

8. PERFORMING ORGANIZATION REPORT NUMBER
AEOSR-TR- 93 0814

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
110 Duncan Avenue Suite B115
Bolling AFB DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFOSR-91-0187

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
UNLIMITED

This document has been approved for public release and sale; its distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

WORKSHOP WAS HELD

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASS	UNCLASS	UNCLASS	UL

GRANT # AFOSR-91-0187

FINAL TECHNICAL REPORT

ENGINEERING FOUNDATION CONFERENCE

"HIGH SPEED/HIGH FREQUENCY OPTOELECTRONICS"

Conference Chairs

Lester Eastman
John Bowers

March 17-22, 1991
Palm Coast, Florida

Report on Conference on
High Speed/High Frequency Optoelectronics
Lester F. Eastman, Conference Chairman

The attached program, and all available abstracts, cover the content of the conference. The 64 participants include 3 from Japan, 3 from England, 2 from Germany, 1 from France, 1 from the Netherlands, and 1 from Canada. The participants were very enthusiastic about the thrust of the meeting, the speakers involved, and the general conference format. They voted nearly unanimously to have another such conference in the 3rd quarter of 1992, (to avoid interfering with other meetings) and possibly every second year thereafter. The next such meeting would be in the Western USA, with the possibility of having more Japanese participation. The possibility of having LEOs jointly sponsor the next meeting, along with the Engineering Foundation will be pursued.

Areas showing remarkable advances, and possibilities for substantial further advances were:

1. High frequency modualtion of multiple quantum well lasers on GaAs (especially strained InGaAs Q.W.'s).

2. High frequency photodetectors, including both surface-illuminated and travelling wave types, and

3. High frequency traveling-wave semiconductor modulators.

An area not yet pursued to high frequencies, but showing great promise, is that of monolithic integration of transistors and semiconductor optical devices.

The financial support of DARPA and the financial and organizational support of the Engineering foundation are gratefully acknowledged.

Ultra-high Speed Mode-locking of Semiconductor Lasers

Kam Y. Lau

Dept. of Electrical Engineering and Computer Science
U.C. Berkeley, Berkeley, CA 94720

Abstract

Recent experiments have shown exceptional results for mode-locked laser diodes at millimeter-wave frequencies of >100GHz, despite the fact that the direct modulation bandwidth of these lasers is limited only to slightly above 10GHz. Theoretical background and experimental results regarding these developments will be discussed.

Monolithic Colliding Pulse Mode-locked Semiconductor Lasers

Ming C. Wu, Young-Kai Chen, Tawee Tanbun-Ek, and Ralph A. Logan

AT&T Bell Laboratories, Murray Hill, NJ 07974

Monolithicly integrated mode-locked semiconductor lasers [1-7] are compact and stable sources of ultrashort optical pulses. Their applications include multi-hundred Gbit/sec time-division multiplexed communication systems, ultra-high speed electro-optic sampling systems, soliton transmission in optical fibers, and generation of millimeter and sub-millimeter waves. The fully integrated optical cavities not only eliminate the tedious optical alignment processes in mode-locked semiconductor lasers using external cavities, they also suppress the undesired multiple pulse output generated by residue intra-cavity reflections. Picosecond pulses have been generated in semiconductor laser with an integrated passive cavity [2], tandem-contact semiconductor lasers [3,5], and hybrid mode-locked semiconductor laser with active waveguide [4]. The monolithic colliding pulse mode-locked (CPM) multiple quantum well (MQW) lasers [6,7] are the first monolithic mode-locked semiconductor lasers that generate optical pulses into the femtosecond regime.

In this paper, we report the monolithic colliding pulse mode-locked (CPM) MQW lasers generating optical pulses as short as 600 femtoseconds. The CPM laser is built on a single-chip buried heterostructure InGaAs/InGaAsP GRINSCH ($\lambda = 1.55\mu m$) MQW wafer [8]. It has a saturable absorber in the center of the linear cavity [9], two modulators near the facets for synchronization with external electric clocks, and two active waveguides linking the modulators and the saturable absorber. The pulse repetition rates are synchronized with an rf synthesizer up to 40 GHz in hybrid mode-locking. The rf signal is sent to the modulators through integrated microstrip transmission lines to guarantee the exact timing between the two counter-propagating pulses. In passive mode-locking, a record high repetition rate of 350 GHz has been achieved. The pulse width of 600 fs is the shortest ever reported for monolithic mode-locked lasers. All the sub-picosecond pulses obtained have pulse shapes of $sech^2$ and transform-limited time-bandwidth products between 0.30 to 0.34.

[1] Lau, Appl. Phys. Lett., 52, 2214 (1988).

[2] Tucker, Koren, Raybon, Burrus, Miller, Koch, Eisenstein, and Shahar, Electron. Lett., 25, 622 (1989).

[3] Vasil'ev and Sergeev, Electron. Lett., 25, 1050 (1989).

[4] Morton, Bowers, Koszi, Soler, Lopata, and Wilt, Appl. Phys. Lett., 56, 111 (1990).

[5] Sanders, Eng, Paslaski, and Yariv, Appl. Phys. Lett. 56, 310 (1990).

[6] Wu, Chen, Tanbun-Ek, Logan, Chin, and Raybon, Appl. Phys. Lett., 57, 759 (1990)

[7] Chen, Wu, Tanbun-Ek, Logan, and Chin, to be published.

[8] Tanbun-Ek, Logan, Temkin, Berthold, Levi, and Chu, Appl. Phys. Lett., 55, 2283 (1989).

[9] Fork, Greene, and Shank, Appl. Phys. Lett., 38, 671 (1981).

Passive mode-locking of quantum well lasers

Steve Sanders, Thomas Schrans, Lars Eng, and Amnon Yariv
128-95 Caltech, Pasadena, California 91125

Joel Paslaski, Jeffrey E. Ungar, and Hal A. Zarem
Ortel Corporation, 2015 W. Chestnut, Alhambra, California 91803

Abstract

Quantum well lasers with their optical cavities electrically divided into regions of saturable absorption and gain were passively mode-locked. Both monolithic devices with repetition rates exceeding 100 GHz and lasers coupled to external cavities, with repetition rates around 1GHz will be described. High frequency mode-locking was observed in both GaAs/AlGaAs and InGaAs/AlGaAs quantum well monolithic stripe lasers; buried heterostructure GaAs/AlGaAs quadruple quantum well lasers were used at the lower frequencies, where one may more easily study the gain and absorber recovery dynamics and measure pulse train stability. Stable passive mode-locking usually requires that the absorber saturation intensity is lower than the gain saturation intensity and that the absorber recovers faster than the gain. A reverse biased quantum well section satisfies both criteria due to the increase in differential gain with decreasing carrier density and fast recovery time.

The basic laser structure used in all the experiments is shown in Figure 1. A monolithic GaAs/AlGaAs device was mode-locked to produce a sustained pulse train at 108 GHz with pulsewidths averaging 2.4 ps. Lower frequency relaxation oscillations and self-sustained pulsations can cause large pulse-to-pulse amplitude fluctuations, but these instabilities are greatly reduced in longer devices, probably due to lower linear cavity losses, as can be shown from stability analysis of a 2-section laser model.

By coupling a 2-section laser to an external cavity, the repetition rate becomes comparable to the gain and absorber recovery times and compatible with conventional detectors and electronics. The optical pulses are measured by a single-shot streak camera to have 7-8 psec FWHM, and the laser can operate at different harmonics of the cavity round-trip frequency by changing only the gain current. Stablity of the pulse train at the fundamental repetition rate is studied by focusing the laser output onto an $\sim$ 10 GHz bandwidth photodetector and analyzing the photocurrent spectrum. Preliminary results show that RMS pulse-to-pulse energy fluctuations are less than 0.5%, and RMS timing jitter is less than 0.3% of the 1.9 nsec pulse repetition period at offsets of 500 Hz to 24 MHz from the 529 MHz mode-locking frequency. At higher offsets, the noise to carrier power spectral density ratio is lower than the system sensitivity limit of -135 dBc/Hz. An understanding of stability and noise mechanisms in passively mode-locked quantum well lasers is important for determing their potential use in measurement and communication systems.

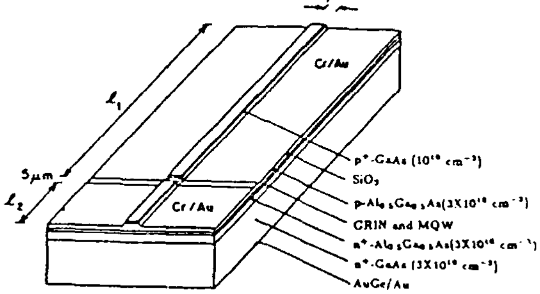

Figure 1

Saturable absorption in voltage controlled InGaAs/InP quantum well lasers

J. O'Gorman, A. F. J. Levi,
T. Tanbun-Ek and R. A. Logan

AT&T Bell Laboratories
Murray Hill, New Jersey 07974

SUMMARY

Intracavity loss modulated, (ICLM), multiple quantum well, (MQW), lasers are attractive as light sources for high bit rate voltage controlled digital optical interconnects [1,2]. The performance of these devices is ultimately determined by the dependence of optical absorption in the laser loss section on intensity, (I), voltage, (V_S), and temperature, (T). We have investigated the (I, V_S, T) dependence of InGaAs/InP MQW absorption and relate our results to the observed lasing characteristics of ICLM MQW InGaAs/InP lasers [3,4]. We have also investigated the temporal and spectral response of ICLM MQW lasers when used for high speed (Gbit s^{-1}) digital data transmission [4,5]. We find good agreement between the observed laser response and that calculated with a rate equation model [6] which incorporates the experimentally determined (I, V_S) absorption dependence [5]. In addition, we find that spectral line-width broadening in Gbits^{-1} modulated single mode ICLM MQW lasers is less than that ocurring in conventional digital current modulation schemes [4,5].

References

1. J. O'Gorman, A. F. J. Levi, T. Tanbun-Ek, and R. A. Logan, Appl. Phys. Lett. *58*, 669 (1991).
2. A. F. J. Levi, R. N. Nottenburg, R. A. Nordin, T. Tanbun-Ek, and R. A. Logan, Appl. Phys. Lett. *56*, 1095 (1990).
3. J. O'Gorman, A. F. J. Levi, T. Tanbun-Ek, and R. A. Logan, (to be published)
4. J. O'Gorman, A. F. J. Levi, T. Tanbun-Ek, D. L. Coblentz and R. A. Logan, (to be published)
5. J. O'Gorman and A. F. J. Levi Electron. Lett. *26*, 1785 (1990).
6. J. O'Gorman, A. F. J. Levi, R. N. Nottenburg, T. Tanbun-Ek, and R. A. Logan, Appl. Phys. Lett. *57*, 968 (1990).

Absolute and Residual Timing Jitter in Actively Mode-Locked Monolithic and External Cavity Semiconductor Lasers

D. J. Derickson, P.A. Morton, R. L. Thornton*, and J. E. Bowers
University of California, ECE Dept., Santa Barbara, Ca. 93106 (805)-893-4235
*Xerox Research Center, 3333 Coyote Hill Road, Palo Alto, Ca. 94304

ABSTRACT

Timing jitter in mode-locked lasers is an important parameter in applications such as electro-optic sampling or high speed telecommunications in which the timing jitter directly degrades the system performance. In active mode-locking, both the laser and the electrical driving source can cause timing jitter. Absolute timing jitter includes both jitter sources and residual timing jitter includes only laser contributions. In this work, the timing jitter is measured for mode-locked semiconductor lasers with external cavities and for monolithically integrated cavities. The absolute and residual timing jitters are measured using a frequency domain technique [1] and then converted into an r.m.s timing jitter over a specified offset frequency range. The measurements show that the timing jitter of mode-locked lasers can be very low but it is found to increase as the percentage of active waveguide in the cavity increases.

The timing jitter of a monolithic cavity device with 100% active waveguide and an external cavity device were compared. The monolithic device is a 7 mm long, three section laser with a four GaAs quantum well active region [2]. The external cavity device had a 300 μm active length of the identical material with an AR coated facet coupled into a 100% mirror [similar to 1]. Both devices had a 5 GHz fundamental mode-locking frequency with approximately 12 ps pulsewidths and 750 μW of average output power. The timing jitter of the external cavity device was dominated by the driving source with absolute and residual r.m.s timing jitters of 200 fs and 80 fs respectively (150 Hz - 50 MHz offsets). The timing jitter of the monolithic cavity device was dominated by the mode-locked laser with absolute and residual timing jitters of 600 fs and 530 fs respectively (150 Hz - 50 MHz offsets). The differences between the two cavity types is explained by the following mechanism: Random carrier density fluctuations in the active waveguide couple to index of refraction variations. Index of refraction variations lead to a phase modulation on the envelope of the mode-locked pulses. The spectral density of these fluctuations controls the frequency response of the phase noise and the length of the active region controls the magnitude of the phase noise. Therefore the all-active waveguide laser has a larger value of timing jitter. Considerations for cavity design, material choice and driving sources will be given for the minimization of timing jitter in mode-locked semiconductor lasers.

[1] D. J. Derickson et. al.,(accepted Dec. 20, 1990), Electronics Letters

[2] R. L. Thornton et. al.. Journal of Lightwave Tech. 6, 786, (1988)

Compensating the group velocity dispersion in quantum well lasers

Hong Lin and John Stephen Smith

Department of Electrical Engineering and Computer Sciences
and the Electronics Research Laboratory
University of California, Berkeley, CA 94720

Recently there have been significant developments [1] on monolithic mode lock semiconductor lasers. One of the important characteristics of semiconductor lasers which influence the mode locking process is the group velocity dispersion. We conduct theoretical studies on the group velocity dispersion of quantum well lasers. We find that a quantum well under certain current excitation conditions can exhibit negative (anomalous) group velocity dispersion at the wavelength where the maximum gain occurs. Therefore, with proper design, it is possible to compensate the positive group velocity dispersion of the cladding region of a multiple quantum well laser by the dispersion of the gain region.

We use the density matrix formalism to calculate the contribution of optical transition near bandgap to the complex dielectric constant [2]. Then the group velocity dispersion and the gain are derived from the complex dielectric constant. The plot of group velocity dispersion vs energy near bandgap of a quantum well has two distinct features: (1) just above the band gap there is a wide region where group velocity dispersion is negative and varies slowly. (2) below the edge of bandgap there is a region where group velocity dispersion varies rapidly, changing from negative to large positive value. We find out that as the carrier densities in a quantum well increase to more than several 10^{18} cm^{-3}, the maximum gain point moves higher relative to the bandgap, i.e. to the region where group velocity dispersion is negative and varies slowly. The magnitude of this negative dispersion ranges from -20 eV^{-1} to -10 eV^{-1} for a 100 Å GaAs/AlGaAs quantum well.

The AlGaAs cladding regions exhibit positive dispersion at the GaAs bandgap energy [3]. This positive dispersion ranges from 1.0 eV^{-1} to 3.0 eV^{-1} depending on the Al concentration. Since the confinement factor of a 100 Å quantum well is about 3%, the positive dispersion of the cladding region can be compensated by three to five quantum wells, if the Al concentration in the cladding region and the threshold carrier densities are properly designed. We also carry out the similar analysis for 1.3-1.55 μm InGaAsP quantum well lasers and obtain similar conclusions.

References

1. M. C. Wu, Y. K. Chen, T. Tanbun-Ek, R. A. Logan, and M. A. Chin, the technical digest of the International Electron Device Meeting, p137-140, 1990
2. Frank Stern, Physical Review, A1653-A1664, 133, 1964
3. M. P. Kesler, and C. Harder, IEEE Photonics Technology Letters, p464-466, 2, 1990

Space-time Duality and Temporal Imaging

Brian H. Kolner

Hewlett-Packard Laboratories

Palo Alto, California

Abstract

There exists an elegant duality between the problems of free-space diffraction and temporal dispersion of electromagnetic waves. By extending the analysis of optical pulse compression in terms of this duality we have discovered a fully equivalent time-domain analog to spatial imaging. In this system quadratic optical phase modulation plays the role of a "time lens" for which we can define an equivalent focal length (or "focal time") and f-number. By placing dispersion ahead of, as well as after, the phase modulation, the system is equivalent to its spatial imaging counterpart composed of a simple lens with appropriate image and object distances. Apart from a residual quadratic phase, the output temporal waveform can be shown to have substantially the same profile as the input waveform except for a linear rescaling of the amplitude and time coordinates. We call this new concept "temporal imaging" and systems based on it should be capable of nearly distortionless expansion or compression of optical waveforms. This would allow, for example, the expansion of sub-picosecond waveforms to a time scale that is accessible to high-speed photodiodes and sampling oscilloscopes or the compression of data streams for high-speed multiplexing. Optimally shaped waveforms for coherent spectroscopy could be prepared on a long time scale and compressed while maintaining their profile. Many other applications in communications and signal processing can also be envisioned.

In this presentation the mathematical foundations of the space-time duality and temporal imaging will be explored and the device requirements to realize practical imaging systems will be described.

Parallel Transport in GaAs Quantum Wells Studied by Femtosecond Optical Spectroscopy

T.B. Norris and W. Sha,
Ultrafast Science Lab, University of Michigan, Ann Arbor, MI 48109-2099

Abstract

High field, and particularly ballistc effects in transport play an important role in the operation of state-of-the-art semiconductor devices. There are basically two ways in which one can observe ballistic transport: (i) using devices of submicron dimension, or (ii), by probing the transport on a sufficiently short time scale. We describe experiments using femtosecond time-resolved optical spectroscopy to probe high-field parallel transport in GaAs quantum wells.

The experiments were performed on a MQW structure situated in a horizontal p-i-n diode so that fields as high as 20 kV/cm could be applied in the plane of the wells. A short (100 fs) pump beam was tuned to resonantly excite n=1 heavy hole excitons, thus producing a carrier distribution with an initial temperature of 0 K. By monitoring the transient absorption spectrum, we have been able to observe exciton ionization and heating of the electron-hole plasma by both phonon absorption and the electric field. Additionally, we have observed the presence of a nonequilibrium electron distribution at short times following the pump pulse when a 16 kV/cm field is applied. This nonequilibrium distribution is associated with a rapid rise and overshoot in the average energy per carrier, which we attribute to quasi-ballistic acceleration of the electrons. Finally, by probing the absorption spectrum in the region of the barrier band gap, we have observed a buildup of population in the above-barrier continuum states, i.e. the occurrence of real-space transfer.

Multigigabit HBT-Based Long-Wavelength OEIC Photoreceivers

M. A. Pollack and S. Chandrasekhar
AT&T Bell Laboratories
Crawford Hill Laboratory
Holmdel, New Jersey 07733

Long-wavelength (1.3-1.6 μm) photoreceivers based on optoelectronic integrated circuit (OEIC) technology have been the focus of considerable research activity over the past decade. A photoreceiver, required in every lightwave link, consists of a photodetector followed either by a discrete or integrated electronic preamplifier. The potential advantages of monolithically integrating the photodetector and preamplifier on the same semiconductor chip include improvement in performance and reliability, and reduced manufacturing costs.

In the past, most research on high-speed, long-wavelength photoreceiver OEICs centered on the integration of InGaAs detectors (PIN or MSM) with field effect transistor (FET) preamplifiers fabricated from either InP or InGaAs. Heterojunction bipolar transistors (HBTs), while offering potentially higher transconductances and speeds, initially proved more difficult to fabricate than FETs in the InP-based material systems. However, progress in the molecular beam epitaxial (MBE) and metal-organic vapor phase epitaxial (MOVPE) growth technologies, coupled with advances in self-aligned device fabrication technology, have allowed ultra-high speed HBT devices to be demonstrated in the last couple of years [1].

The first reported HBT-based long-wavelength OEIC photoreceiver utilized a phototransistor, combining photodetection and amplification, as the input stage. Because of the relatively large device dimensions, the circuit was limited to operation at 100 Mb/s [2]. A later transimpedance OEIC photoreceiver design, with an integrated PIN as photodetector, gave a sensitivity of -26.1 dBm (10^{-9} BER) at a wavelength of 1.5 μm for NRZ signals at 1 Gb/s [3]. This sensitivity was identical to that of a photoreceiver consisting of a discrete PIN photodetector wired to a similar HBT-based preamplifier, and is comparable to the sensitivities of OEIC photoreceivers fabricated using more well-developed FET technology. By reconfiguring the circuit as a cascode amplifier, a 4 Gb/s photoreceiver with a sensitivity of -21 dBm (10^{-9} BER) at 1.55 μm was demonstrated [4]. A similar OEIC photoreceiver circuit fabricated from chemical beam epitaxial (CBE) material had a bandwidth of 3.8 GHz, and operated up to 5 Gb/s with a sensitivity of -18.8 dBm (10^{-9} BER). The HBTs of this circuit were characterized by f_t of 32 GHz and f_{max} of 28 GHz. The performance of these multigigabit OEICs is within just a few dBs of the best hybrid photoreceivers at these bit rates.

In the future, OEIC photoreceiver circuits, as well as OEICs for other novel applications, will operate at even higher speeds and will include increased functionality. More complex functions certainly will require larger-scale electronic integration as well as the integration of additional photonic devices.

[1] R. N. Nottenberg, *et al.*, IEEE Electron Device Lett., *EDL-9*, 524 (1988); Y.-K. Chen, *et al.*, IEEE Electron Device Lett., *EDL-10*, 267 (1989).
[2] S. Chandrasekhar, *et al.*, Electron Lett., *24*, 1443 (1988).
[3] S. Chandrasekhar, *et al.*, IEEE Photon. Tech. Lett., *2*, 505 (1990).
[4] S. Chandrasekhar, *et al.*, Electron. Lett., *26*, 1880 (1990)
[5] S. Chandrasekhar, *et al.*, (unpublished).

Material Considerations for Ultrafast Waveguide Switching

George I. Stegeman
Center for Research and Education in Optics and Lasers
University of Central Florida
Orlando, FL 32826

Abstract

The implementation of ultrafast all-optical signal processing functions such as switching and logic in waveguides requires appropriate materials which can meet certain specifications. The key physical parameter is the nonlinear phase shift induced by the light over the device length. A number of switching devices, and their required phase shifts will be described.

There are three important material limitations which can affect the maximum achievable nonlinear phase shift. They are a possible saturation in the index change with increasing power, linear absorption and two photon absorption (absorption which increases linearly with intensity). Combinations of these two parameters lead to figures of merit against which prospective materials can be compared. In addition, parameters such as the magnitude and sign of the nonlinearity, its response time, the processibility of the material into waveguide structures etc. are also important. In this presentation we will tabulate and compare the various figures of merit and material parameters for representative materials.

Ultrafast optical processing in nonlinear optical loop mirrors.

N J Doran, B P Nelson, K J Blow, J Lukic and I Marshall

British Telecom Research Laboratories, Ipswich IP5 7RE, UK

Abstract

This paper will review the potential of the all-fibre nonlinear loop mirror for all-optical switching at terahertz rates. It will be shown that this device is currently the only nonlinear configuration capable of accessing the full potential of the silica nonlinear figure of merit. The ratio of nonlinearity to loss in silica gives a very favourable ratio for nonlinear switching however this can only be utilised if the device is working close to the loss length. Up to now all fibre based switches have operated far from this optimum. The loop mirror by allowing operation in this limit will enable switching at terahertz or faster rates with modest average powers requirements obtainable from semiconductor sources and switching energies of less than 1pJ/bit. Results will be presented from devices operating with several kilometres in the loop and with switching in the multigigabit/sec regime.

Ultrafast All-Optical Soliton Logic Gates

Mohammed N. Islam
AT&T Bell Laboratories
Holmdel, N.J. 07733

We describe the first Terahertz bit-rate, all-photonic logic gates that satisfy all requirements for a clocked digital optical processor. A three terminal NOR-gate based on soliton dragging in fibers has a gain of six, switching energy of 5.8 pJ and logic level restoration at the output. To prove the cascadability and fan-out of the gates, we implement the first all-optical multivibrator in which the NOR-gate output is fed back to the input. The logic in these gates is based on time-shift-keying where a "1" corresponds to a pulse that arrives within the clock window and a "0" either to no pulse or an improperly timed pulse.

The soliton dragging logic gates are one realization of a novel architecture for all-optical time-domain chirp switches (TDCS) in which switching is achieved with much less than a π-phase shift from the nonlinear interaction. The TDCS consists of a nonlinear chirper followed by a soliton dispersive delay line and has two orthogonally polarized inputs (signal and control pulses). In the absence of a signal pulse, the control pulse propagates through both sections and arrives at the output within the clock window. Adding the signal pulse creates a time-varying index change that chirps the control pulse and shifts its center frequency. Since a fundamental soliton acts like a particle, even a slight shift in the center frequency can cause the complete control soliton to shift in time after propagating in the dispersive delay line.

Understanding the TDCS architecture permits us to optimize the switch performance and to extend the architecture to other materials. For example, as a proof of principle we demonstrate using two fibers a soliton dragging logic gate with a switching energy of 1 pJ and a fan-out of 28. Furthermore, we confirm the mechanisms in the TDCS by implementing a hybrid TDCS in which the nonlinear chirper is an AlGaAs waveguide and the dispersive delay line is a polarization maintaining fiber. The hybrid switch represents the first step toward a compact, integrable, all-semiconductor TDCS.

Optically-Processed Control of Photonic Switches

Paul R. Prucnal

Department of Electrical Engineering
Princeton University
Princeton, New Jersey 08544
USA

As transmission rates in fiber-optic networks increase, routing optical signals using electronic processing will become increasingly difficult. This limitation can be overcome by performing the required processing optically. Self-routing of optical signals through a switching node using optically-processed control is demonstrated. Packet headers are encoded with packet destination addresses using either optical code-division or time-division encoding schemes. An optical routing controller reads the destination addresses and appropriately sets the optical switch using an optical look-up table. The results of several experiments demonstrating optical control of a photonic switch are described.

III-V TRAVELING-WAVE ELECTRO-OPTIC MODULATORS

R.G. Walker

Plessey Research Caswell Ltd.
Allen Clark Research Center
Caswell, Towcester, Northants, NN12 8EQ
United Kingdom

GaAs/AlGaAs, loaded-line, traveling-wave modulators have achieved bandwiths up to 36GHz to date with low (<6 volt at 1300nm) drive voltage into 50Ω. The loaded-line design concept, in which segmented electrodes provide capacitive loading to a coplanar transmission line, is able to combine the high efficiency of vertical-field p-i-n or schottky phase modulators with a velocity-matched, 50Ω structure to obtain very high bandwidth/voltage ratios. Electro-optic and microwave design considerations are largely decoupled in this design and its evolution is traced through lumped precursor devices which, using the same processes and waveguide optimisations, developed and proved the trench-isolation and series push-pull technologies required for the traveling-wave modulator. At 1150nm, a bandwidth of 25 GHz for V_π=4.85 volts typically represents the performance of devices with 10-fold electrode segmentation over 10mm. At 1300nm the bandwidth is unchanged but the drive voltage is higher by the expected wavelength-ratio factor. Modeling shows that bandwidths of 40-60 GHz are possible with this traveling-wave scheme using a finer segmentation. 36GHz bandwidth has been demonstrated with electrodes segmented 20-fold over 10mm.

8:30 A.M. March 20

High Speed Semiconductor Laser Modulation

Introduction:
The Promise and Problems of High-Bandwidth Quantum Well Lasers

Joanne LaCourse, GTE Laboratories

In the past few years, great expectations have been created for the bandwidth potential of quantum well lasers, particularly those with strain introduced by lattice mismatch. While resonance frequencies of up to 36 GHz have been reported in the GaAs/AlGaAs system, similar results have not yet been achieved for longer-wavelength lasers. In addition, unexpectedly strong damping has been reported for some quantum well lasers, limiting the maximum bandwidth to as little as 4 GHz. Other quantum well lasers show much less damping, with correspondingly higher maximum bandwidths possible, and the cause (and *cure!*) for the strong damping is the subject of great debate.

The target of this session is to address the question, "*How fast can quantum well lasers be?*"

Key issues to be covered include:

Enhanced differential gain:	I. Suemune
	C. Kazmierski
	Luke Lester
Success to date:	Steve Offsey
	Hans Wolf
	Radhakrishnan/Toru Fukushima
	Niloy Dutta
Fundamental limitations:	Luke Lester
including damping	Kam Lau
due to gain compression	Radhakrishnan/Toru Fukushima
	Wayne Sharfin
	Katie Hall
	Al DeFonzo

Theoretical Study of Differential Gain in Strained Quantum Well Lasers

Ikuo SUEMUNE
Faculty of Engineering, Hiroshima University

Abstract

Differential gain in semiconductor lasers is closely related with the high-frequency capability, and the modulation bandwidth is expanded with the enhancement of the differential gain by the increase of the resonant oscillation frequency[1] and by the reduction of the damping constant[2]. In this paper, the differential gain expected in a strained quantum well (QW) laser will be discussed based on a theoretical treatment of the band structures where the subband nonparabolicity both in the conduction and valence bands are taken into account. The calculated band-edge effective masses and the calculated laser properties are compared with the available measurements. The differential gain in strained QW's will be larger by about 3~4 times relative to lattice-matched QW's, and the maximum differential gain of $4\text{~}6\times10^{-15}$ cm^2 will be possible in strained QW's. The absolute value of the differential gain will be compared with the values measured in strained and unstrained QW lasers up to now. It will be shown that the most of the measured values are much lower than the present theoretical estimation. The main factors giving the discrepancy will be discussed by the comparison of the measured gain properties with the theory, and some comments will be given for realizing high-speed strained QW lasers.

References

[1] I. Suemune, L. A. Coldren, M. Yamanishi, and Y. Kan, *Appl. Phys. Lett.*, 53, p. 1378, 1988.

[2] K. Uomi and N. Chinone, *Japan. J. Appl. Phys.*, 28, p. L1424, 1989.

Palm Coast, 17-22 March

9:15 A.M. March 20

LOGARITHMIC GAIN APPROACH IN THE STRAINED AND UNSTRAINED MQW LASER DESIGN FOR HIGH FREQUENCY OPERATION

C.KAZMIERSKI, A.OUGAZZADEN, B.SERMAGE, and M.BLEZ

Centre National d'Etudes des Télécommunications
Laboratoire de Bagneux
196, avenue Henri Ravera, 92220 BAGNEUX, France

A simple logarithmic gain formula has been shown to approximate static characteristics of GaAs [1] and, more recently, GaInAsP [2,3] QW lasers. Using this nonlinear-gain approach, we obtained an excellent fit to experimental threshold current density-laser length data in the case of unstrained [3] and strained MQW-SCH broad-area and Buried Ridge Stripe structure lasers. According to this fit, extremely low threshold current (below 2mA) lasers have been designed and experimentally demonstrated. Moreover, more important gain per well has been deduced for the strained well as compared to the unstrained one.

As the logarithmic gain leads also to a nonlinear differential gain, we studied consequences of the nonlinear gain model on the high frequency laser design. Following recent theoretical calculations [4], the optimized differential gain should lead to the optimized high frequency laser behaviour whatever be the photon saturation coefficient (ε).

Due to carrier-concentration dependence of the nonlinear gain, the differential gain is shown to be strongly dependent on the laser geometry and facet treatment design as well as on the quantum well material properties (well number, internal quantum efficiency). Using the experimental data fit, the differential gain as a function of laser length for unstrained lasers is compared to equivalent structure lasers with a compressive strain. The strained well structure can have up to 50 % higher resonance frequency if the carrier concentration at threshold be equivalent to that of the unstrained structure. The differential gain increases with the laser length owing to the decreasing carrier concentration at threshold. This effect leads to an optimum MQW laser length for high frequency operation because the photon lifetime is decreasing with laser length. This length is found to be shorter than 200 µm. The calculations shows that the differential gain can be much larger for 10 or 15 wells and saturates with further increase of the well number.

The consistency of the logarithmic gain model is checked using laser resonance frequency measurements in the case of very short cavity devices.

In conclusion, the nonlinear gain approximation is shown to give a simple MQW laser design approach for both static and dynamic laser operation. The gain-carrier dependence leads to an optimum laser length from the high speed operation capability point of view. The optimum length is shorter than 200µm for well number larger than 5 showing an interest of very short cavity length devices for the high-speed operation. Also, the simple design indicates that much larger well number up to 15 together with a compressive strain would be better choices for high frequency MQW laser.

This work has been done under European Community Project RACE 1057 AQUA

[1] P.W.A.McILROY, A.KUROBE, and Y.UEMATSU, IEEE J.Quantum Electronics, 21,(1985) p.1958

[2] J.E.A.WHITEAWAY, G.H.B.THOMPSON, P.D.GREENE, and R.GLEW, submitted to Electron.Lett. 1990

[3] C.KAZMIERSKI, A.OUGAZZADEN, B SERMAGE, M.BLEZ, J.LANDREAU, A.MIRCEA and J.C.BOULEY, 12th IEEE Laser Conference, Davos, Sept 9-11, Switzerland

[4] G.P.AGRAWAL, Appl.Phys.Lett. 57, (1990), p.1

Theoretical Calculation of Differential Gain in Strained-Layer InGaAs/GaAs Lasers: Comparison with Experimental Results

Luke Lester, S.D. Offsey, B.K. Ridley*, W.J. Schaff, B.A. Foreman, and L.F. Eastman
Cornell University, School of Electrical Engineering, Ithaca, NY 14853
* Permanent address: Dept. of Physics, University of Essex, Cochester, U.K.

A theoretical model that uses simple, analytic valence band equations to calculate the differential gain in strained layer InGaAs/GaAs quantum wells shows good agreement with experimental differential gain values obtained from multiple quantum well strained layer lasers. The differential gain in these devices is about 16 times greater than in bulk, p-type doped InGaAsP devices.

With respect to the damping of the resonance frequency, the very high differential gain in strained layer quantum well (SLQW) lasers more than offsets their relatively large non-linear gain suppression factor, and thus the damping in SLQW lasers is not as strong as in bulk InGaAsP lasers. The model is also used to compute the maximum -3dB bandwidth as a function of optical loss in order to find the optimum cavity length for high speed operation. Calculations which consider gain suppression at high powers indicate that a 60 GHz modulation bandwidth should be achievable in SLQW lasers.

Ultra-high Speed Mode-locking of Semiconductor Lasers

Kam Y. Lau

Dept. of Electrical Engineering and Computer Science
U.C. Berkeley, Berkeley, CA 94720

Since the first demonstration of mode locking of semiconductor lasers[1], there has been an on-going effort to attempt mode-locking at ever higher frequencies. This arises in part from the potential for applications in communications and microwave systems, and in part by the desire to avoid external cavity arrangements which are needed for mode-locking at lower frequencies (<20GHz). Despite early experimental demonstrations to the contrary[2,3], it was not intuitively obvious that mode-locking can take place at frequencies much above the intrinsic 3dB cutoff in the direct modulation of these lasers - in the 10GHz range. Later[4,5], it was theoretical shown that contrary to intuition, both active and passive mode-locking can indeed take place at frequencies much higher than the modulation cutoff - up to and beyond 100GHz. Early experimental evidences[4] gave way to recent demonstrations which showed that it not only works at these high frequencies but works extraordinarily well, with 100% modulated pulses in the low-picosecond to subpicosecond range[6-9].

These developments will be reviewed in this talk. In particular, the fundamental question of why mode-locking can take place at a frequency much higher than the intrinsic modulation bandwidth will be addressed.

References

1. P.T. Ho, L.A. Glasser, E.P. Ippen and H.A. Haus, Appl. Phys. Lett., 33, 241 (1978); E.P. Ippen, D.J. Eilenberger and R.W. Dixon, Appl. Phys. Lett., 37, 267 (1980).
2. S. Akiba, G.E. Williams and H.A. Haus, Electron. Lett., 17, 527-528 (1981); K.Y. Lau, and A. Yariv, Appl. Phys. Lett., 46, 326 (1985).
3. K.Y. Lau, and A. Yariv, Appl. Phys. Lett., 46, 1117 (1985).
4. K.Y. Lau, Appl. Phys. Lett., 52, 2214 (1988).
5. K.Y. Lau, IEEE J. Quantum Electron., QE-26, 250 (1990).
6. R.S. Tucker, U. Koren, G. Raybon, C.A. Burrus, B.I. Miller, T.L. Kock and G. Eisenstein, Electron. Lett., 25, 621 (1989).
7. J.E. Bowers, P.A. Morton, A. Mar and S.W. Corzine, IEEE J. Quantum Electron., QE-25, 1425 (1989).
8. S. Sanders, L. Eng, J. Paslaski and A. Yariv, Appl. Phys. Lett., 56, 310 (1990).
9. M.C. Wu and Y.K. Chen, Appl. Phys. Lett., 57, 759 (1990).

High-speed performance of GaAs/AlGaAs multiple quantum well lasers

H.D. Wolf
Siemens AG, Corporate Research and Development
D-8000 München 83, Otto-Hahn-Ring 6, Germany

Abstract

Results on the performance, primarily at high-speed modulation, of GaAs/AlGaAs multiple quantum well ridge waveguide (RW) lasers will be presented and discussed. The relatively low temperature sensitivity of AlGaAs lasers makes them attractive for integration, e.g. to laser arrays or with other semiconductor devices.

The lasers have been fabricated using MOVPE and a dry etch process for the ridge structure. The RW structure seems favorably in respect to the fabrication process and to reliability and despite of the lack of barriers for lateral carrier confinement in this structure its threshold current may be fairly low. Threshold currents of below 10 mA, modulation bandwidths of up to 16 GHz and relaxation frequencies of up to 36 GHz have been measured for optimized devices. Eye diagrams at up to 8 GBit/s at least (limit of the measurement system used) are well opened. Stable laser characteristics have been achieved at temperatures up to 120 °C.

11:30 March 20

High Speed Semiconductor Laser Modulation

Modulation and Noise Properties of Strained InGaAs/GaAs Multiple Quantum Well Lasers

L.N. Radhakrishnan, Toru Fukushima, and John Bowers
University of California at Santa Barbara

Large damping in MQW lasers has recently been reported. Although MQW structures show extremely high differential gain, this merit is negated by a large damping effect which causes a serious limitation to the maximum modulation bandwidth of the MQW lasers. In this talk, we report the measurement results of the damping factor and the resonance frequency of the strained and unstrained InGaAs/InP MQW lasers. A reduction of the K factor by increasing the thickness and the number of wells is proposed, and the result will be shown for both InGAAs/GaAs strained MQW lasers and InGaAs/InP MQW lasers.

High Speed Modulation of Multiple Quantum Well Lasers

Niloy Dutta, H. Temkin, R.A. Logan, and T. Tanbun-Ek
AT&T Bell Laboratories, Murray Hill, NJ 07974

Measurements of small signal and large signal frequency response of buried heterostructure lasers fabricated using regular double heterostructure, multiquantum well and strained multiquantum well active regions are reported. Bandwidths as high as 18 GHz have been obtained for multiple quantum well lasers. Measurements of the effect of active layer doping on bandwidth and saturation parameter are reported. Bandwidth limitation of lasers due to saturation, heating, and parasitics will be discussed.

Structure-Dependent Gain Compression and Damping of QW Lasers

Wayne Sharfin, W. Rideout, E. Koteles, J. Schlafer, B. Elman, M. Vassell, and J. Lee
GTE Laboratories, Incorporated, 40 Sylvan Road, Waltham, MA 02254

Measurement of the relative intensity noise spectra of quantum well lasers of various material compositions indicate structure-dependent damping of their frequency response. The magnitude of this damping (i.e., the *k*-factor) is as much as an order of magnitude larger than typically observed in bulk lasers. This severely limits the maximum attainable modulation bandwidth of some quantum-well lasers. A damping mechanism and rate-equation model are proposed in which the recapturing of carriers (which have been excited into the higher-bandgap confinement and barrier layers) limits the high-frequency response of the laser. Additional experimental support for this mechanism is presented.

Femtosecond Gain Dynamics and Pulse Saturation Behavior in InGaAsP Optical Amplifiers

K.L. Hall, Y. Lai, E.P. Ippen, G. Eisentein[a] and U. Koren[b]

Department of Electrical Engineering and
Computer Science and Research Laboratory
of Electronics
Massachusetts Institute of Technology
Cambridge, MA 02139

ABSTRACT

We present femtosecond pump-probe measurements of gain and loss dynamics in bulk and multiple quantum well (MQW) optical amplifiers at 1.5 μm. Optically induced changes in diode junction voltage are also observed. The short-pulse output energy saturation behavior of these amplifiers has been studied for input pulsewidths of 15 psec and 150 fsec. A simple rate equation model based on pump-probe results has been developed to predict the observed pulsewidth-dependent saturation behavior.

---

a) Permanent address: Electrical Engineering Department, Technion, Haifa 32000, Israel.
b)Permanent address: AT&T Bell Laboratories, Holmdel, NJ 07733-1988.

Characterization and Application of Gain-Switched Semiconductor Lasers

J. M. Wiesenfeld
AT&T Bell Laboratories
Crawford Hill Laboratory
Holmdel, NJ 07733

Gain-switching is a convenient method for the generation of ultrashort optical pulses from semiconductor lasers. No external cavity is required and the repetition rate is broadly tunable. Gain-switched lasers are strongly chirped. However, this chirp can be used to advantage in pulse compression schemes which require only linearly dispersive media, such as optical fiber, grating pairs, or Gires-Tournois interferometers. Pulses from gain-switched lasers have been used in optical communication experiments and in optical sampling experiments. In particular, high-speed signals internal to integrated circuits have been measured using electro-optic sampling systems based on gain-switched lasers.

Gain Switching in Vertical Cavity Lasers

J.R. Karin, L.N. Radhakrishnan, L.G.Melcer and R.S. Geels
Ultrafast Optoelectronics Laboratory
Department of Electrical and Computer Engineering
University of California, Santa Barbara

Abstract

Vertical cavity semiconductor lasers have received a tremendous amount of attention in the past few years. Their small size, low threshold current and inherent single longitudinal mode operation make them extremely attractive for applications such as optoelectronic integrated circuits and optical computing. Considerable progress has been made in the development of very low threshold[1] and very compact vertical cavity lasers. However, a complete understanding of the capabilities of these devices requires knowledge of the critical design parameters for high speed operation as well as for low threshold current. It has been suggested that the very features designed to lower the threshold of vertical cavity lasers, in particular the very high mirror reflectivity, will inhibit their high speed operation. Optical gain switching provides a technique for measuring the dynamics of the vertical cavity structure, without the intrusion of parasitic effects of electrical contacts. In this paper we present measurements[2] and numerical simulations of optically gain-switched GaAs vertical cavity lasers, and discuss the implications of the results for designing these lasers for high speed or short pulse operation.

A GaAs vertical cavity laser with 20, 300 Å quantum wells in a periodic gain configuration was optically pumped with 6 ps pulses from a synchronously-pumped dye laser. Light from the vertical cavity laser was measured with a high speed detector and sampling oscilloscope to determine the turn-on delay, and an autocorrelator was used to measure the pulsewidth. Pulses as short as 4 ps (autocorrelation FWHM) were obtained, with peak-to-peak delays of ~20 ps. Both pulsewidth and delay were measured as a function of pump power, and the measured results agree well with numerical simulations. The numerical model can be used to generate design curves, showing the effects of cavity length and mirror reflectivity on pulsewidth and delay. The results show that for a given active region width, the shortest cavity length produces the shortest pulses. The pulsewidth is found to decrease with increasing mean mirror reflectivity, up to a reflectivity of ~99.5%. Beyond that point, the pulsewidth increases because the cavity photon lifetime becomes significantly longer. These results demonstrate the potential of vertical cavity lasers for high speed operation and provide guidelines for future vertical cavity designs.

---

1 R.S. Geels and L.A. Coldren, Appl. Phys. Lett. 57 (16), 1605, 15 October 1990

2 J.R. Karin, et al., Appl. Phys. Lett. 57 (10), 963, 3 September 1990

ABSOLUTE AND RELATIVE SYSTEMS FOR THE MEASUREMENT OF HIGH SPEED PHOTODIODES

D A Humphreys: National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW, England.

J Schlafer: GTE Laboratories Inc., 40 Sylvan Road, Waltham, MA 02254, USA.

Abstract

High-speed photodiodes are important for the development of future advanced optoelectronic systems and therefore confidence in the accuracy of measured results is vital. The relative merits of different systems will be discussed and the results of an informal intercomparison of three measurement systems will be presented.

Once a photodiode has been accurately characterised against absolute standards of RF power or electrical risetime using an optical source with known characteristics, it can be used as a reference for the measurement of other devices. The requirements of a photodiode "Transfer standard" will be outlined and the advantages and penalties of this approach, when compared with absolute methods, will be discussed. A comparison of results obtained by two relative and two absolute methods will be presented, together with a description of the measurement systems.

PRELIMINARY RESULTS OF AN INTERNATIONAL HIGH-SPEED PHOTODIODE BANDWIDTH INTERCOMPARISON

D A Humphreys (*1), T Lynch, D Wake (*2), D Parker (*3), C A Park (*4), S Kawanishi (*5), M McClendon (*6), J Schlafer (*7), A H Gnauck, G Raybon (*8), T Hawkins II (*9).

Abstract

The frequency response of high speed photodiodes can be measured using a number of different techniques. An international intercomparison has been performed to assess possible sources of systematic error associated with different measurement methods.

Two photodiode modules, with bandwidths in the range 10 - 20 GHz, were circulated to each of nine establishments for characterisation. The measurements were carried out at the optical fibre communication wavelengths of 1.3 µm and 1.55 µm. A total of nineteen measurments were made on each of the devices using sixteen measurement systems.

Preliminary results will be presented, together with brief descriptions of the measurement systems used.

(*1) National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 OLW, UK.

(*2) British Telecom Research Laboratories, Martlesham Heath, Ipswich, IP5 7RE, UK.

(*3) BT&D Technologies Ltd, Whitehouse Lane, Ipswich, Suffolk, IP1 5PB, UK.

(*4) Plessey Research & Technology, Caswell, Towcester, Northamptonshire, NN12 8EQ, UK.

(*5) NTT Laboratories, 1-2356, Take, Yokosuka-Shi, Kanagawa-Ken, 238-03, JAPAN.

(*6) HP Network Measurement Division, 1400 Fountaingrove Parkway, Santa Rosa, CA 95401-1799, USA.

(*7) GTE Laboratories Inc., 40 Sylvan Road, Waltham, MA 02254, USA.

(*8) AT&T Crawford Hill Laboratory, PO Box 400, Holmdel, NJ 07733, USA.

(*9) Tektronix Laboratories, Mail Station 50-383, PO BOX 500, Beaverton, OR 97077, USA.

CHARACTERISTICS OF WIDEBAND MONOLITHIC OPTICALLY PREAMPLIFIED PIN PHOTODIODES

D Wake

British Telecom Research Laboratories,
Martlesham Heath, Ipswich, England. IP5 7RE

Optical preamplification of wideband photodetectors is a useful technique for increasing the signal to noise ratio in a wide variety of high speed/high frequency applications, and has been used with considerable success, for example, in receivers for optical communication systems [1]. To date, this technique has been realised in hybrid form, using optical preamplifiers based on either semiconductor or erbium doped fibre, and high speed PIN photodiodes. In the device described here, these functions have been integrated monolithically, with the attendant benefits of ruggedness, compact size and low cost.

The device consists of a semiconductor laser preamplifier and an edge-coupled PIN photodiode, in an essentially butt-coupled configuration. The structure is based upon the ridge waveguide laser, and the photodiode absorbing layer is an unpumped extension of the preamplifier gain layer. Details of the structure, and preliminary results on uncoated chips have been published previously [2]. For this work, devices were produced having peak wavelength at 1550nm, and the input facets were anti-reflection coated to provide near travelling wave amplification.

Optical and electrical measurements were performed on devices having a preamplifier length of 500μm and a photodiode length of 20μm, at a preamplifier bias of 200mA and a photodiode bias of -2V. Parameters of primary interest in these devices are internal responsivity and electrical bandwidth, which have values of 170 A/W and 35GHz respectively.
Results from other measurements, such as optical bandwidth, wavelength sensitivity, and spectral noise current density will be presented, together with the implications that these parameters have for the application areas of these devices.

[1] I W Marshall et al, Electron. Lett., vol. 23, pp.1052 - 1053, 1987.

[2] D Wake et al, Electron. Lett., vol. 26, pp.1166 - 1167, 1990.

Graded Double Heterostructure PIN Photodetectors

Y. G. Wey, D. L. Crawford, K. Giboney, A. Mar, and J. Bowers

Department of Electrical and Computer Engineering
University of California
Santa Barbara, CA 93106

Abstract

High speed photodetectors are of great importance in broad bandwidth optical communications and ultrafast measurement techniques. In this presentation, we describe the use of double heterostructure photodetectors to decrease the diffusion current typical in homojunction devices and to increase the quantum efficiency through double pass absorption. Further, we describe the effects of carrier trapping at heterojunctions and the grading layers that are used to remove this effect. By combining these layer changes with a detector structure that allows for simple scaling to small areas, we have reduced the width of the impulse response to a record low value of just 3.8 ps. The quantum efficiency was 31%, corresponding to a bandwidth efficiency product of 20 GHz.

Recent developments in ways to increase the quantum efficiency of high speed detectors will be described. In particular, quantum confinement can be used to increase the absorption coefficient and the saturated velocity and result in large increases in the bandwidth efficiency product. The uniformity of the wires is a severe concern that limits the increase in detector performance.

Nonlinear Transmission Lines and their Applications in Picosecond Optoelectronic and Electronic Measurements

M. Rodwell, M. Kamegawa, M. Case, R. Yu, K. Giboney, J. Karin, S. Allen, J.E. Bowers
Department of Electrical and Computer Engineering, University of California, Santa Barbara,
Jeff Franklin, Varian Associates III-V Device Center, Santa Clara, CA 95054

Through appropriate grading of the Bragg frequency vs position (fig. 1), nonlinear transmission lines (NLTLs) can be used for step-function or impulse compression and frequency multiplication. Shock-wave NLTLs have attained 1-2 ps falltimes (fig. 2), enabling ≈DC-275 GHz sampling circuits for sampling oscilloscopes and network analyzers. Using soliton propagation on exponentially-graded NLTLs, large-amplitude picosecond impulses are directly generated (fig. 3). NLTLs with low Bragg frequencies serve as efficient monolithic broadband frequency multipliers (fig. 4), whose parameters are readily scaled for millimeter-wave multiplication. Picosecond Schottky photodetectors have been directly integrated with the ultrafast sampling circuits (fig. 5), forming a 4.5-ps-speed (fig.6) picosecond optoelectronic sampling head for measurement of optical waveforms. These solid-state devices may supplant correlation methods in measurements of picosecond optical phenomena

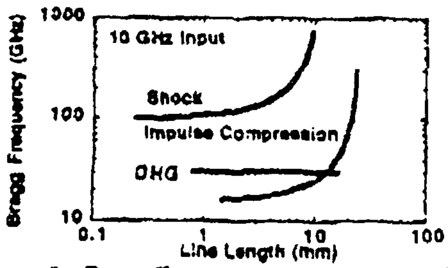

Figure 1 : Bragg Frequency vs position: NLTLs for Shock, impulse compression, and Distributed Harmonic Generation.

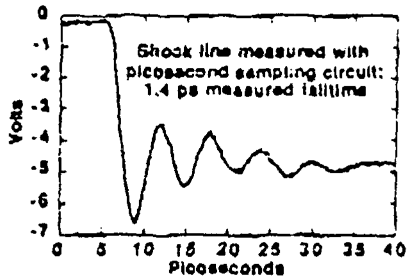

Figure 2: 1.4 ps shock-wave NLTL output measured by a ≈275 GHz-bandwidth NLTL-gated sampling circuit

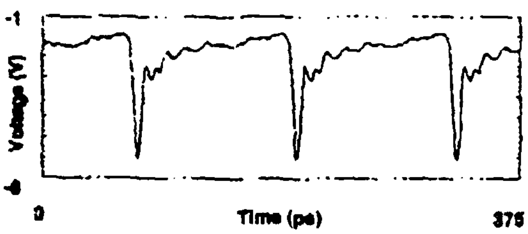

Figure 3: 5.5 ps FWHM 3.9 Vp-p impulse train generated by a tapered soliton NLTL.

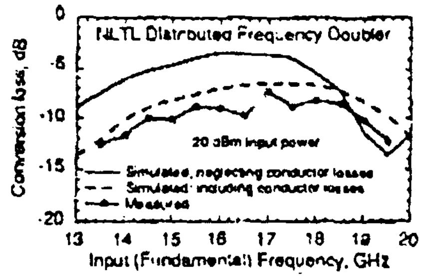

Figure 4: Conversion efficiency for NLTL distributed harmonic generation

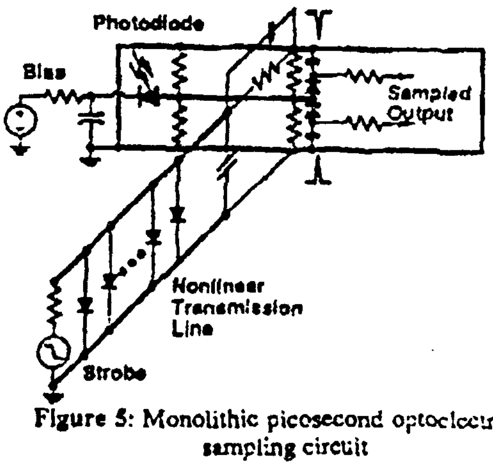

Figure 5: Monolithic picosecond optoelectronic sampling circuit

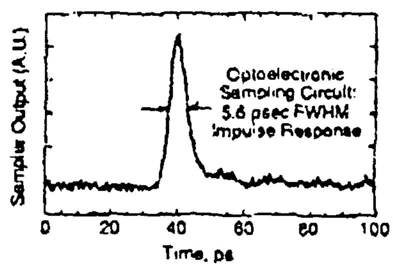

Figure 6: Impulse response of the optoelectronic sampling circuit when illuminated by an 850 nm dye laser. The deconvolved (combined photodiode and sampling circuit) response is 4.5 ps FWHM.

REMOVAL OF JITTER FROM MEASURED SIGNALS. A NOVEL APPROACH TO DATA AQUISITION AND NUMERICAL PROCESSING

D A Humphreys: National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 OLW, England.

Abstract

Measurements of high speed devices using sampling oscilloscopes are often limited by the uncertainty, in time, between the trigger and measurement points. This effect is known as Jitter. The effects of noise and jitter on a waveform are described and an algorithm to remove, or reduce, the effects of jitter is presented. Sources of jitter, and their associated probability density distributions, are discussed and the algorithm is demonstrated using simulated data.

Methods of acquiring jittered signals using both analogue and digital sampling oscilloscopes are described and the measured and processed results are presented.

High-Efficiency Waveguide InGaAs pin Photodiode with Bandwidth of over 40 GHz

KAZUTOSHI KATO, SUSUMU HATA, ATSUO KOZEN, JUN-ICHI YOSHIDA, AND KENJI KAWANO

NTT Opto-electronics Laboratories, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa Pref., 243-01, Japan

ABSTRACT

A waveguide pin photodiode structure was designed in consideration of both wide bandwidth and highly efficient coupling to the fiber. The device performed with a bandwidth higher than 40 GHz and had high responsivity of 0.85 A/W (external quantum efficiency of 68%), showing superiority of bandwidth-efficiency product over the surface-illuminated photodiodes in the ultra high frequency region.

A New Optoelectronic Device Based on A Modulation-Doped Heterostructure and Its Monolithic Integration

Ikuo Suemune, Yoshiaki Honda+ and Masamichi Yamanishi
Faculty of Engineering, Hiroshima University, Higashihiroshima 724 Japan

For optoelectronic integration, the structural difference of especially lasers and electronic devices has been one of the major difficulties for the further development. We propose a new type of optoelectronic semiconductor device which utilizes the modulation-doped (MOD) heterostructure[1]. The device operates as not only a lateral-current-injection (LCI) laser but also as a junction field-effect transistor (J-FET) based on the MOD heterostructure[2]. A monolithic integration of a MOD-LCI laser and a J-FET will be demonstrated utilizing the common two-dimensional electron gas.

Figure 1 shows the schematic of the monolithic integration of the MOD-LCI laser and the J-FET[3]. The two ridges correspond to the laser and the J-FET. Both of them have the same structure based on the common MOD structure. The GaAs quantum well(QW) where the two-dimensional electron gas is accumulated will be an active layer for lasing as well as the FET channel. The lowest lasing threshold up to now in this structure is 6.5mA for the stripe width of 3μm. The ON/OFF ratio of 9 in the light output was observed in the integrated device with the modulation of the gate voltage at the frequency of 50MHz.

Feasibility of optoelectronic integration in the pseudomorphic InGaAs system with the present scheme will be discussed where a high-speed strained-QW laser[4] and a pseudomorphic HEMT will be integrated.

+ On leave from Matsushita Electric Works Ltd., Kadoma, Osaka, 571, Japan.

References

[1] N. Yasuhira, I. Suemune, Y. Kan, M. Yamanishi, APL, 56 (1990) 1391.
[2] Y. Honda, I. Suemune, N. Yasuhira, M. Yamanishi, IEEE PTL to be published
[3] Y. Honda, I. Suemune, M. Yamanishi, 22nd Conf. SSDM (1990,Tokyo)1179.
[4] I. Suemune, L. A. Coldren, M. Yamanishi, Y. Kan, APL, 53 (1988) 1378.

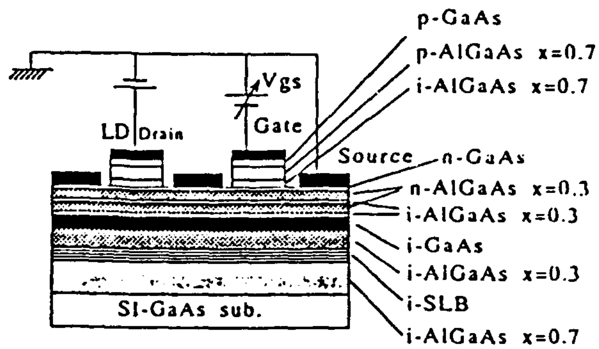

Fig. 1 Schematic monolithic integration of LCI laser and J-FET on MOD structure.

OEIC Transmitter Array for High Speed and High Density WDM Communication Systems

Y. H. Lo
Cornell University, Ithaca, NY 14853

R. Bhat, P. S. D. Lin, and T. P. Lee
Bellcore, 331 Newman Springs Rd.
Red Bank, NJ 07701

Abstract

We integrated 1.5 μm wavelength DFB laser diodes with driving transistors to make optoelectronic integrated circuit (OEIC) transmitters. The layers for lasers and transistors were lattice matched to InP substrates and were grown by OMVPE. The DFB laser, having a self-aligned constricted mesa (SACM) structure has a typical threshold current of 7 mA. To operate the circuit at a high bit rate and a low power level, the differential gain of the DFB laser was maximized by the scheme of negative detuning. The DFB lasers detuned by 10 nm from the gain peak showed an intensity modulation bandwidth of 12 GHz at a bias current of as low as 40 mA. The transistors are MODFETs made of InGaAs/InAlAs. The current density and the transconductance of the MODFET with a 1.5 μm gate length are 250 mA/mm and 150 ms/mm, respectively.

The OEIC chip was made of an array of four identical DFB laser transmitters. Each transmitter was individually tested at 10 Gb/s using pseudo random NRZ signals and a clean eye pattern was obtained. Transmission experiment was conducted at a bit rate of 5 Gb/s using the OEIC transmitter and a PIN/HEMT hybrid receiver. A sensitivity of -20 dBm after a transmission distance of 29 km was demonstrated, limited by the receiver sensitivity. We also measured the RF crosstalk between two adjacent transmitters up to 12 GHz. It was found that the crosstalk was mainly due to the bonding wires and its value was lower than -15 dB in the entire frequency range. The low crosstalk value indicates that the sensitivity penalty from the interchannel interference is negligible.

Finally, we showed that by setting each transmitter with a particular wavelength, the OEIC array can function as a wavelength division multiplexing transmitter. Incorporating the wavelength tuning capability in each laser diode, we demonstrated a transmitter array having a wavelength spacing as close as 3Å. The optical channel spacing between two transmitters can be adjusted anywhere from 1Å to 1 nm. This accomplishment makes the OEIC transmitter array a viable circuit for both high speed and high density WDM communication systems.

High-Speed InGaAs Metal-Semiconductor-Metal Photodetectors

D. Kuhl, F. Hieronymi, E.H. Böttcher, T. Wolf, and D. Bimberg
Institut für Festkörperphysik I, Technische Universität Berlin, Hardenbergstraße 36, D-1000 Berlin 12, Germany

J. Kuhl
Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, D-7000 Stuttgart, Germany

Abstract

The impulse response of interdigitated metal-semiconductor-metal (MSM) photodetectors with an Fe-doped InGaAs absorbing layer and an Fe-doped InP barrier enhancement layer is investigated. Results are presented for different illumination wavelengths (620 nm, 840 nm, 1.3 µm)) with optical pulse durations (FWHM) of 150 fs, 15 ps, and 33 ps, respectively. The response of the MSM devices mounted in packages with 46 GHz K-connectors is monitored by a 40 GHz digitizing sampling oscilloscope. For short wavelength (λ = 620 nm) and ultra-short pulse excitation (FWHM = 150 fs), the FWHM of the impulse response is 13 ps for detectors with 1 µm and 2 µm interfinger spacing, thus indicating that the FWHM is measurement-limited by the impulse response of the sampling system. The 13 ps impulse response is the lowest one reported so far for InGaAs MSM detectors. Above a certain illumination level (0.1 pJ/pulse), the impulse response exhibits a nonlinear behaviour with increasing optical pulse energy which is reflected by the following features: The peak amplitude of the response increases sublinearly and the relative contribution of the tail observed in the detector response is appreciably enhanced. We attribute this nonlinearities to the screening of the electric field by photo-generated space charges. For detectors with relatively wide finger spacing (5 µm) and illuminated with long-wavelength (λ = 1.3 µm) light pulses (FWHM = 33 ps), space charge perturbation of the impulse response manifests itself by a decrease of FWHM and increase of the fall time with increasing illumination level. The practical consequences in terms of application and testing of speed performance of MSM detectors are discussed. Moreover, we compare our results with a recent theoretical study of the impulse response of interdigitated MSM detectors which is based upon a Monte-Carlo particle calculation.[1] Qualitatively, the observed nonlinearities are very well explained within the framework of that theoretical approach.

---

[1] J. Rosenzweig et al., "Characterization of GaAs MSM photodectectors", Proc. SPIE, vol. 1362, Intern. Conf. on Physics and Concepts for Novel Optoelectronic Devices

Wave-Coupled Millimeter-Wave Electro-Optic Modulator

William B. Bridges and Finbar T. Sheehy
California Institute of Technology
Pasadena CA 91125
and
James H. Schaffner
Hughes Research Laboratories
Malibu CA 90265

Abstract: The phase velocity mismatch due to material dispersion in traveling-wave $LiNbO_3$ modulators may be reduced greatly by breaking the modulator electrodes into short segments and connecting each segment to its own surface antenna. The array of antennas is illuminated at an angle which assures that each short modulator segment is driven in the proper phase. Improved performance can be obtained at the design frequency by increasing the number of modulator elements without any resulting loss of bandwidth. Wave-coupled phase modulators have been demonstrated at 7-12 GHz and 61-63 GHz with good performance. Amplitude modulators and broader-bandwidth devices are being developed.