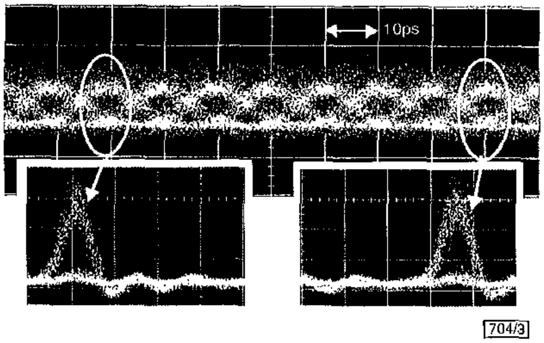

Fig. 3 *Eye diagram of 100Gbit/s signal (photodiode bandwidth 50GHz)*

Insets: Eye diagrams showing clear and open eyes of two demultiplexed 10Gbit/s signals

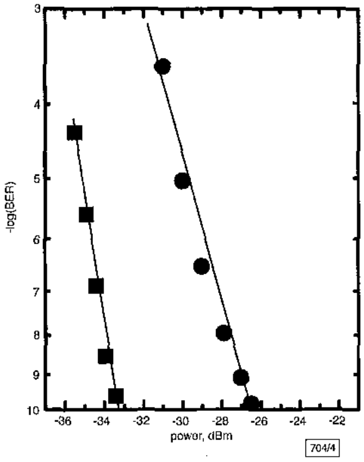

Fig. 4 *Measured BER of 100Gbit/s wavelength converted signal against received power at input to optical preamplifier*

PRBS = $2^{31}-1$
◆ back-to-back
● BER of converted signal

Eye diagrams of the 100Gbit/s signal as recorded with a 500Hz bandwidth photodiode are shown in Fig. 3. There is not sufficient resolution to resolve the 100Gbit/s eye diagram. However, the 100Gbit/s signal was subsequently demultiplexed into ten signal streams of 10Gbit/s [9] and the eye diagrams of these demultiplexed signals show clear and open eyes. The eye diagrams of the second and ninth demultiplexed signals are shown as an example in the lower left and right inset of Fig. 3. The BER of the converted 100Gbit/s signal, as shown in Fig. 4, was measured after demultiplexing back to 10Gbit/s and feeding this signal to an optically preamplified *pin* receiver. Thus, the received power was measured for 10Gbit/s. The penalty is due to format conversion (~2dB), extinction ratio degradation (~0.5dB), the pattern dependence of long words (~3dB) and signal-to-noise ratio degradation. All ten demultiplexed signals gave a BER within 1dB around the depicted curve. The polarisation sensitivity against the input signal was below 2dB.

Conclusions: We have performed the first 100Gbit/s wavelength conversion experiment exploiting cross-phase modulation in an SOA. A novel compact and fully packaged SOA delayed-interference wavelength converter was employed to perform the experiments. BER measurements show that these are the best SOA based wavelength conversion results ever obtained at 100Gbit/s.

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J. Leuthold, C.H. Joyner, B. Mikkelsen, G. Raybon, J.L. Pleumeekers, B.I. Miller, K. Dreyer and C.A. Burrus (*Bell Labs, Lucent Technologies, Holmdel, NJ 07733, USA*)

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3.7ps pulse generation at ≥ 30GHz by dual-drive electroabsorption modulator

V. Kaman, Yi-Jen Chiu, S.Z. Zhang and J.E. Bowers

The authors describe optical short pulse generation at frequencies ≥ 30GHz by a dual-drive scheme of a high-saturation power travelling-wave electroabsorption modulator. Sub-4ps almost-transform-limited pulses are achieved with > 20dB dynamic extinction ratio and low polarisation sensitivity.

Introduction: Optical fibre transmission based on single channel optical time division multiplexing (OTDM) has recently attracted a lot of attention as a means of upgrading future TDM systems [1, 2]. Sinusoidally driven electroabsorption (EA) modulators play a key role in OTDM systems as optical short pulse generators and optical demultiplexers. Owing to advances in high-speed electrical TDM, it is inevitable that next-generation OTDM systems will operate at a base rate of 40Gbit/s with optical multiplexing to 160Gbit/s or more [3]. Therefore, it is important to investigate the high-frequency switching performance of EA modulators. Owing to its nonlinear attenuation characteristic, a highly reverse biased EA modulator with an applied sinusoidal RF signal is capable of producing switching windows with duty ratios as small as 7.2% [4]. However, since the optical loss depends strongly on the insertion loss and the duty ratio of the pulses, the average optical output power and consequently the signal-to-noise ratio (SNR), especially at high frequencies, can be very low. Therefore, an EA modulator with a high-saturation input power is required [5]. Another limiting factor at high-frequency operation is the available RF power as well as the response of the modulator, which can result in broader pulses with degraded extinction ratios than is theoretically predicted [6].

In this Letter, we demonstrate ≥ 30GHz pulse generation of a high-saturation power travelling-wave EA modulator. A novel dual-drive scheme is employed to effectively double the RF drive and to achieve < 15% duty ratios, which we believe is the smallest duty ratios ever reported for these frequencies using a single EA modulator.

Experimental setup: The travelling-wave EA modulator, fabricated using MOCVD grown InGaAsP-InGaAsP quantum wells, is similar to the device used in the previously demonstrated 30Gbit/s data modulation experiment [7]. The fibre-to-fibre insertion loss at 1555nm was 10.8dB while the maximum extinction ratio was 36.4 and 40.3dB at a reverse bias of –6V for the TE and TM polarisations, respectively. It is important to mention that the optical input power was +7.5dBm, which demonstrates the high saturation power characteristic of this 2µm wide, 300µm long modulator. The 3dBe bandwidth of the device was 26GHz.

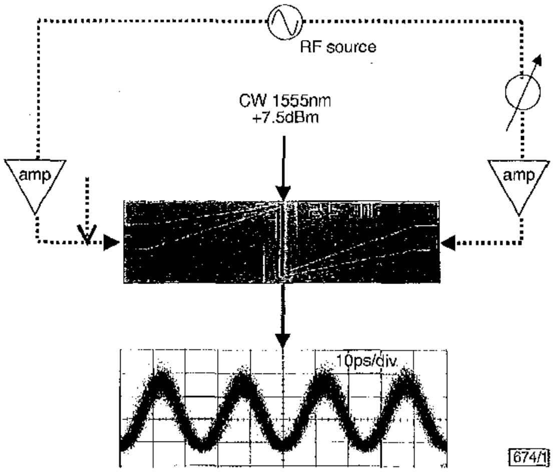

Fig. 1 *Experimental setup for dual-drive scheme of EA modulator*

– – – – electrical path
——— optical path
Optical output is a typical 40GHz waveform

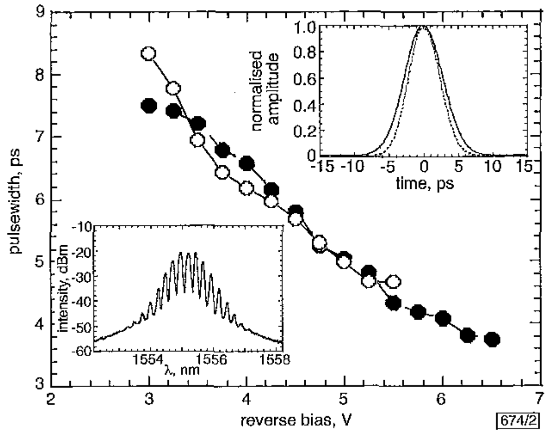

Fig. 2 *Pulsewidth against reverse bias for 30GHz modulation*

○ single drive
● dual drive
Upper inset: autocorrelation traces of pulses
- - · · single drive
– – – – dual drive
Lower inset: optical spectrum for dual-drive modulation

Fig. 1 shows the device operation for the dual-drive scheme. Two RF signals, synchronised by an electrical delay line, were fed into the two electrodes of the modulator while a single reverse bias was applied. Since AC-coupled amplifiers effectively terminated both electrodes, heating effects were reduced and external temperature cooling was not employed. The optical output of the modulator was then amplified by an optical amplifier, which was followed by a 1.9nm optical bandpass filter. The output pulses were then measured on a second-harmonic generation autocorrelator and an optical spectrum analyser. The width of the obtained pulses was deconvolved assuming a Gaussian pulse shape as inferred from the optical spectrum measurements. It is very important to note that the following criteria were used for the these measurements: (i) the average optical output power was higher than –25dBm in order to ensure a high SNR, and (ii) the dynamic extinction ratio was estimated to be > 20dB.

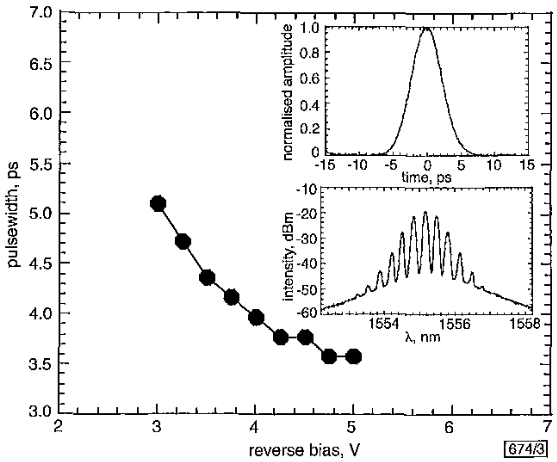

Fig. 3 *Pulsewidth against reverse bias for 40GHz dual-drive modulation*

Upper inset: autocorrelation trace of pulse
Lower inset: optical spectrum

High-frequency operation: Fig. 2 shows the obtained pulsewidths as a function of reverse bias at 30GHz. The RF amplifiers generated $7V_{pp}$ into a 50Ω load. Using only a single drive (the other electrode was terminated in 50Ω), a minimum pulsewidth of 4.7ps was achieved at a reverse bias of –5.5V. Under the dual-drive modulation, an almost-transform-limited pulsewidth of 3.7ps was obtained with a low polarisation sensitivity of 0.3ps. This result corresponds to a duty ratio of ~11% at 30GHz. Further pulse compression was not observed when the EA modulator was followed by dispersion-compensating fibre. The inset in Fig. 2 shows the autocorrelation trace of the pulses achieved for single and dual modulation. The optical spectrum obtained for the dual-drive operation is also shown as an inset in Fig. 2. The bandwidth was 0.84nm, resulting in a time-bandwidth product of 0.39. It is important to mention that shorter pulsewidths were obtained at higher reverse biases at the expense of a degraded SNR and dynamic extinction ratio.

The EA modulator was also driven with 40GHz $7V_{pp}$ dual RF signals. Fig. 3 shows the pulsewidths obtained as a function of reverse bias. A minimum pulsewidth of 3.6ps with an optical bandwidth of 0.83nm was achieved at –5V (insets to Fig. 3), which corresponds to a duty ratio of 14.4%. These results indicate that 160 to 40Gbit/s optical demultiplexing should be feasible with an optical power penalty of < 1dB [8].

Summary: We have successfully demonstrated optical short pulse generation at frequencies ≥ 30GHz using a dual-drive scheme in a travelling-wave EA modulator. Sub-4ps pulses were obtained with low polarisation sensitivity (0.3ps), high dynamic extinction ratio (> 20dB), high optical input power (+7.5dBm) and high average optical output power (> –25dBm).

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V. Kaman, Yi-Jen Chiu, S.Z. Zhang and J.E. Bowers (*Department of Electrical and Computer Engineering, University of California, Santa Barbara, Santa Barbara, CA 93106, USA*)

E-mail: kaman@opto.ucsb.edu

S.Z. Zhang: Currently at Zaffire, Inc., San Jose, CA 95134, USA

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Interferometric crosstalk reduction by phase scrambling in WDM integrated cross-connects

E. Tangdiongga, R. Jonker, H. de Waardt and G.D. Khoe

Interferometric crosstalk mitigation in a four-channel 2.5Gbit/s InP-based 2 × 2 cross-connect using phase scrambling is reported. Bit error rate performance is improved from a large power penalty indicated by a floor at 10^{-8} to a penalty of < 1dB.

Introduction: A phase scrambling (PS) technique has been investigated as a means for mitigating the detrimental effects of interferometric noise in optical links [1]. This type of noise may occur in integrated wavelength-selective devices such as InP-based optical cross-connects (OXCs). Owing to the compact size of a few millimetres and the switching speed of a few nanoseconds, the InP-based OXC is very attractive for packet switching applications. As a disadvantage, InP-based OXCs still show moderate crosstalk levels [2], although considerable improvements have been achieved recently [3]. A theoretical study of PS for a single-channel point-to-point transmission has been published in [4]. In this Letter, we report for the first time the application of the PS technique to a multi-channel 2 × 2 InP-based OXC in order to improve its performance. Without the PS, a 2.5Gbit/s bitrate transmission showed poor performance due to interferometric crosstalk and bit error rate (BER) floors occured at 10^{-8}. By using the PS, error-free transmission with a penalty of < 0.5dB is obtained. This result demonstrates clearly the potential of the PS technique in WDM networks employing OXCs for which the crosstalk performance does not yet fully comply with the stringent telecom requirements.

Experimental setup: A four-channel integrated InP-based OXC was placed in the experimental setup (Fig. 1). Four DFB lasers provided CW sources at wavelengths of 1551.0, 1554.2, 1557.4 and 1560.6nm. Pseudorandom nonreturn-to-zero (NRZ) data of a sequence length of $2^{31} - 1$ was encoded at a bit rate of 2.5Gbit/s using an external modulator to generate optical signals with narrow spectra. The four channels were subsequently scrambled in phase by the phase scrambler section to broaden their spectra, and amplified by an EDFA before being split to create two paths for feeding both input ports of the OXC. To obtain two uncorrelated input signals, we inserted a delay fibre in one arm before the input. The delay fibre was chosen to be much longer than the coherence length of each laser source. Two polarisation controllers were used to maximise the detrimental effects of interferometric beating noise. The combination of the power splitter and polarisation controllers created a worst-case condition in the setup: wavelength and polarisation alignment. The experimental results represent, therefore, the worst-case crosstalk performance that may occur in WDM networks. To couple the signals into and out of the OXC, we adopted the same technique as [5]. After travelling through the single-phase array OXC, the channels were amplified to compensate for fibre-to-fibre losses. The BER evaluation for each channel was performed by an optical demultiplexer (bandwidth 90GHz) for channel selection and a variable attenuator before the receiver for input power adjustment. The receiver consisted of an InGaAs *pin* photodiode followed by a variable gain electrical amplifier to boost the photocurrent. The electrical bandwidth of the receiver circuit is 1.8GHz, which is sufficient to detect 2.5Gbit/s signals without significant signal distortion. The phase scrambler section was realised by using a phase modulator driven by a noise signal. The noise signal was made by mixing a 200MHz band-limited white noise source with an RF signal. The obtained noise signal caused a phase deviation of the value π and it was centred at the RF frequency of 2.5GHz. The spectrum of the 2.5Gbit/s signal due to the PS is shown in Fig. 2. Compared to the original spectrum, there is a phase scrambler induced spectral broadening of 75pm (measured at –20dB). This spectral broadening will cause an additional penalty of < 1dB after 200km standard fibre due to chromatic dispersion [4].

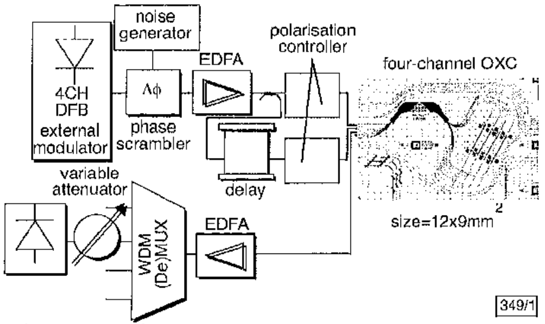

Fig. 1 *Experimental setup*

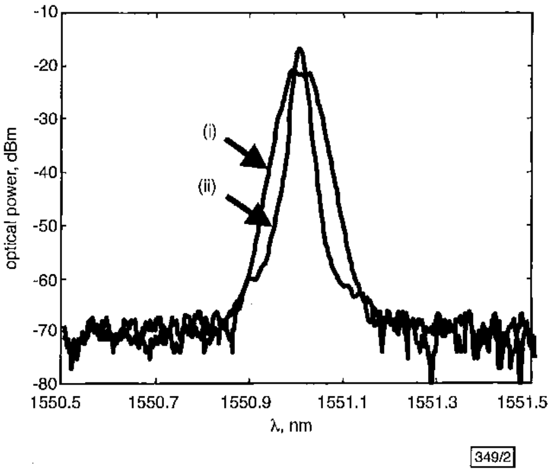

Fig. 2 *Signal spectrum*

(i) due to phase scrambling
(ii) original spectrum

Results: The penalties due to interferometric crosstalk in the OXC were measured by taking input powers corresponding to a BER value of 10^{-9}. As a reference, the BER of a scheme without crosstalk (only one input port being used) was used. Measurement of the statical transmission properties of the OXC showed that the