Switchable $\text{Al}_x\text{Ga}_{1-x}\text{As}$ all-optical delay line at 1.55 $\mu$m

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The authors demonstrate an on-chip optical delay in $\text{Al}_x\text{Ga}_{1-x}\text{As}$ that operates at room temperature and 1.55 $\mu$m. A nonlinear directional coupler for optical switching and a 188 ps long racetrack structure provide bit delays of $>100$ for picosecond pulses. In the linear regime the transmission ratio of the slow channel is 74%, which reduces to 40% with increasing peak intensity. (Meanwhile, the fast channel output increases from 26% to 60%.) Switching occurs due to a nonlinear detuning of the directional coupler, limited by three-photon absorption and time-averaging effects. This proof-of-principle device can operate at up to 5 GHz and is promising for optical buffering applications. © 2007 American Institute of Physics. [DOI: 10.1063/1.2679838]
The bit delay is $>100$, allowing a potential operation rate of at least 5 GHz (and more likely an order of magnitude higher). This device has a total linear loss (excluding insertion) of $\sim 6$ dB for TE polarized light in the slow channel.

Figure 3 shows the TE polarized temporal response of the all-optical delay line for a range of peak intensities inside the structure, after taking into account the 70% coupling efficiency and the 0.28 Fresnel reflection. As the peak intensity increases the overall signal amplitude increases in both channels. More interestingly, the dominant signal is exchanged from the slow channel (at low peak intensities) to the fast channel (at high peak intensities). This self-switching occurs all optically because the large nonlinear refractive index of the $A_{l0.18}Ga_{0.82}As$ waveguide core layer, this is predominantly three-photon absorption. Furthermore, this effect occurs at intensities well above the onset of the nonlinear switching.

The switching properties are more clearly illustrated by plotting the transmission ratio of the fast (slow) channel ($T_{f(s)}$) as a function of peak intensity, as shown in Fig. 4(b). The transmission ratios are obtained by normalizing the amplitudes of the individual channels against the total; thus, $T_{f(s)} = A_{f(s)}/(A_f + A_s)$, where $A_{f(s)}$ is the amplitude of the fast (slow) channel, shown in Fig. 4(a). In the linear regime the transmission ratios of the fast and slow channels are 26% and 74%, respectively. This corresponds to an $\sim 91\%$ one-way coupling efficiency in the NLDC after the linear loss and the length of the two paths are considered. While there are no physical limits to half Beat length NLDCs with 100% cou-

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**FIG. 2.** (Color online) Temporal response of the linear transmission through the optical delay line for TE polarization measured with the fast photodetector. The inset shows the autocorrelation of the pulse from the OPO (solid red line) compared to the impulse response measured on the fast photodetector (dotted blue line).
pling in the linear regime, the value we obtained is sufficient for demonstration purposes. A 50% switching occurs at approximately 1.4 GW cm$^{-2}$, above which the transmission ratio of the fast and slow channels flatten out at 60% and 40%, respectively. At these high peak intensities the two ratios do not completely invert (compared to the values in the linear regime) due to the observed nonlinear absorption and time-averaging effects, whereby the wings of the pulse continue to traverse the slow channel.\(^{12}\) Time-averaging effects can be minimized by modifying the input pulses, for example, by using either square pulses\(^{14}\) or solitons.\(^{15}\) Further improvements can be achieved by altering the band gap of the waveguide core with respect to the wavelength of operation, which has been supported by preliminary data for different excitation wavelengths on this device.

At higher peak intensities, the exiting pulse shape is unclear from the above experiments. For comparison, the linear and nonlinear transmissions of a 2 mm long section of a straight waveguide cleaved from this structure were examined using an optical spectrum analyzer. At the onset of the nonlinear absorption (discussed above), the observed self-phase modulation corresponds to a nonlinear phase shift of $\sim 1.5\pi$. These results agree well with numerical simulations of the self-phase modulation and with expectations from the literature.\(^{12}\)

In summary, an all-optical Al$_x$Ga$_{1-x}$As racetrack delay line is demonstrated at room temperature with 1.55 $\mu$m light pulses. This proof-of-principle device has a bit delay of $>100$ that can be operated at 5 GHz, and it can simultaneously buffer up to $\sim 50$ bits. The delay can be switched off by nonlinear optical interactions in the coupling region, which can attain a $<15$ dB switching ratio by engineering the material absorption and the length of the nonlinear directional coupler. Furthermore, the on-chip nature of this device allows its integration into more complex architectures.

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