Faster Switching with Semiconductor Optical Amplifiers

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Abstract: We review recent methods to increase the speed of the nonlinear optical response of semiconductor optical amplifiers (SOAs), including the use of filters and of an additional SOA in the 'Turbo-Switch' configuration. We also consider the effects of optimising parameters, such as the confinement factor and optical area, on the recovery rate.

Keywords: Semiconductor optical amplifier, wavelength conversion, all-optical signal processing.

Introduction

There is much continuing research interest in the use of semiconductor optical amplifiers (SOAs) as nonlinear elements for all-optical switching applications at very high bit rates (>40 Gbit/s) [1-3]. These rates are much faster than the natural recovery rates of SOAs (whose lifetimes are typically ~100ps), and so patterning of the output signal occurs [2]. Generally speaking, a faster response speed is required to prevent such patterning. Recent innovations to improve the observed response speed have concentrated upon the use of various linear spectral filtering schemes [1-3] or the use of second SOA in the so-called Turbo-Switch arrangement, which is effectively a nonlinear filter [4,5]. However, none of these techniques reduce the recovery time of the SOA itself, and therefore ways to achieve this are also receiving attention [5-7].

In this paper we review these various approaches, including recent advances in achieving high–speed response from an SOA, to allow very high bit rate optical signal processing (~160 Gbit/s).

Linear and Nonlinear Filtering Schemes

The most straightforward approach is to use a narrow-band selective optical filter to pass only part of the spectrum of a continuous wave (CW) beam after it has been cross-modulated by the effect of a high bit rate 'pump' in an SOA [1]. This has usually been done in conjunction with an asymmetric Mach-Zehnder interferometer (or DISC), which may also be regarded as a filter in the frequency domain [2], and the two filters are used to pass red and/or blue shifted parts of the signal spectrum. Highly sophisticated linear filtering schemes which pass and recombine both red and blue shifted parts of the spectrum have also been reported [3].

The simplest scheme, used by Liu et al [1], is shown schematically in Fig 1, where a narrow band-pass filter, placed after the SOA, is designed to select the blue- shifted part of the modulated spectrum. The DISC filter is used to re-invert the signal from the band-pass filter. The overall result is the transmission of a short pulse, corresponding to the high-speed part of the overall response of the SOA. This arrangement has been used for wavelength conversion at bit rates as high as 320 Gbit/s [1]. A drawback of this scheme is that the band-pass filter removes power due to suppression of part of the signal spectrum, resulting in a reduction in the OSNR [2].

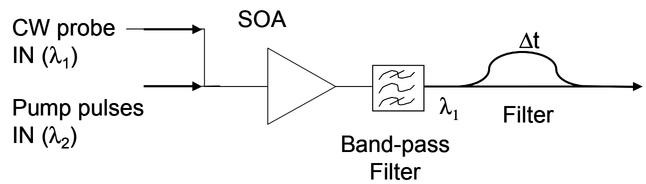

Fig 1. Use of a pass-band filter and 'DISC' filter to pass parts of the modulated CW probe spectrum (after Liu et al [1])

One way of avoiding this is to use a second SOA to act as a nonlinear filter, in the Turbo–Switch arrangement (Fig 2).

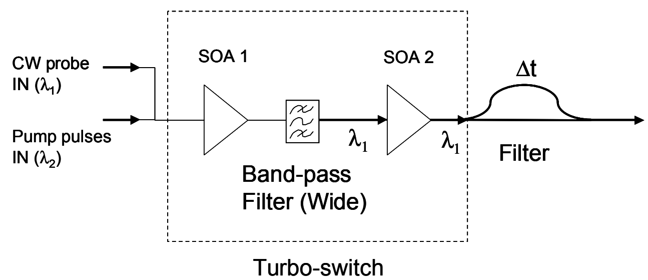

Fig 2. Turbo-Switch scheme. The band pass filter blocks the pump and allows the entire modulated CW spectrum to pass.

The band-pass filter here passes the entire modulated spectrum on the CW probe, and blocks the pump. The somewhat complex action of the second SOA is explained [4] in terms of the self-gain dynamics of the second SOA, which act in opposition to the slow recovery of the amplitude and phase modulation of the CW beam from the first SOA, considerably enhancing the high-speed response of the SOA combination, as in Fig 3.

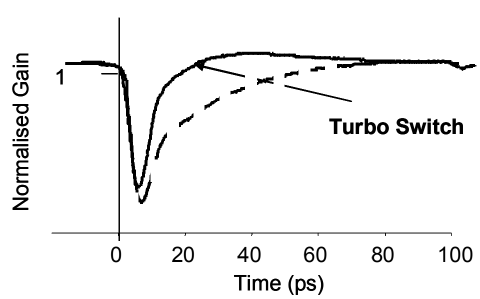

Fig 3. Measured response of the Turbo-Switch to a ~3ps pulse (from [6]). The slower response (dashed line) is for a single SOA.

Fig. 3 shows the experimentally measured gain recovery times for a single SOA and for the Turbo-Switch combination. In the frequency domain the second SOA can be regarded as a nonlinear filter, and the output of the combination is very similar to that from a high pass filter.

For wavelength conversion experiments, a DISC can be used with the Turbo-Switch, as in Fig 2. Modelling suggests that low patterning is due both to the presence of the overshoot in the gain response, and the differential gain and phase changes acting in opposition in the DISC interferometer [4]. Wavelength conversion at rates up to 170 Gbit/s has been achieved, with ~3 dB penalty [4]. In that experiment the DISC was 'distributed', in that the birefringent fibre, giving different path lengths for the two orthogonal polarisations, was placed between the two SOAs, and the polariser, which completes the interferometer, was placed after the SOA2. This appears to further ameliorate patterning. It should be noted that the DISC filter itself removes power from the signal, as it necessarily translates the CW signal into pulses of a few ps in duration, reducing the power by the mark-space ratio.

Modelling suggests that, in the filtering approach of Fig 1, patterning is reduced because smaller gain changes caused by the second and subsequent pulses in data sequences are compensated by larger blue shifts. Hence both methods described in this section rely on a fortuitous balance of the gain and phase (or chirp) dynamics to give an output with low patterning. Clearly there is a close similarity between the two schemes, both of which have advantages. The Turbo-Switch arrangement does not require detailed filter design, but uses two SOAs which increase the power consumption. Both schemes use filters which reduce the signal power. The single filter scheme has been demonstrated to 320 Gbit/s, whilst the ultimate switching rate achievable with the Turbo-Switch is under investigation. It appears to offer a 3-4 times improvement in bandwidth compared to a single SOA-DISC combination.

SOA design

All of these schemes use filtering because the response bandwidth of the SOA is too small for very high speed switching. A different and obvious approach to increasing switching rates with SOAs is to design a faster device. The effective lifetime of the SOA in the presence of a CW holding beam or with ASE [6-8] is given by:

$$\frac{1}{\tau_{eff}} = \frac{P}{E_{SAT}} = \frac{\Gamma}{A}\frac{gP}{h\nu} \quad , \qquad [1]$$

where P is the power of the CW beam or ASE, Γ is the confinement factor, g is the differential gain, $h\nu$ is the photon energy, and A is the cross-sectional area of the active waveguide. The design problem consists of minimising τ_{eff} which may be done by maximising g [6], maximising Γ with a separate confinement heterostructure (SCH) layer, or, in the absence of a SCH layer, minimising the optical area (A/Γ) [7-9]. The predicted trends from optimisation of the optical area of a bulk GaInAs device of depth 0.1 μm are shown in Fig 4 [9].

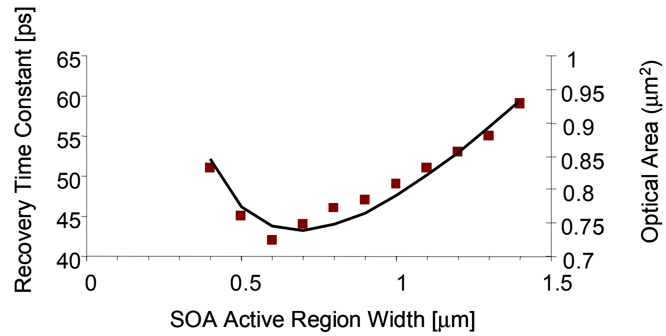

Fig4. Modelled recovery time constant as a function of active region width (points) and modelled area to confinement factor ratio (solid line) overlaid for comparison.

Optimising both the depth and width of the wave-guide predicts an optimal waveguide cross- section is a square of side ~ 0.3μm. Such a device, as well as having a gain recovery time ~ 4 times lower than those of Fig 4, would have the advantage of a polarisation independent gain [9].

Conclusions

We have reviewed some of the recent advances in achieving high speed response from an SOA, which allow very high bit rate optical signal processing (~160 Gbit/s) to be achieved with simple configurations.

Acknowledgment

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