1-1-1995

Time-Domain All-Optical Demultiplexing With A Semiconductor Directional Coupler

A. Villeneuve
University of Central Florida

P. Mamyshev
University of Central Florida

J. U. Kang
University of Central Florida

G. I. Stegeman
University of Central Florida

J. S. Aitchison

Applied Physics Letters

Time domain all-optical demultiplexing with a semiconductor directional coupler

Cite as: Appl. Phys. Lett. **66**, 1668 (1995); https://doi.org/10.1063/1.113887
Submitted: 22 November 1994 . Accepted: 02 February 1995 . Published Online: 04 June 1998

A. Villeneuve, P. Mamyshev, J. U. Kang, G. I. Stegeman, J. S. Aitchison, and C. N. Ironside

Time domain all-optical demultiplexing with a semiconductor directional coupler

A. Villeneuve[a)]
COPL, Pavillon Vachon, Université Laval, Sainte-Foy, Québec G1K 7P4, Canada

P. Mamyshev,[b)] J. U. Kang, and G. I. Stegeman
CREOL, University of Central Florida, Orlando, Florida 32826

J. S. Aitchison and C. N. Ironside
Department of Electronics and Electrical Engineering, University of Glasgow, Glasgow G128QQ, United Kingdom

(Received 22 November 1994; accepted for publication 2 February 1995)

We report the demonstration of demultiplexing of 150 fs pulses, without pulse breakup, in an AlGaAs nonlinear directional coupler operated at photon energies below half the band gap energy of AlGaAs. © *1995 American Institute of Physics.*

The rerouting of single or multiple signal data bits (pulses) out of a high bit rate data sequence can be induced all optically in either fiber or integrated optical waveguides.[1–9] In general, a change in refractive index created by one optical beam (control) leads to a change in the phase, polarization, wavelength, or guiding channel for a signal. In particular, we have previously demonstrated a prototype demultiplexer based on a nonlinear direction coupler (NLDC). Using $Al_{0.18}Ga_{0.82}As$ waveguides, the output channel for TM-polarized signal beams, at a wavelength of 1550 nm was determined by the overlap (or lack of) with a TE-polarized control beam.[9] Although these devices had very high throughputs, because of the low propagation and multiphoton absorption losses, they did suffer from a poor (3:1) switching contrast for two reasons.[9,10] The coupler had different coupling lengths for the two different polarizations, leading to an asymmetric cross-phase modulation of the signal beam. In addition, the usual pulse breakup occurred because nonsoliton pulses of equal duration were used.

In this letter we report a different NLDC implementation of the demultiplexer in which high contrast without pulse breakup was achieved. The control and signal pulses had different wavelengths which could be separated at the output. Hence, it was possible to use copolarized beams with comparable coupling lengths and to use the small difference in group velocity to symmetrically ''walk'' the signal pulse through the control, which was a factor of 4–5 longer than the signal, as shown in Fig. 1.

The experimental apparatus is shown in Fig. 2. An additive pulse mode-locking (APM) color center laser operating at 76 MHz produced 0.6–0.8 ps pulses at 1550 nm. The wavelength shifted signal pulses were obtained by splitting-off 30–50 nW (average power) for transmission through 5.5 m of dispersion-shifted single mode optical fiber from Coring (CPC3). Multisoliton compression and the soliton self-frequency shift resulted in wavelength shifted $N=1$ solitons at 1610 and 1640 nm.[11] An interference filter was then used to isolate the 1640 nm soliton from the other wavelengths present. This soliton has a 20 nm bandwidth and, assuming that the pulse is transform limited, the pulse width should be of order 120 fs which compares well without autocorrelator measurements of 150 fs. We have tested the solitons using autocorrelation and cross-correlation techniques and found out that there was little timing jitter between the control and signal pulses and that the power and wavelength of the 1640 nm soliton were very stable. The control pulses were derived from the laser output, time-delayed to suitably overlap the signal pulses in the NLDC. The NLDC was 2 cm long, an effective channel cross-sectional area of 12 μm^2, and had low propagation and negligible multiphoton losses. Further details can be found in Ref. 10. A 60× lens was used to separate the outputs from the two NLDC channels for detection by matched Ge detectors.

The best demultiplexer response that we obtained by adjusting the relative arrival times of the control and signal pulses is shown in Fig. 3(a). The *bar* and *cross* channels are

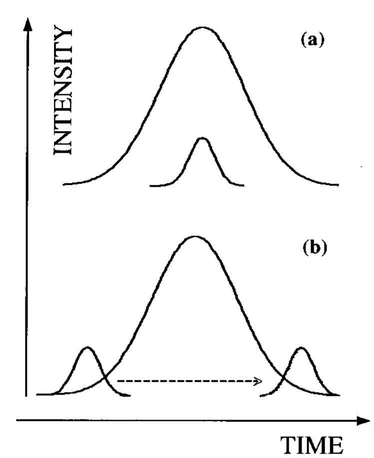

FIG. 1. Schematic representation of the control-signal pulse beam overlap geometry in a nonlinear directional coupler. The short signal pulse symmetrically ''walks through'' the longer control pulse.

[a)]Electronic mail: avillene@phy.ulaval.ca
[b)]Current Address: AT&T Bell Labs, Holmdel, NJ 07733.

 0003-6951/95/66(13)/1668/3/$6.00

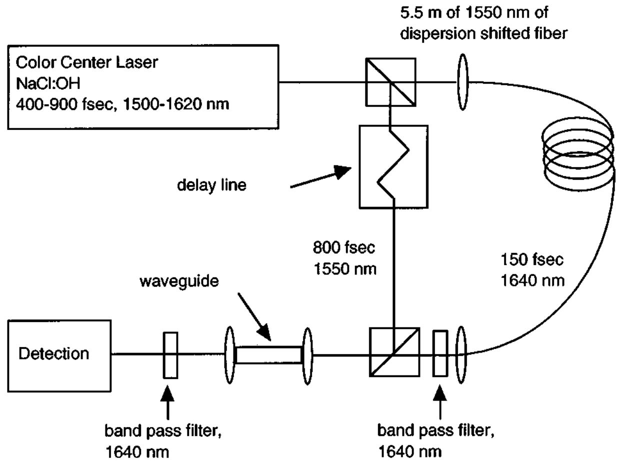

FIG. 2. Experimental setup.

the original input and adjacent channels, respectively. At low control powers the signal is output from the *cross* channel and at high control powers the signal output reverts back to the *bar* channel. The contrast is greatly improved over the previous work.[9] The operation of the demultiplexer was simulated by solving simultaneously the coupled mode equations for both the signal and control beams, including the effects of group velocity dispersion. Details will be reported elsewhere. The results, shown in Fig. 3(b) correspond to the arrival of the peak of control pulse 0.75 ps before the peak of the signal pulse and the exit of the signal pulse by an equal amount prior to the control. Agreement with the experiment is excellent. We also explored both experimentally and numerically the effect of time delay between the arrival of the

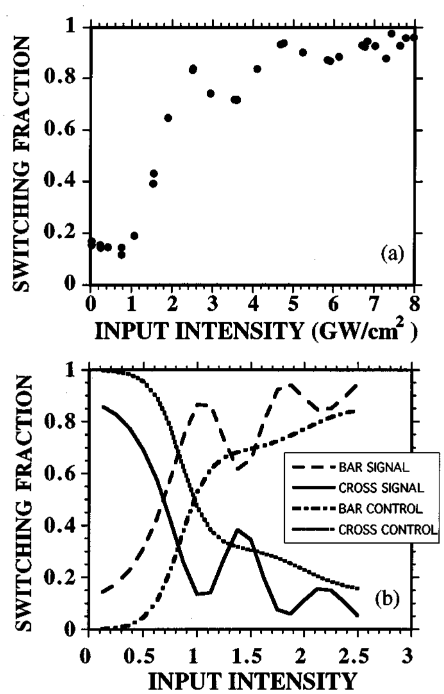

FIG. 3. (a) The experimental "optimum" best switching result (fraction of signal output in the *bar* channel) as a function of input intensity. (b) Simulation of the result in (a).

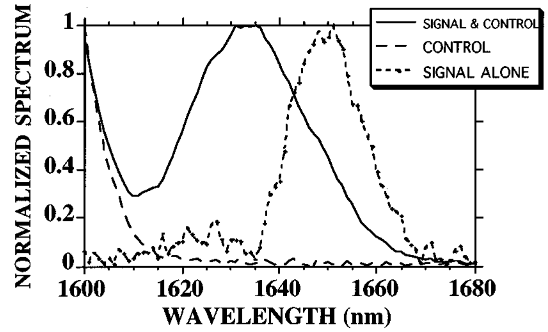

FIG. 4. Experimental observation of the frequency shift of the signal beam in the presence of the control beam for the asymmetric interaction case.

control and signal pulses and found that demultiplexing still occurred within approximately a 1 ps window.

Because of the very short signal pulses used it was not possible to directly determine whether pulse breakup occurred or not. [The high output contrast in Fig. 3(a) is a strong indication that no significant pulse breakup is occurring.] An asymmetric "walk through" of the control and signal pulses not only leads to the pulse breakup, but also to a frequency shift of the output pulse due to asymmetric cross-phase modulation.[2,4,12] An example of this effect for an asymmetric interaction is shown in Fig. 4. For the results discussed previously in Fig. 3(a), there was little measurable shift in the signal beam wavelength, another indication that no significant pulse breakup occurred.

One of the unique properties of the Raman shifting effect used to generate the signal beams is that the frequency shift depends on the power input into the fiber.[11] Therefore, the wavelength filter used at the NLDC output to separate the signal from the control beam can also be used to control the signal output. An example is shown in Fig. 5. As both the control and signal beam powers are increased (not the case in the previously discussed experiments), the signal wavelength is tuned outside the transmission edge of the filter (set by tilting the filter) and the demultiplexer output drops at high powers. Note that the best switching is >95% indicating that the control-signal beam interaction remains symmetric and

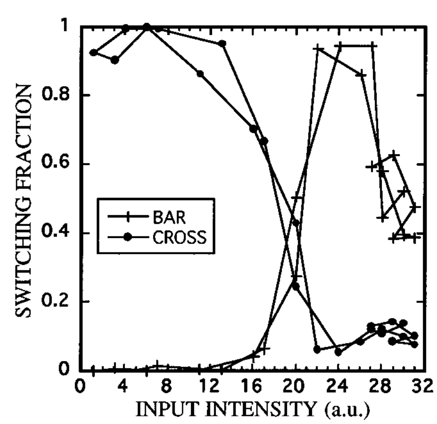

FIG. 5. Switching fraction for the output signal in the *bar* and *cross* states with a 10 nm filter at the output for an asymmetric signal-control beam interaction.

there is little pulse breakup occurring within the NLDC.

In summary, time domain demultiplexing with no measurable pulse breakup and high contrast was demonstrated with an $Al_{0.18}Ga_{0.82}As$ nonlinear directional coupler.

The research was supported at COPL by NSERC and FCAR, at CREOL by NSF, and at Glasgow by the EPSRC.

[1] Many cases reviewed in M. N. Islam, *Ultrafast Fiber Switching Devices and Systems* (Cambridge, Cambridge, MA, 1992); G. I. Stegeman and A. Miller, in *Photonic Switching*, edited by J. Midwinter (Academic, Orlando, 1992), Vol. 1, pp. 81–146.
[2] M. Jinno, Opt. Lett. **18**, 726 (1993).
[3] C. G. Krautschik, P. J. G. Wigley, G. I. Stegeman, and R. H. Stolen, Appl. Phys. Lett. **63**, 860 (1993).
[4] T. Morioka, K. Mori, and M. Sariwatari, Electron. Lett. **28**, 1070 (1993).
[5] D. M. Patrick and A. D. Ellis, Electron. Lett. **29**, 227 (1993).
[6] K. Uchiyama, H. Takara, S. Kawanishi, T. Morioka, S. Saruwatari, and T. Kitoh, Electron. Lett. **29**, 1870 (1993).
[7] A. D. Ellis and D. M. Spirit, Electron. Lett. **29**, 2115 (1993).
[8] I. Glesk, J. P. Sokoloff, and P. R. Prucnal, Electron. Lett. **30**, 339 (1994).
[9] A. Villeneuve, K. Al-henyari, J. U. Kang, C. N. Ironside, J. S. Aitchison, and G. I. Stegeman, Electron. Lett. **29**, 721 (1993).
[10] K. Al-hemyari, A. Villeneuve, J. U. Kang, G. I. Stegeman, J. S. Aitchison, and C. N. Ironside, Appl. Phys. Lett. **63**, 3562 (1993).
[11] P. V. Mamyshev and S. V. Chernikov, Sov. Light. Comm. **3**, 1 (1993).
[12] P. P. Iannone, P. R. Prucnal, G. Raybon, U. Koren, and C. A. Burrus, Electron. Lett. **29**, 1518 (1993).