Generation and Characterisation of 40 GHz Picosecond Optical Pulses Generated Using an EAM

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ABSTRACT

The authors describe the generation of short (< 4 ps) optical pulses at a repetition rate of 40 GHz using an InP Electro-Absorption Modulator. The technique of Frequency Resolved Optical Gating (FROG) is subsequently used to accurately characterize the generated pulses over a range of bias conditions and RF drive voltages. Our results show that the FROG technique will be vital for the optimization of RZ optical transmitters (in terms of pulse width, extinction ratio and frequency chirp) to be used in systems operating at 40 Gb/s and beyond, as standard measurement techniques will not suffice to optimize such high-speed hybrid WDM/OTDM or OTDM systems.

Keywords: optical communications, electro-absorption modulator, optical pulse generation, frequency resolved optical gating, frequency chirp.

1. INTRODUCTION

The current state of the art in commercial Wavelength Division Multiplexed (WDM) systems allows telecommunication operators install fixed WDM systems in which each channel can operate at a bit rate of 10 Gb/s, with a channel spacing of around 100 GHz. However, with the drive to develop long-haul transport networks exhibiting multi-Tb/s capacities, it is anticipated that Wavelength Division Multiplexed (WDM) systems will be upgraded [1]. As optical systems move towards such high data rates on each wavelength channel, and also migrate from NRZ to RZ format (due to enhanced performance of RZ systems at 40 GHz) [2], the impact of chromatic dispersion in transmission fiber becomes more dramatic and the use of dispersion management techniques and/or optical fiber nonlinearities to counteract the dispersive effects, must be precisely regulated [3]. In addition to knowing the dispersion parameter of the transmission fiber, it is essential to know the chirp of the optical data signals generated at the transmitter of these high-speed systems [4]. This is necessary since the propagation of the optical data is determined by the exact intensity and phase of the optical pulses from the transmitter and the dispersion and nonlinearity of the transmission fiber.

Short optical pulses can be generated by employing several different techniques such as mode locking, gain switching or by gating Continuous Wave (CW) light with an Electro-Absorption Modulator (EAM). Mode locking of semiconductor or fibre lasers is a common technique used to generate short optical pulses operating at high frequencies. However, the cavity complexity and limited tunability of the mode locking repetition rate and emission wavelength act as major disadvantages associated with this technique. Alternatively gain-switching offers smaller footprint, efficient wavelength-stable performance and the ability to produce high-repetition rate pulses. Nevertheless this technique also has its fair share of shortcomings such as the generated pulses exhibiting a large chirp, timing jitter and a degraded Side Mode Suppression Ratio (SMSR) [5]. One of the most stable and reliable optical pulse sources is achieved by gating CW light with an EAM. Sinusoidally driven EAMs have been extensively used to generate optical pulses that feature low or zero chirp and low jitter [6]. As a result they have become a key component in WDM and OTDM systems. The main characteristics of an EAM are low insertion loss, broad modulation bandwidth, large extinction ratio and low wavelength chirp.

Even though a lot of emphasis has been placed on pulse generation using EAMs [6-8], complete characterization of these pulses has been ignored. In this paper we have completely characterized the generated pulses for spectral and temporal purity including extinction ratio, pulse width and chirp. We performed this by using the technique of Frequency Resolved Optical Gating (FROG).

2. EXPERIMENTAL SET-UP

The 40 GHz optical pulses are generated using an External Cavity Laser (ECL) working in CW mode followed by a sinusoidally driven external modulator. The external modulator used is a commercially available fibre pigtailed InP EAM that operates over the 1.55 μm C-band with a bandwidth of 40 GHz and has a transfer characteristic versus wavelength curve as shown in Fig. 1. The DC static characterization of the modulator was obtained by recording the optical transmission as the reverse bias was increased. The transfer characteristic illustrates the different performance for pulse generation at different wavelengths and as a result this will have an impact on the optimum operating condition of the EAM.

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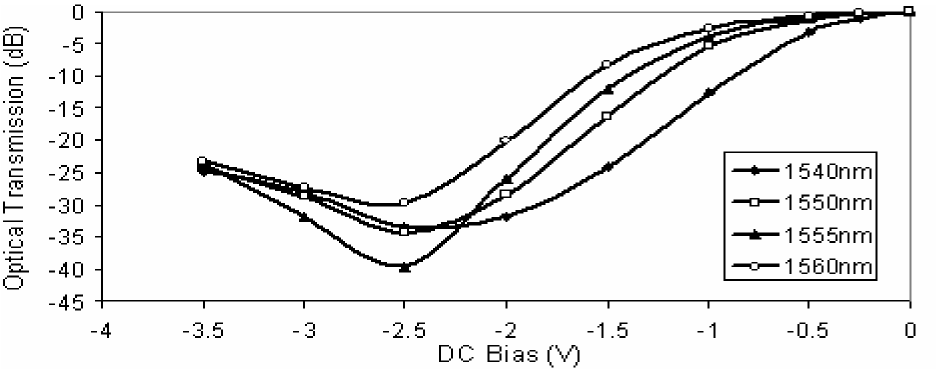

Figure 1. DC transfer characteristic of the EAM. It was performed for a number of wavelengths.

The experimental setup used is shown schematically in Fig. 2. The modulator was driven with a sinusoidal wave at a repetition rate of 40 GHz and RF drive voltage varying from 2.5 Vpp to 4 Vpp. The optical pulses at the output of the EAM were then amplified to an average power of 10 mW and characterized using the standard Second Harmonic Generation (SHG) FROG technique as fully explained in [9], based on the spectral resolution of the output from an autocorrelator.

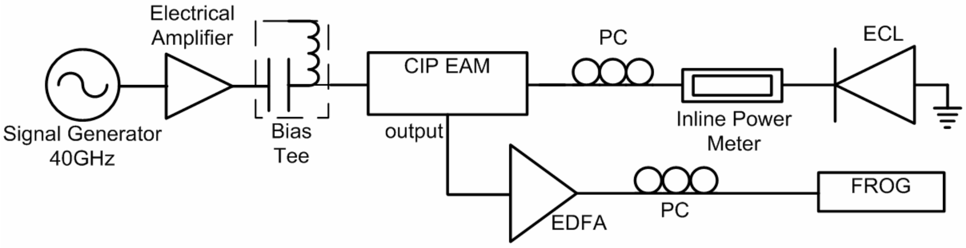

Figure 2. Experimental setup for pulse generation using an EAM.

In addition, the generated pulses were measured using an optical spectrum analyzer and a 50 GHz oscilloscope in conjunction with a 50 GHz detector. For SHG, we used a BBO crystal with an estimated interaction length of 250 µm, which provided a uniform SHG response over a 100 nm bandwidth centered at 1550 nm. The SHG signal was spectrally resolved using a spectrometer with a CCD array mounted on the output. The resulting spectrogram, which is obtained from the experimental FROG setup, can then be used to retrieve the pulse intensity and phase using the FROG phase retrieval algorithm of generalized projections (GP) [9]. Pulse retrieval for the characterization carried out in this work, routinely gave low retrieval errors of less than 0.0004 with a 64x64 grid (i.e., 64 spectral and temporal points). The pulse generation process in the EAM was characterized over a range of operating conditions in order to optimize the pulse generation process to achieve adequate spectral and temporal purity. The bias voltage was altered between 1 and 2 V in steps of 0.2 V and the pulses were analyzed at drive voltages of 2.5, 2.8 3.1 3.4 and 3.7 Vpp respectively. At each bias point and RF drive voltage, the retrieved pulse was analyzed for pulse width, extinction ratio, chirp and time-bandwidth product.

3. RESULTS AND OBSERVATIONS

The bias voltage and RF power applied to the EAM were initially set to those values thought to generate optimum pulses from the setup, as deduced from the transfer characteristic of the modulator (Fig. 1). Fig. 3*a* shows the optical spectrum of the generated pulses and the inset displays the generated pulses using a 50 GHz photodiode in conjunction with a 50 GHz oscilloscope. Due to the limited response time of this detection system, it is difficult to obtain information about the characteristics of the generated optical pulses. In addition, as the bias voltage and RF signal applied to the modulator were varied, no noticeable changes were observed on the oscilloscope (not even the pulse width). The pulses were subsequently characterized using the FROG measurement technique. Fig. 3*b* shows the optical spectrogram obtained from the FROG measurements. The retrieved intensity and chirp of the pulse is shown in Fig. 3*c*. The retrieved pulses had a duration of about 4.4 ps and a time-bandwidth product of 0.43 was achieved.

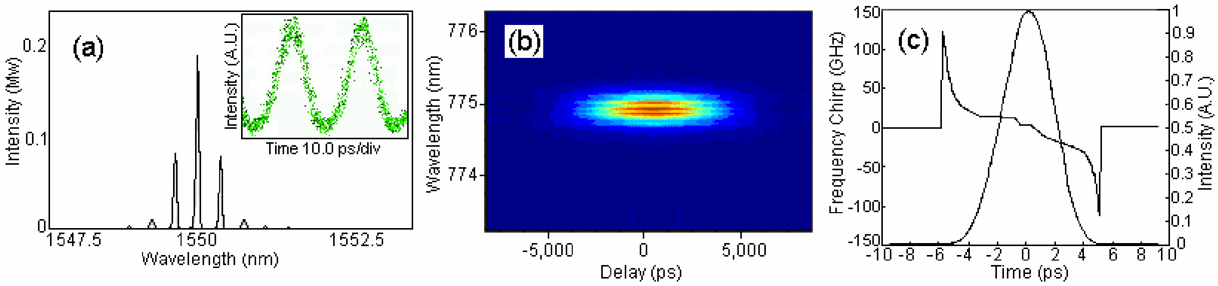

Figure 3. (a) Optical spectrum and generated pulses, (b) Spectrogram of measured FROG trace, (c) Intensity and chirp across retrieved pulse.

From this method we were capable of completely characterizing the EAMs operating conditions. Fig. 4 shows the pulse width variation as a function of reverse bias and RF drive voltage. It can be observed that as the reverse bias is increased there is a corresponding decrease in the pulse width.

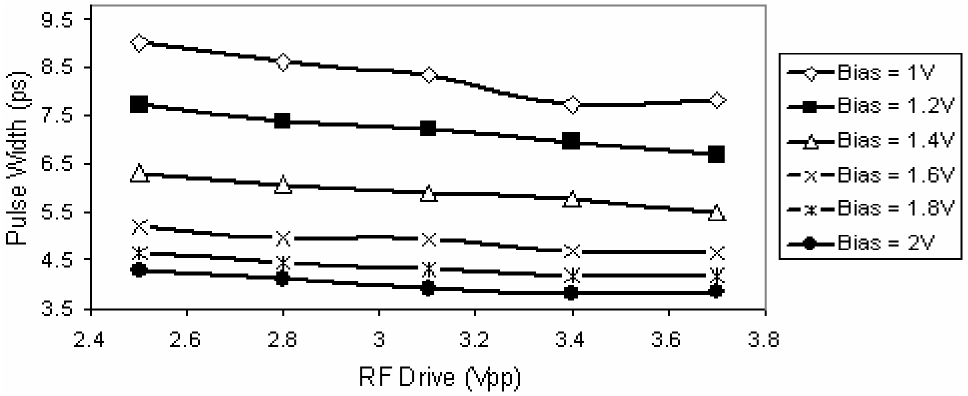

Figure 4. Pulse width as a function of bias voltage and RF drive voltage.

This is also true for the RF drive voltage, as it increases the pulse width decreases. This would indicate that to achieve a pulse width of approximately 4 ps, the EAM would have to be biased at 2 V with and RF drive voltage of between 3.2 to 3.8 Vpp. The extinction ratio varied slightly with alternating RF voltage but had a larger dependence on the biasing of the EAM. To achieve an extinction ratio greater than 30 dB required the use of a bias voltage between 1.2 and 2 V, with an RF drive voltage greater that 2.5 Vpp. As discussed in the introduction, while operating in a 40 Gb/s optical communications system it is the broad modulation bandwidth and low chirp that are of most importance. For this reason it was important to characterize the EAMs performance in terms of frequency chirp. Fig. 5 shows the chirp expressed in GHz/ps, expressed as a function of bias voltage with an RF drive voltage of 2.5 Vpp. Again as with the pulse width the chirp decreases as the reverse bias increases. The chirp is not as dependant on the RF drive voltage and its values reach a peak of 7.261 GHz/ps. It can be observed that as the reverse bias voltage increases the chirp decreases, down to a value as low as 0.117 GHz/ps, which is essentially chirp free.

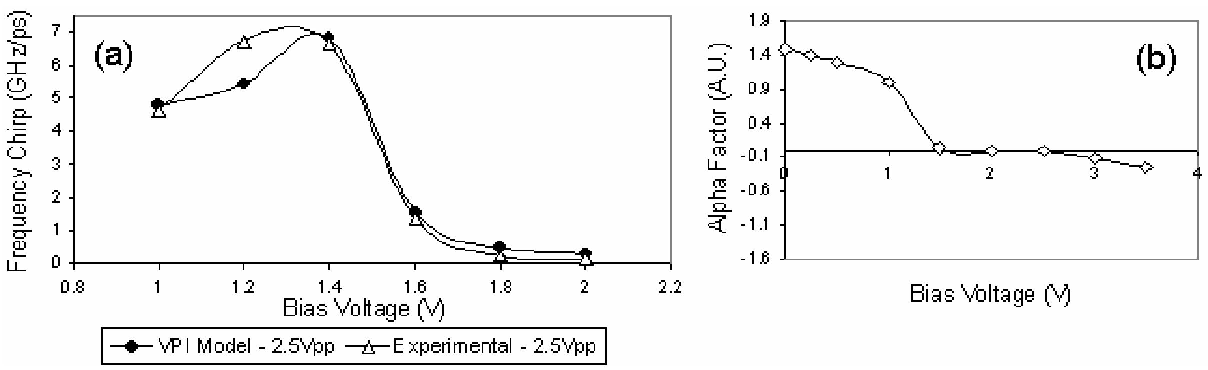

Figure 5. (a) Experimental and theoretical chirp expressed in GHz/ps as a function of bias voltage, (b) Alpha factor curve used in VPI Photonics model.

A corresponding simulation model of the pulse generation process was constructed using the Virtual Photonics Incorporated systems software package. Using the experimental results of frequency chirp from the FROG measurements we determined the alpha factor versus bias voltage curve for the EAM to give good agreement between experimental and simulation results. Fig. 5*a* illustrates the chirp, expressed in GHz/ps, for both the experimental and modeled pulse generation process, at a drive voltage of 2.5 Vpp. There is a close correlation between the results and they tend to follow the same trend. As the reverse bias is increased the chirp decreases until it levels out between the 1.8 and 2 V bias region. Fig. 5*b* shows the alpha factor curve used in the EAM model. The frequency chirp and pulse width are at its lowest in or near the 2 V reverse bias voltage range where the extinction ratio still remained above 30 dB indicating that this range is the optimal operating window for a narrow pulse generation that is essentially chirp free with good extinction.

4. CONCLUSIONS

This paper has illustrated the importance of completely characterizing the pulses generated by using a sinusoidal driven EAM after a CW optical source. The large deviation in pulse width, extinction ratio and chirp with a variation in the bias and RF drive voltages applied to the EAM show that the complete characterization is vital for the optimization of the pulse parameters. By using the FROG measurement technique we can accurately characterize the pulse width and frequency chirp, thus enabling the optimization of the EAM driving conditions to achieve the required pulse characteristics for optimum system performance. Future work will focus on characterizing the EAM over a large range of wavelengths to show that as the emission wavelength of the laser source changes the bias and drive conditions of the EAM will also need to be changed to ensure adequate operation in high speed applications. By achieving this it will enable us to tailor the pulses at each wavelength for different systems.

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