INTEGRATED TANDEM ELECTROABSORPTION MODULATORS FOR HIGH-SPEED OTDM APPLICATIONS

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Abstract: An integrated tandem traveling-wave electroabsorption modulators is demonstrated as an optical short pulse generator and demultiplexer for >100 Gbit/s optical time-division-multiplexed systems. Optical pulses of 4.2 ps width at 30 GHz with an extinction ratio in excess of 30 dB are achieved.

Introduction:

Optical fiber transmission based on single channel optical time division multiplexing (OTDM) has recently surpassed 100 Gbit/s [1-3]. These experiments make it likely that future TDM systems will employ optical means of increasing the transmission capacity of a single channel. Sinusoidally driven electroabsorption (EA) modulators have become key devices as optical short pulse generators and optical demultiplexers for high-speed OTDM experiments. An 80 Gbit/s OTDM data stream was realized by short pulses generated from EA modulators without using any non-linear pulse compression, which is the highest aggregate data rate achieved using this technique to date [4]. On the other hand, a 160 Gbit/s optically multiplexed data stream was demultiplexed down to 10 Gbit/s using only EA modulators [1]. Due to the advances in high-speed electrical TDM, it is inevitable that the next generation of OTDM systems will operate at a base rate of 40 Gbit/s with optical multiplexing to 160 Gbit/s or more [5].

High-speed OTDM systems, unlike electrical TDM systems, require very high extinction ratios and short pulsewidths for both the optical transmitter and the demultiplexer [2]. Single EA modulators are usually limited to ~20 dB dynamic extinction ratio, which is sufficient for demultiplexing purposes, but can lead to incoherent interference between multiplexed adjacent pulses at the transmitter. Therefore, a fiber-coupled pair of separate modulators was used for pulse generation in [4] and for demultiplexing in [1]. The use of tandem EA modulators has its advantage of not only increasing the dynamic extinction ratio, but also in reducing the switching window. However, it is desirable to integrate these modulators on a single chip to eliminate the optical amplifier, which compensates for coupling losses between the modulators [6-7]. This will not only result in a compact and cost-effective transmitter (or receiver), but also the configuration will be more robust to environmentally induced timing asynchronization.

In this paper, we investigate the optical short pulse generation and optical demultiplexing capability of an integrated tandem traveling-wave EA modulators at repetition frequencies of 30 and 40 GHz for > 100 Gbit/s OTDM systems. This is also the first demonstration of optical pulse generation using traveling-wave EA modulators, which were previously demonstrated in a 30 Gbit/s data modulation experiment [8].

Device Characteristics:

The 2-µm wide, 300 and 400-µm long traveling-wave EA modulators were fabricated with MOVCD grown ten periods of strain-compensated InGaAsP quantum wells on semi-insulated InP substrate [9]. The 20-µm long optical waveguide between the two modulators was defined by H^+ ion implantation to render the region semi-insulating. The measured impedance was about 10 kΩ. The ion implantation also extended 50 µm into each modulator in order to reduce capacitance and microwave crosstalk; however, the absorption region for each modulator was shortened by 100 µm. Both modulators were terminated in a thin-film resistor and a dielectric capacitor, which reduced heating effects in the modulators and the terminations. This allowed for long-term operation of the tandem without any external temperature cooling. Figure 1 shows a photograph of the integrated tandem EA modulators.

Static Characteristics:

Figure 2 shows the attenuation characteristics of the tandem as a function of reverse bias. An optical input power of 6.5 dBm was applied at 1555 nm. The insertion loss of the device was 15 dB, which will be improved by AR-coating the facets. Each device was individually characterized by keeping the other modulator at zero bias. The 400-μm device achieved a maximum extinction of 38.8 dB at -6 V while 26.2 dB of extinction was observed for the 300-μm device. The difference in the maximum extinction ratio is due to the shorter absorption region of the 300-μm device. It should also be noted that for higher reverse biases, a saturation of absorption is observed for both devices. Even though it is desirable to apply a high reverse bias for very short pulse generation using sinusoidal modulation, the absorption saturation at high reverse biases will deteriorate the extinction ratio. On the other hand, the tandem configuration shows an improved extinction ratio with a maximum of 55.3 dB at –6V. The absorption saturation is well suppressed in comparison to single device operation.

Dynamic Characteristics:

The optical switching capability of the tandem EA modulators was first characterized at 30 GHz. Both modulators were driven with 7 V_{pp} sinusoidal RF signals, which were synchronized by an electrical delay line. The width of the obtained pulses were measured using an autocorrelator and deconvolved assuming a gaussian pulse shape as inferred from the optical spectrum measurements. Figure 3 shows the obtained pulse widths as a function of reverse bias to the modulators. It is very important to mention that the following criteria were used for these measurements: (1) the average optical output power of the tandem was higher than –24 dBm in order to ensure that the signal-to-noise ratio of the pulses would not be deteriorated after subsequent amplification for system experiments, and (2) the dynamic extinction ratio was estimated to be > 30 dB. The minimum pulse width satisfying these criteria was 4.9 ps at reverse biases of –4.5 V and –4 V for the 300-μm and 400-μm devices, which is shown in Figure 4. This optical switching window is well suited for > 100 Gbit/s optical demultiplexing applications [2]. The pulse widths obtained from the individual 300-μm and 400-μm devices at a reverse bias of –4.5 V were 6.9 ps and 6 ps, respectively. Figure 5 shows the optical spectrum of the modulated tandem EA modulators, which has a gaussian shape of 0.75 nm bandwidth. The time-bandwidth product of 0.46 for the 4.9 ps pulses suggests that the pulses were slightly chirped. When the tandem was followed by dispersion compensating fiber (DCF) with a dispersion of about –6 ps/nm, the pulses were linearly compressed to a transform-limited pulse width of 4.2 ps (Figure 4). This pulse width suggests that the tandem is suitable as an optical pulse source for simultaneous polarization and time division multiplexed systems in excess of 100 Gbit/s.

The optical switching response of the tandem EA modulators was also performed at 40 GHz. The RF drive was limited to 4 V_{pp}, which resulted in a compromise between minimum pulse width, dynamic extinction ratio and average optical output power. A minimum optical pulse width of 5.9 ps with a bandwidth of 0.58 nm was achieved. The extinction ratio was estimated to be ~20 dB. These results should improve when the tandem is driven with higher power RF amplifiers at 40 GHz and enable low-penalty optical demultiplexing of a 160 Gbit/s OTDM data stream [1].

Conclusion:

An integrated tandem traveling-wave EA modulators was demonstrated as a viable high-speed optical source and demultiplexer. Optical pulses with high extinction ratios and less than 5 ps width were achieved for repetition frequencies of > 20 GHz.

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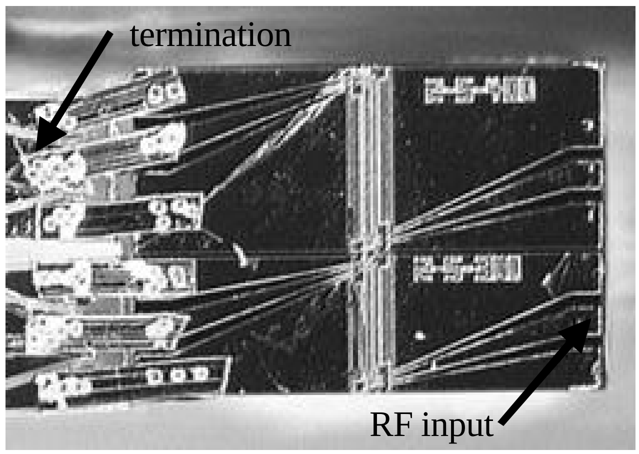

Figure 1 – Photograph of the integrated tandem EA modulators

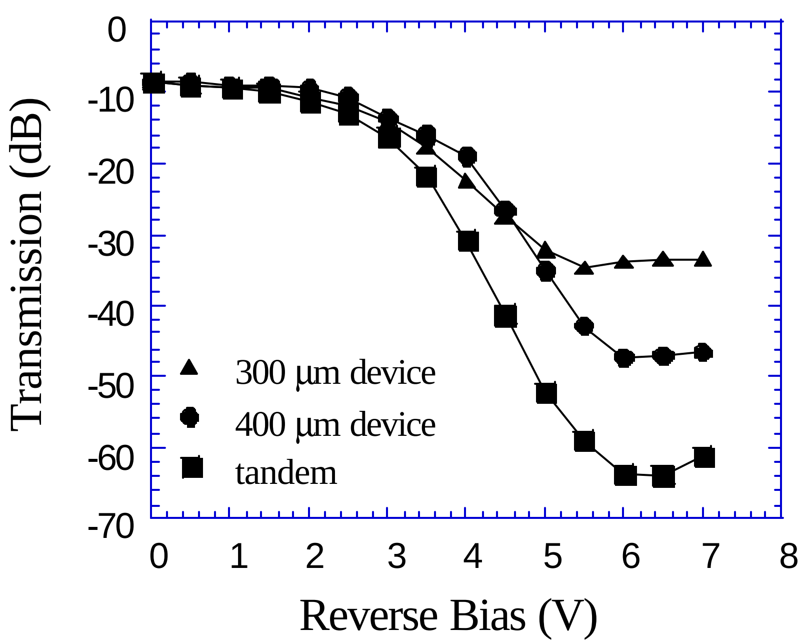

Figure 2 – Attenuation vs. reverse bias characteristics

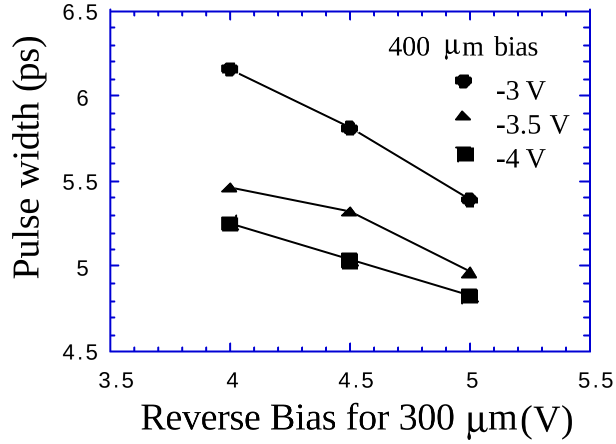

Figure 3 – Pulse widths vs. reverse biases of 300-μm (x-axis) and 400-μm (symbols) devices

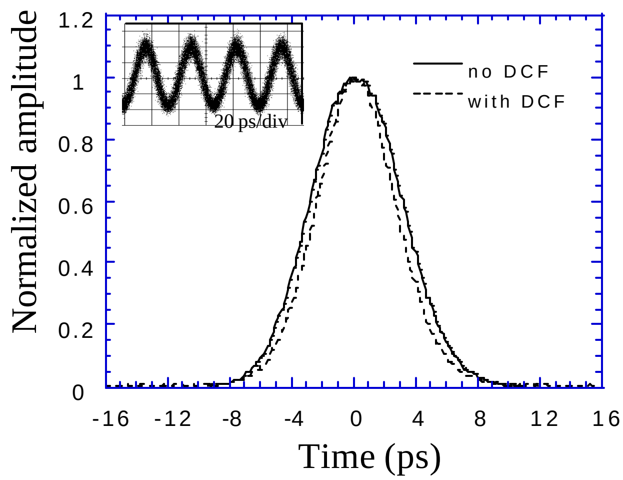

Figure 4 – Autocorrelation trace of 30 GHz pulses (inset: oscilloscope trace)

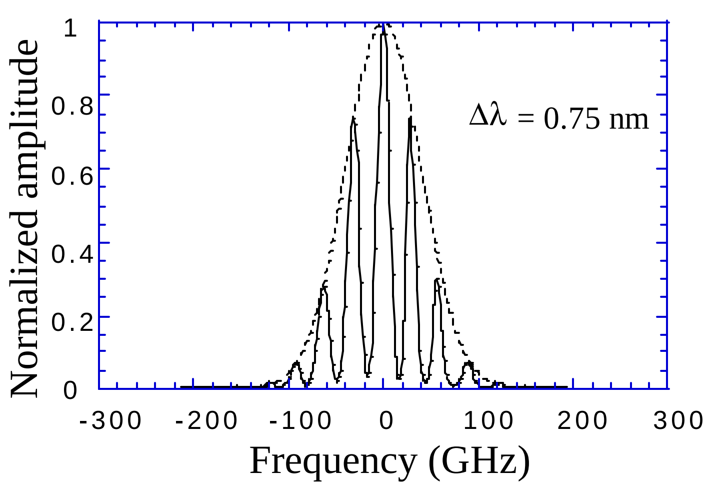

Figure 5 – Optical spectrum of 30 GHz pulses