A Novel Monolithically Integrated Mach-Zehnder Wavelength Converter Using Cross Modulation in Electro-Absorber

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Abstract *We present a novel monolithically integrated all-optical MZI switch for wavelength conversion consisting of MQW based electro-absorbers. The device has the potential of providing low noise and high-speed wavelength conversion.*

Introduction

All-optical switch is one of the key components in ultra fast optical communications. Mach-Zehnder interferometer (MZI) [1] type of all-optical switches have been frequently used for wavelength conversion [2] in Wavelength Division Multiplexing (WDM) applications, for demultiplexing [3] in Optical Time Division Multiplexing (OTDM) systems, for thresholding detection [4] in Optical Code Division Multiple Access (OCDMA) networks, for synchronous modulation [5] and for all-optical 3R regeneration [6]. Conventional all-optical MZI switches are based on semiconductor optical amplifiers (SOAs), where the cross-phase modulation (XPM) of the SOAs provides differential phase shift required for the interferometric switching. While the monolithically integrated MZI combines high contrast performance and required stability [7], the inclusion of SOAs in the two interfering arms adds noise at the output. Further, the carrier recovery time within the SOA is approximately ~100 psec even at high current injections. To enable the fast switching within the SOA based MZI, even higher current density levels in long SOAs, higher optical injection power levels, or differential input signal mode MZI operation becomes necessary. Power consumption beyond 1 W and complicated input signal configuration with low differential output is quite common in high speed (>10 Gb/s) SOA-MZI devices.

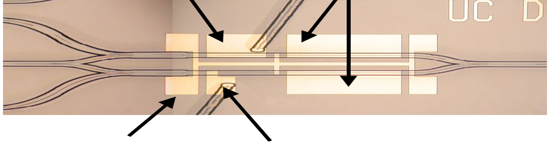


Figure 1. Photograph of the monolithically integrated MZI wavelength converter based on Electro-Absorbers and Phase Shifters

New EA based all-optical MZI

We propose and demonstrate a new class of all-optical monolithically integrated MZI based on biased electro-absorbers (EA) [8]. The carrier sweep-out time under the reverse bias condition typically in the tens of picoseconds determines the fast switching time of the EA based MZI. The passive nature of this novel switch also eliminates the SOA induced noise within the MZI. The combined effects of reduced noise and faster response time indicate favourable high-speed operation with increased cascadability without requiring high injection current into SOAs. Fig. 1 depicts the photograph of such an integrated EA-MZI successfully fabricated using active-passive integration involving MOCVD growth, RIE dry etching, and MOCVD lateral regrowth of Fe-doped InP. As Fig. 1 indicates, the EA-MZI consists of four multi-mode interference (MMI) based 3dB couplers, two EAs (MQW) of unequal lengths and two phase shifters (passive waveguide) of equal lengths.

The two EA sections in the EA-MZI are purposely designed to have unequal lengths to achieve balanced absorption strength when one of the EAs (shorter EA) is reverse biased. At this balanced amplitude condition, one of the phase modulators receive adjusted injection currents to achieve destructive interference at the output. The light injection into one of the EAs (shorter EA) will induce cross modulation [9] in phase and amplitude to break the balanced destructive interference condition at the output. Hence, the device operates as a 'non-inverting' mode switch (or wavelength converter). Similarly, 'inverting' mode operation can be achieved by applying the bias on the longer EA and achieving balanced destructive interference when desired level optical input is present.

Experimental results and discussion

Current injection in the phase shifter sections of the EA-MZI will indicate the sensitivity of the interferometric switch under various conditions. We observed this while injecting a CW probe signal at 1550nm through the centre probe input port of the MZI. Fig. 2 shows the measurement of the probe signal transmission (shown in relative to the lowest power throughput) while varying the bias current on the upper arm phase shifter. We repeat two sets of measurements with (solid line) and without (dashed line) injecting of a 1540 nm CW pump signal into the upper EA at 1540nm. The injected optical power for both probe and pump signals are 3dBm and 12dBm, before the estimated coupling loss of 9 dB. The lengths of the monolithically integrated EAs in the upper and lower branches of the EA-MZI and the length of the phase shifter sections are 200um, 50um, and 600um, respectively. The reverse bias voltages for upper and lower EAs are 1V and 12V.

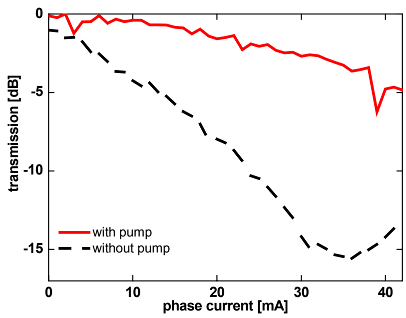
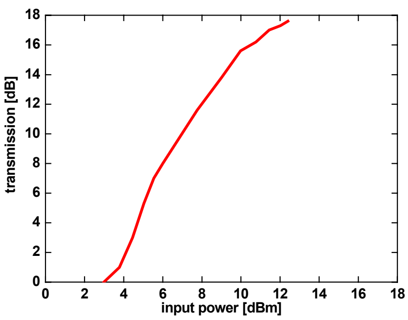


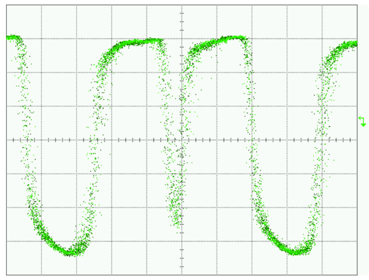
Figure 2 Transmission of the probe signal in absence and in presence of injected optical pump signal.

Fig. 2 indicates that the destructive interference occurs at approximately 35 mA current injection into the phase section when no pump signal is present, but that the pump signal injection significantly modifies the EA-MZI transmission response through amplitude and phase modulation of the EA section. At the given 35 mA level phase current injection and the pump signal present, the on-off ratio of 13dB can be achieved.

Fig. 3 shows all-optical switching experiment results obtained under the 35 mA phase current injection. Fig. 3(a) is the static switching result showing the transmission of the probe light in dB scale (normalized against the lowest throughput) against the input pump light power in dBm. Approximately 18dB extinction ratio is obtained for 10 dB variations in the input power, indicating the potential optical signal regeneration capability of the EA-MZI. Fig. 3(b) shows the electric waveform at the receiver after wavelength conversion of 2.5 Gb/s signal modulated with 2^7-1 pseudo-random-bit-sequence.



(a)



(b)

Figure 3. (a) MZI output power as a function of the input pump power; (b) Electrical waveform after wavelength conversion.

Conclusions

We proposed a novel monolithically integrated EA-MZI wavelength conversion device via cross modulation effects in a reverse biased EA. We demonstrate wavelength conversion ability of this device at 2.5 Gb/s. The realized EA-MZI structure combines the added cross phase modulation and the cross-absorption modulation effects to achieve very high contrast switching compared to the cross-absorption modulation EA wavelength conversion. Compared to SOA based MZI devices, the EA-MZI devices suffer from no ASE noise from the SOA and expect to achieve higher speed operation. Dynamic characterizations and all optical switching at higher bit rate with this novel device are currently in progress.

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