INCOHERENT-TO-COHERENT WAVELENGTH CONVERSION USING SEMICONDUCTOR OPTICAL AMPLIFIER

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Centre d'optique, photonique et laser

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Introduction

- Incoherent broadband optical communication systems like optical code-division-multiplexed access (OCDMA) and spectrum-sliced wavelength division multiplexing (SS-WDM) offer low cost alternatives to conventional wavelength division multiplexed (WDM) networks.
- The major weakness of systems using broadband sources generated from spontaneous emission is the beat-noise generated by square-law photodetection.
- A bit error rate floor exists for SS-WDM due to signal dependent noises, as opposed to coherent systems without such a floor. In order to avoid the bit error rate (BER) floor, and/or accommodate a higher bit rate, a wider optical bandwidth is required for SS-WDM, reducing the spectral efficiency and increasing the effects of dispersion [3].

Proposed Solution

- Proposed Solution $\Longrightarrow$ We use the cross-gain modulation mechanism in semiconductor optical amplifiers (SOAs) to reduce the beat noise via conversion of the modulated incoherent optical signal into a coherent signal before the detection process.
- A continuous-wave (CW) probe beam together with the incoherent modulated channel is injected into the SOA.
- The incoherent optical signal modulates the gain of the SOA by depleting the carriers. The CW laser encounters the modulated gain and will carry the inverted data carried initially by the incoherent optical signal.
- . The proposed scheme can also operate as an all optical converter.

SOA Model

- We use a wideband model for a bulk SOA based on numerical solution of coupled equations for carrier-density rate and traveling-wave (or photon rate) for both forward and backward propagating signals, and spectral components of amplified spontaneous emission (ASE) powers [1].
- Each signal obeys the complex traveling-wave equations :

$$\frac{dE^{\pm}_{S_k}(z)}{dz} = \left\{ \mp j\beta_k \pm \frac{1}{2}\left[\Gamma g_m\left(\nu_k, N(z)\right) - \alpha\right] \right\} E^{\pm}_{S_k}(z) \qquad (1)$$

where β_k is the signal propagation coefficient, Γ the optical confinement factor, $g_m(k, N(z))$ the material gain coefficient, $N(z)$ the carrier density, and α is the material loss coefficient. It is assumed that the squared modulus of the amplitude of the traveling-wave is equal to the photon rate of the wave in that direction, so $N^{\pm}_{S_k} = \left|E^{\pm}_{S_k}\right|^2$.

- The carrier density N(z,t) at z acquires the form :

$$\begin{aligned}\frac{dN(z)}{dt} &= \frac{I}{edLW} - R\left(N(z)\right) \\ &- \frac{\Gamma}{dW}\left\{ \sum_{k=1}^{N_s} g_m\left(\nu_k, N(z)\right)\left(N^{+}_{S_k}(z) + N^{-}_{S_k}(z)\right) \right\} \\ &- \frac{2\Gamma}{dW}\left\{ \sum_{j=1}^{N_m - 1} g_m\left(\nu_j, N(z)\right) K_j \left(N^{+}_{j}(z) + N^{-}_{j}(z)\right) \right\} \qquad (2)\end{aligned}$$

where I is the bias current, e the electric charge, d the active region thickness, L the active region length, W the central active region width, $R(N(z))$ the recombination rate term, N_s the number of injected signals with optical frequencies $\nu_k (k = 1 \text{ to } N_s)$, and N_m the number of spectral components of amplified spontaneous emission powers.

Experimental demonstration

- Our experimental setup is depicted in Fig. 1. A continuous-wave signal from a tunable DFB laser is injected into a Kamelian optical preamplifier SOA, via an optical isolator, in counter-propagation

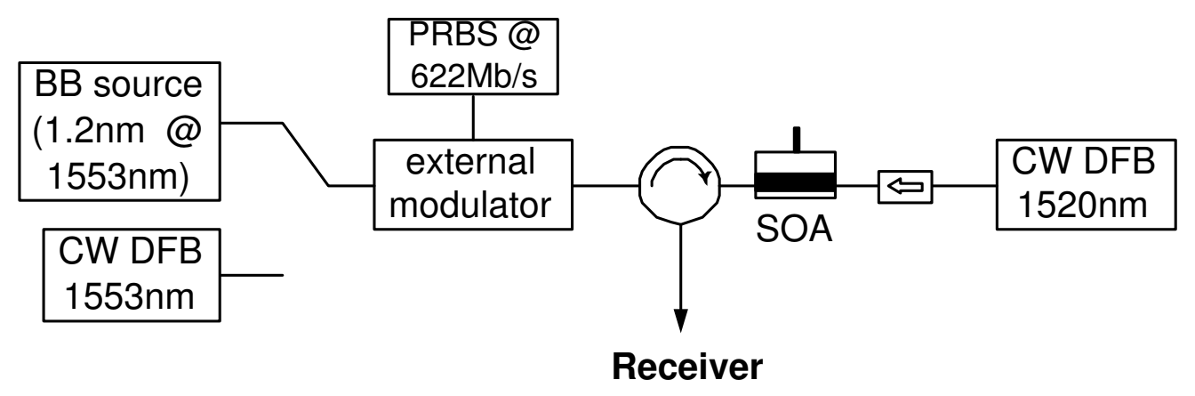

FIGURE 1: Experimental setup

- In order to evaluate the effectiveness of the conversion of a modulated incoherent broadband source to a modulated coherent signal, we adopt the extinction ratio as a figure of merit. We compare the extinction ratio before and after conversion for two cases: 1) conversion of a modulated incoherent input signal to a coherent output, and 2) wavelength conversion of a modulated coherent input signal to a coherent output.

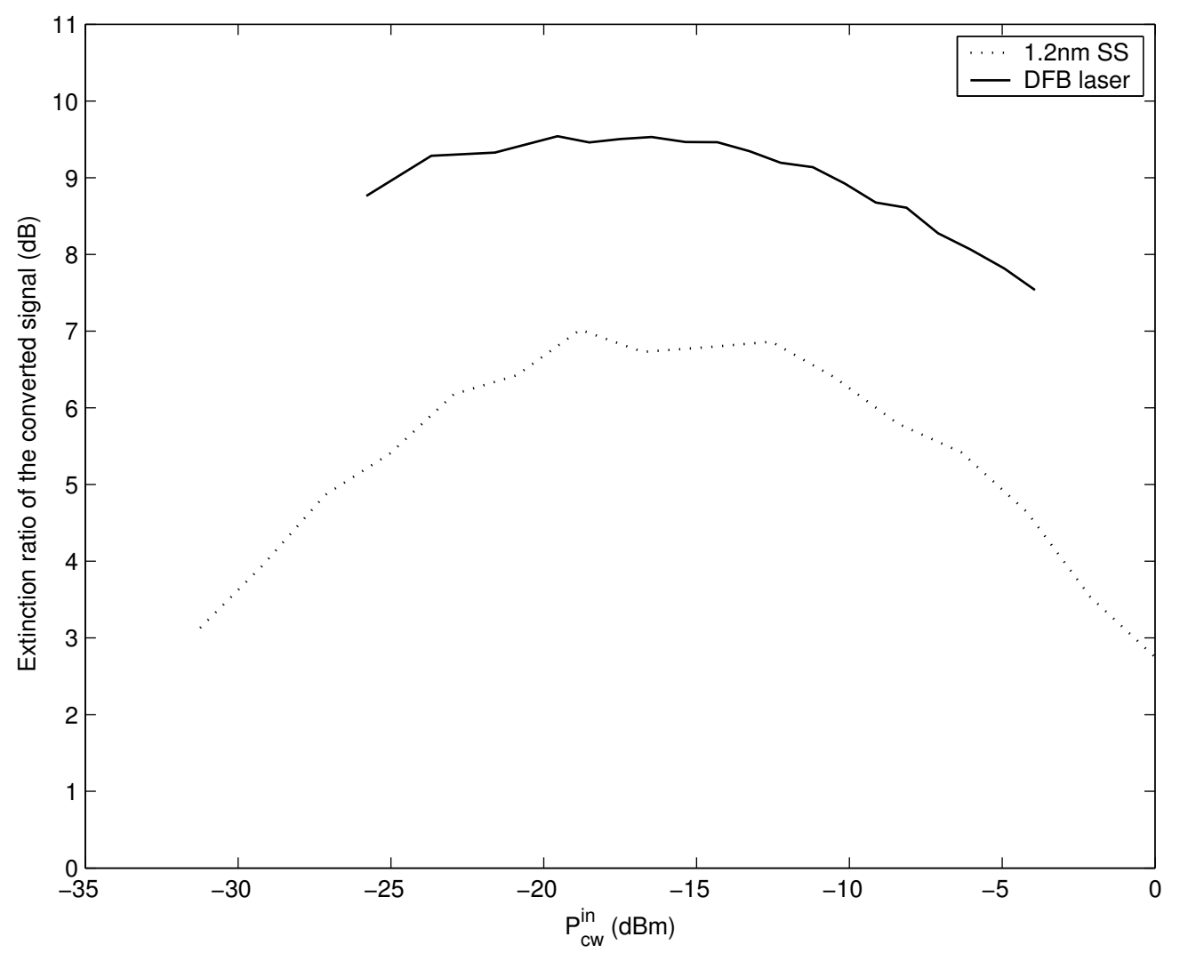

FIGURE 2: Measured extinction ratio of the converted signal as a function of the CW input power for a laser as modulated channel (solid line) and incoherent spectrum-sliced modulated channel (dashed line).

- For a fixed bit rate of 622 Mb/s, an extinction ratio of 11 dB at a power of around -8 dBm for the modulated channel, we obtain a minimum extinction ratio penalty of 1.5 dB and 4 dB respectively, for the coherent-to-coherent and incoherent-to-coherent conversions with a CW power of -15 dBm.
- Although the extinction ratio is degraded for the non-coherent signal, the bit error rate is improved given that a coherent signal is now incident on the photo-detector.

Simulation Results

A. SOA Characterization

- In order to predict extinction ratio improvement, we must characterize the Kamelian SOA through static measures to model it. This characterization takes into account the output power level and the ASE profile in order to approximate the material gain coefficient $g_m(\nu_k, N(z))$ and the spontaneously emitted noise $R_{sp}(\nu_j, N(z))$.
- We model the material gain as having a Lorentzian lineshape and fit this with experimental measurements..

$$g_m\left(\nu_k, N(z)\right) = \frac{a\left[N(z) - N_0\right]}{1 + \frac{\left(\lambda - \lambda_N\right)^2}{\left(\Delta\lambda\right)^2}} \qquad (3)$$

where the gain constant,a, is $7.10 \times 10^{-20}\ m^2$; the carrier density at the transparency,N_0, is $1.2 \times 10^{24} m^{-3}$; the 3-dB bandwidth of the linear gain coefficient, $\Delta\lambda$, is 122.5 nm; and the spectral shift, λ_N, is represented by $\lambda_N = \lambda_0 - \kappa_0(N(z) - N_0)$ where the peak wavelength at transparency, λ_0, is 1639 nm and κ_0 is a constant characterizing the gain-peak shift.

- Fig.3 shows the predicted and measured fiber-to-fiber signal gain as a function of wavelength. The two other curves, which represent the Kamelian optical pre-amplifier SOA, have the same profile with some dissimilarity.

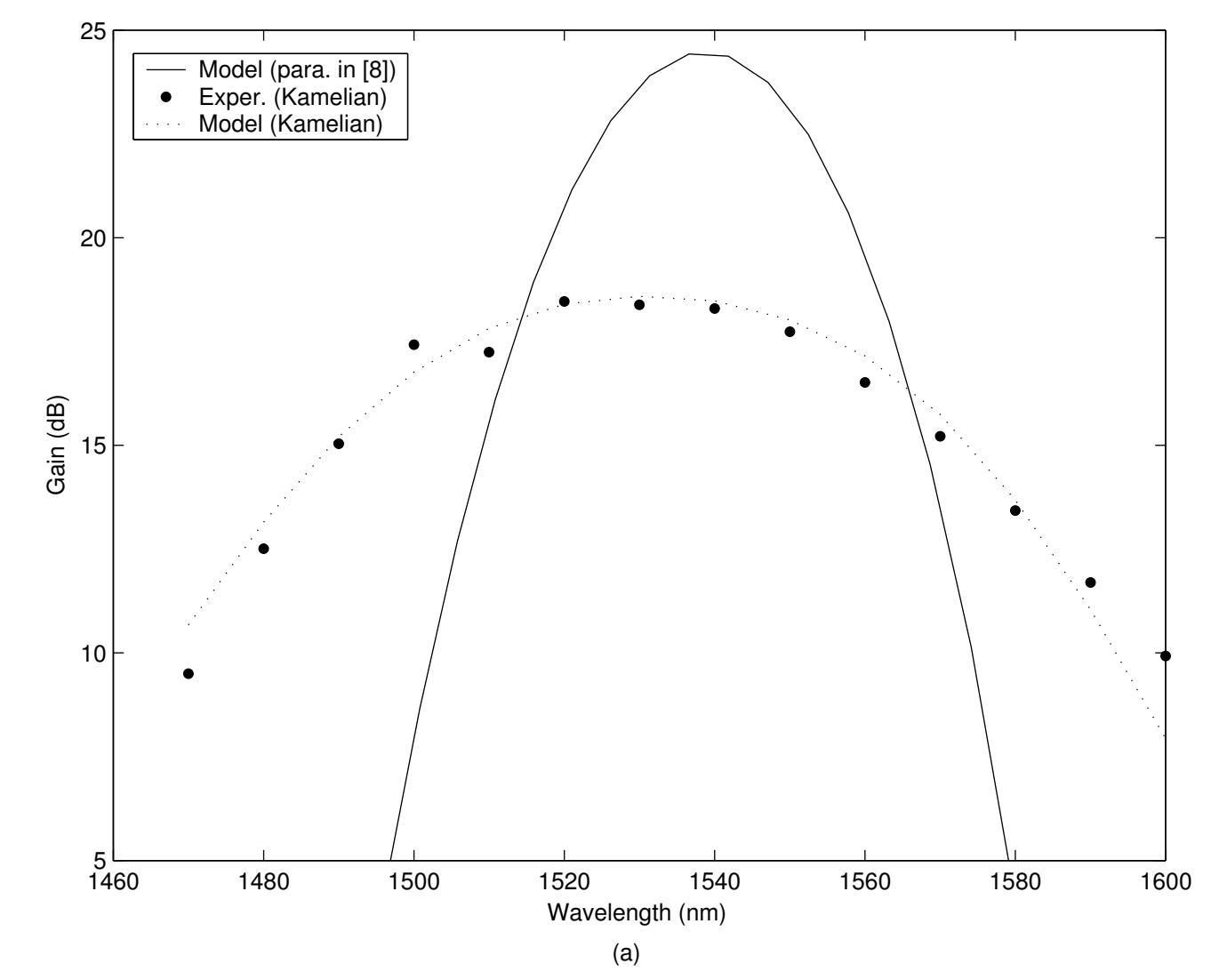

FIGURE 3: Predicted (line) and measured (markers) fiber-to-fiber signal gain as function of wavelength with -20 dBm input power, bias current 130 mA.

B. Simulation of output extinction Ratio

- Whereas for our experiment we consider only one input extinction ratio, one conversion wavelength and one input power, in our simulations we consider three input extinction ratios, and the gamut of conversion wavelengths
- In Fig.4, we compare the output extinction ratio for the Kamelian SOA and the SOA model proposed by Connelly.The input modulated broadband signal was at 1553 nm and -5 dBm; The CW channel power was -15 dBm.

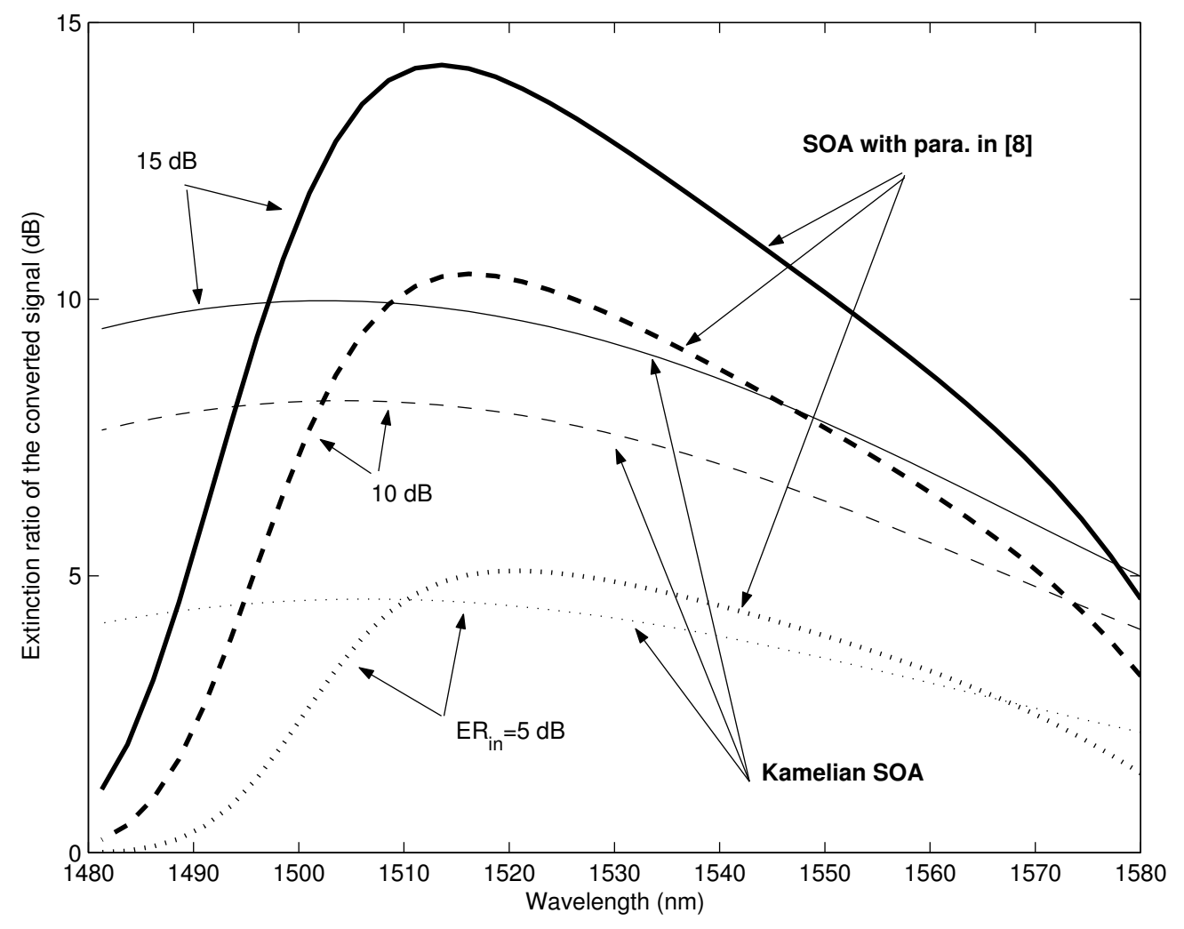

FIGURE 4: Output extinction ratio of the converted CW signal as function of wavelength for the two SOAs.

BER Measurement

- As a final step of this validation, we recently reported in [2] a measured bit error rate for a spread-spectrum WDM channel without and with the incoherent-to-coherent conversion for different levels of optical received power as shown in Fig. 5

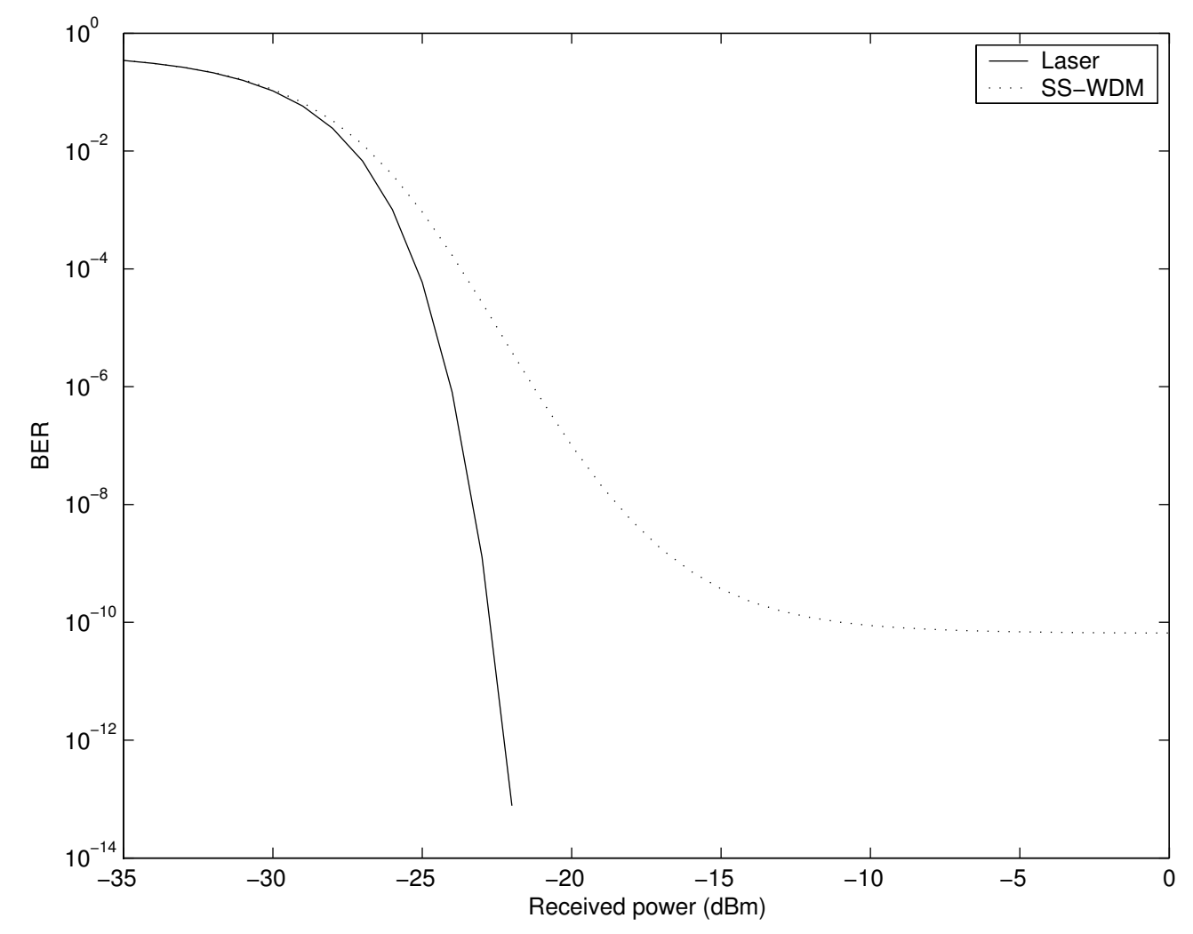

FIGURE 5: BER measurement for SS-WDM and converted signal, respectively for bit rate of 2.5 Gb/s and Bo = 1.2 nm.

- The curve for the converted channel shows both the elimination of the BER floor, and a performance improvement of 6 dB at 10^{-9}.

Conclusion

- We report for the first time an all-optical wavelength conversion of an incoherent optical signal to a coherent optical signal using the cross-gain modulation in semiconductor optical amplifiers.
- We were able to observe BER improvement for the converted signal compared with the SS-WDM channel.

References

1. M. J. Connelly, "Wideband semiconductor optical amplifier steady-state numerical model," IEEE Journal of Quantum Electronics, vol. 37, pp. 439-447, 2001

2. M. Menif, L. A. Rusch, and W. Mathlouthi, "Error-free transmission of SS-WDM using incoherent-to-coherent wavelength conversion," GlobeCom 2004, submitted, 2004.

3. W. Mathlouthi, M. Menif, and L. A. Rusch, "Beat noise effects on spectrum-sliced WDM," in 2003 International Conference on Applications of Photonic Technology (Photonics North), Montreal, May 2003.