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CThM30

Pulse distortion in a quantum dot optical amplifier

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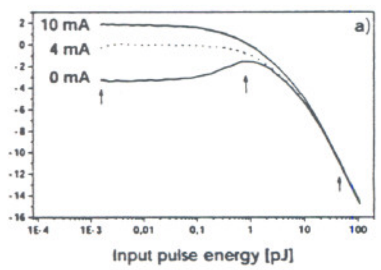
Semiconductor optical amplifiers are essential elements in all-optical signal processing due to their high gain and high bandwidth.[1] With the increasing bit rate demand in OTDM systems, subpicosecond pulse dynamics becomes important. The superiority of optical amplifiers based on quantum dot (QD) gain materials with respect to temperature stability and low drive current makes these devices especially interesting to study.[2] Experimental results on pulse propagation in an electrically-pumped QD amplifier using a novel phase-sensitive pulse characterization technique are presented.

The QD device is a P-I-N structure grown by MOCVD. The active region consists of three layers of binary/ternary InAs/InGaAs QDs separated by 21-nm-thick GaAs barriers, in the center of a 120-nm-thick GaAs layer. Two A1GaAs cladding layers and ridge structure of 8-m width and 400-m length provide the optical confinement and waveguiding. Tilted facets inhibit laser action. Ground state dot emission occurs at 1.08-μm wavelength.

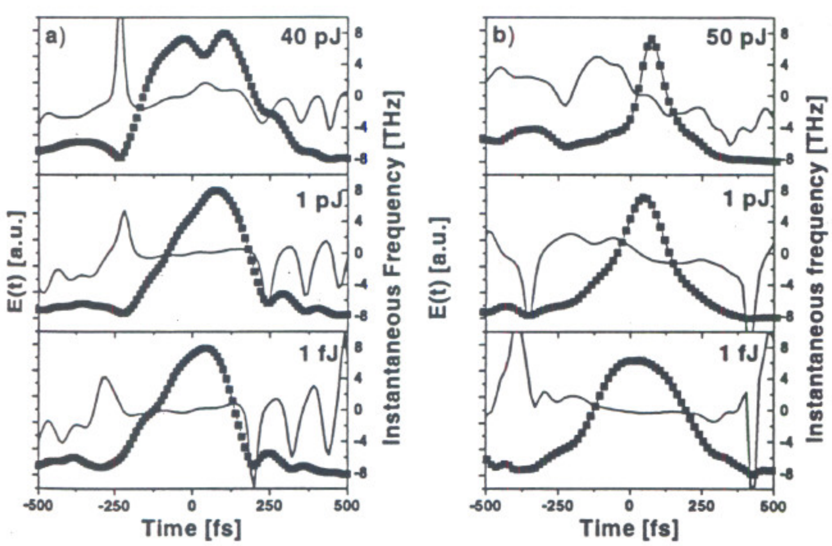


CThM30 Fig. 1. Device transmission for 0, 4, 10 mA.

Pulse amplitude and phase were measured using a XFROG (cross-frequency-resolved optical gating) technique[3] based on the principle of sum frequency cross correlation. The pulse of interest is cross-correlated with a known reference pulse and the upconverted signal is spectrally analyzed for different time-delays between the reference and the output pulse. An algorithm is then used to retrieve the amplitude and phase of the electric field of the output pulse from the experimental traces.[3] The laser source is the idler of an optical parametric amplifier providing 150-fs pulses at 300-kHz repetition rate.

In Fig. 1 the transmission of the device is shown as a function of the input pulse energy. In the small signal regime a transmission from −3.35 dB to 1.85 dB is measured with bias currents ranging from 0 to 10 mA. For pulse energies above few pJ, nonresonant two-photon absorption leads to a strong transmission decrease. At 5 mA, pulses with 1 fJ, 1 pJ and 40 pJ energies after propagation through the QD device are shown in Fig. 2(a) (see also arrows in Fig. 1). For small energies the pulse experience only weak distortion. The constant instantaneous frequency over the pulse indicates a nearly-transform-limited pulse. For increasing intensities the pulse broadens and finally at 40 pJ a weak breakup of the pulse is observed together with a nonlinear frequency chirp. This behavior is characteristic for all bias currents. The results are compared to the distortion observed at material transparency in a 250-m bulk amplifier[4] [see Figure 2(b)]. The pulse narrowing seen in the bulk amplifier is not observed in the QD amplifier, indicating a strong effect of the dimensionality of the active medium in the measured pulse distortion.

Modeling of the processes behind the observed distortion (self-phase modulation and gain-dispersion) will be presented.



CThM30 Fig. 2. (a) Pulse after propagation through the QD device, (b) pulse after propagation through the bulk device.

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1. S. Diez, *et al.*, "Gain-transparent SOA-switch for high-bitrate OTDM add/drop multiplexing," IEEE Photon Technol. Lett. **11**, 60 (1999).
2. D. Bimberg, *et al.*, "InGaAs-GaAs Quantum-Dot Lasers." IEEE Journal Sel. Topics Quantum Electr. **3**, 196 (1997).
3. S. Linden, *et al.*, "XFROG-a new method for amplitude and phase characterization of weak ultrashort pulses," phys. stat. sol. b **206**, 119 (1998).
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CThM31

Compact photoconductive-based sampling system with electronic sampling delay

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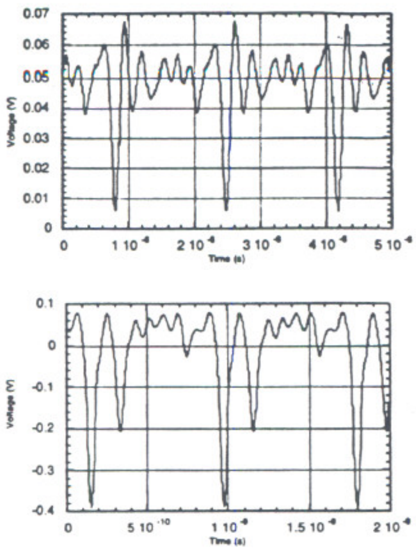
As electronic signals move to higher frequencies and wider bandwidths, there is need for new methods of measuring these high-frequency/high-speed (tens of GHz) and/or high bit rate (tens of GBs/s) signals.[1,2] In this work, critical technical issues associated with the design of a rugged, compact, "real-time" sampling system using photoconductive switches as the test signal generator and sampler were investigated. The design concept is based upon an optoelectronic equivalent time sampling principle and optical-microwave signal mixing. It involves first phase locking of the periodic input signal to be measured to the periodic optical pulses from a mode-locked laser and subsequent sampling of the locked signal by the optical pulses. A photoconductive switch is used for the optical-microwave mixer and another photoconductor for the sampler. The optical pulses we use were provided by 100-fs pulses from a Ti-Sapphire laser. The optical-microwave intermixing process generates a low-frequency replica of the high-frequency input signal. The ratio of the repetition rate of the input signal to its low-frequency replica is the time expansion factor. The repetition rate of the low-frequency signal provides the offset frequency for the equivalent time sampling. Because there is no electro-mechanical moving parts required to acquire a waveform, the sampling is done at a fast rate, and acquisition times of 10 ms or less are possible. The success of this technique depends critically on the stability and reliability of the optical microwave phase-locked loop (OMPLL), which locks the phase of the signal generator's trigger to the optical pulses.

There are two methods for phase locking, one is phase sensitive and the other is frequency sensitive. This work shows that the phase-sensitive method yields the more desirable result, that is, stable locking is achieved in the presence of amplitude and phase noise. However, the requirement for the phase-



CThM31 Fig. 1. (a) OM sampled replica waveform; (b) Microwave waveform.

sensitive detector is very stringent: the intermediate frequency signal used by the phase detector, which is generated by OM mixing, must have exactly a 50% duty cycle in order to achieve the full locking range. Toward this goal we discovered that a flip-flop circuit served exactly this purpose, resulting in almost perfect phase locking.

The phase-locked microwave signal was then used to drive a step recovery diode (SRD) in order to generate high-frequency signals for testing. The measured replica waveform [Fig. 1(a)] is compared to the waveform obtained by using a 20-GHz sampling oscilloscope [Fig. 1(b)]. The traces in Fig. 1 clearly show that the OM sampling technique has a faster response. The 10%-to-90% rise time of the measured OM-sampling-system-acquired waveform was determined to be 7 ps, limited by the bandwidth of the input signal.

The spectrum of the SRD output signal and that of the replica were measured. The maximum harmonics of the signal from SRD extend beyond 30 GHz, which is beyond the bandwidth of the 20-GHz sampler. The low-frequency replica, on the other hand, had its harmonics extending only to 18 MHz, which is well within the bandwidth of the 20-GHz sampler and most digitizing waveform recorders. It is clear that information above 20 GHz is lost using the 20-GHz sampling oscilloscope while its replica preserves all information. The experimental detail and results will be reported.

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2. S.L. Huang, C.H. Lee, H.-L.A. Hung, "Broadband and Real Time Waveform Sampling Using Optic-Microwave Phase-Locking," IEEE MTT-S International Microwave Symposium, Paper QQ-1, Atlanta, Georgia, June 1993.

CThM32

10-Gbits/s all-optical 3R regeneration and format conversion using a gain-switched DFB laser

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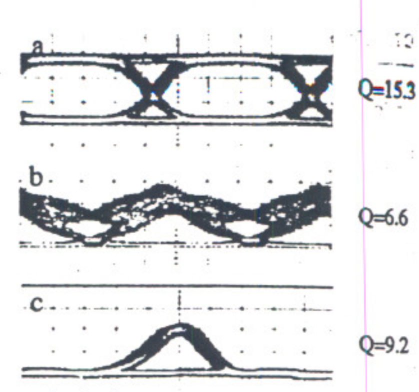
The regeneration of optical data signals is likely to be an important requirement of WDM and OTDM networking schemes.[1] All-optical regenerators are currently complicated and require several optical components together with complex control. As a result there has been interest in developing robust and simple single chip schemes, which allow regeneration.[2] Here we demonstrate for the first time to our knowledge simultaneous all optical 3R regeneration and format conversion in a single DFB laser. An NRZ data signal at 10 Gbits/s with poor Q is reamplified, retimed and reshaped by the laser. The key to this regeneration process is to gain switch the DFB with the extracted clock signal in order to retime the converted signal. This process also simultaneously converts the input NRZ format to an output RZ data format and results in a signal whose optical power and extinction ratio are considerably improved by the regeneration process.

The DFB laser used in these experiments is a strain-compensated multiple quantum well device, which has been optimized for low jitter gain switched operation at 10 GHz.[3] The device threshold is approximately 8 mA and lases at a wavelength of 1558.8 nm. The experimental setup used to demonstrate 3R regeneration in this device is shown in Fig. 1. An integrated Mach–Zehnder laser source at 1555 nm (λ_1) is modulated with a NRZ 2^7-1 10-Gbit/s PRBS. The signal is transmitted down 80 km of standard fiber then amplified, filtered and polarization controlled before being injected into a DFB laser. The coupled input power after amplification is estimated to be ~10 dBm. A bias-T is used to apply the gain-switched drive signal to the laser, which consists of a DC bias of 50 mA and a 10-GHz local clock electrically amplified to an RF power of 30 dBm. After filtering the input signal, the wavelength-converted signal at 1558.8 nm is detected on a 32-GHz pin photodiode and analyzed with a 50-GHz oscilloscope.



CThM32 Fig. 2. Eye diagrams showing (a) back-to-back NRZ signal with Q = 15.3. (b) Received eye after 80 km of standard fiber with Q = 6.6. (c) 3R regenerated RZ signal with improved Q = 9.2.

Figure 2 shows the received eye diagrams before and after transmission down 80 km of standard fiber together with the 3R regenerated optical signal. There can be observed a considerable improvement in eye quality after regeneration. This may be quantified by calculating the Q factor in each case as shown in Fig. 2. It may be observed that there is a Q factor improvement of 2.6 after regeneration.

It should be noted that a local clock has been used here to simplify the experimental setup, a system with true remote clock extraction will be presented at the conference, together with BER measurements for the 3R regenerator system.

Simultaneous NRZ to RZ format conversion and 3R regeneration has been achieved using one compact device at 10 Gbit/s. The regenerated signal exhibits a Q factor improvement of 2.6 dB between input and output of the 3R regenerator.

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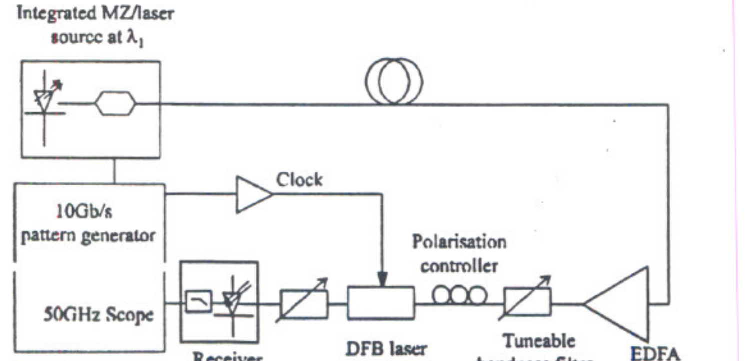
2. M.F.C. Stephens, R.V. Penty, I.H. White, "All-optical regeneration and wavelength conversion in an integrated semiconductor optical amplifier/distributed-feedback



CThM32 Fig. 1. Experimental setup used to demonstrate 3R all-optical regeneration in a gain-switched DFB laser.