Interferometric crosstalk suppression using polarization multiplexing technique and an SOA

Liu, Fenghai; Xueyan, Zheng; Pedersen, Rune Johan Skullerud; Jeppesen, Palle

Published in:
CLEO 2000 Technical Digest

Link to article, DOI:
10.1109/CLEO.2000.906765

Publication date:
2000

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Liu, F., Xueyan, Z., Pedersen, R. J. S., & Jeppesen, P. (2000). Interferometric crosstalk suppression using polarization multiplexing technique and an SOA. In *CLEO 2000 Technical Digest* (pp. 91-92). Optical Society of America. https://doi.org/10.1109/CLEO.2000.906765

nant structure as the measured spectrum. The calculated peak spacing (free spectral range) of 1.34 ± 0.04 THz is in excellent agreement the measured spacing of 1.30 ± 0.04 THz. Both values are close to that obtained using a simple Fabry-Perot model, which predicts 1.6 THz. The calculated envelope differs from the measured spectrum, which is likely caused by a difference in the facet geometry.[4] The bandwidth of the guided mode extends over almost the entire width of the gap except for a small frequency range around 0.41c/a. This feature appears in the measured spectrum at 0.45 c/a, and the shift is attributed to a difference in the size of the holes closest to the waveguide.

These results illustrate, for the first time to our knowledge, the detailed spectral signature and resonant features of a photonic crystal waveguide.

Max-Planck-Inst. of Microstructure Physics, Germany

***MIT, USA*

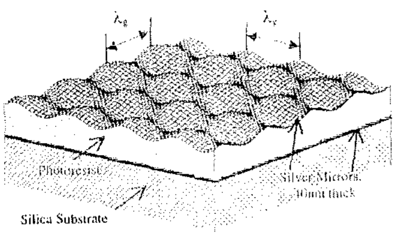
1. T. Baba, N. Fukaya, J. Yonekura, Electron. Lett. **35**, 654 (1999).
2. O. Hanaizumi, Y. Ohtera, T. Sato, S. Kawakami, Appl. Phys. Lett. **74**, 777 (1999).
3. S.-Y. Lin, E. Chow, V. Hietala, P.R. Villeneuve, J.D. Joannopoulos, Science **282**, 274 (1998).
4. J. Yonekura, M. Ikeda, T. Baba, IEEE J. Lightwave Tech. **178**, 1500 (1999).

JMA6 3:00 pm

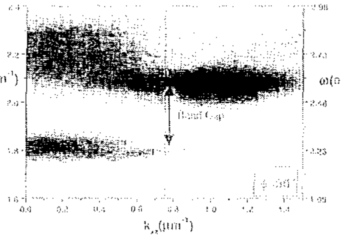
Guided modes with flat photonic bands in textured metallic microcavities

M.G. Salt, W.C. Tan, W.L. Barnes, *Thin Film Photonics Group, School of Physics, Univ. of Exeter, Stocker Road, Exeter, Devon, EX4 4QL, United Kingdom; E-mail: m.g.salt@ex.ac.uk*

The use of planar microcavity structures to control spontaneous emission from optical devices is now a well-established technique. The simplest geometry is that of a pair of planar mirrors separated by a distance of order the wavelength of light, with the emissive species situated between the two mirrors. It has been clearly demonstrated that the boundary conditions imposed by such planar microcavity systems can modify the spatial and spectral distribution of the emitted radiation from such devices,[1] and also the spontaneous emission lifetime of the emitter.[2,3] However, the extent to which spontaneous emission may be controlled is limited by the planar symmetry of the microcavity. In order to modify the spontaneous emission process further, the dimensionality of the system needs to be reduced,[4,5] and it is this that we have sought to do in the present study.



MA6 Fig. 1. A schematic of the two-dimensionally textured, metal-clad microcavity.



JMA6 Fig. 2. An example of a typical dispersion curve map, as obtained via transmissivity measurements. A photonic band gap in the dispersion of the lowest-order waveguide mode can clearly be seen for this direction of propagation within the waveguide. All other directions of propagation investigated exhibit a near-identical band gap for TE polarization.

We first examine the case of a solid-state microcavity textured with a single, periodic corrugation. We explore how the depth of the corrugation and the waveguide thickness affect the width of the band gap produced in the dispersion of the guided modes. We discover that substantially flat bands are generated for the dispersion of the waveguide modes supported by the structures. We then experimentally examine band gaps produced in the guided modes of a two-dimensionally textured microcavity (Fig. 1), and demonstrate the existence of a complete band gap for all directions of propagation of the lowest-order TE-polarized mode (Fig. 2).

We compare our experimental results with those from a theoretical model and find good agreement. We also use the theoretical model to investigate the electric field profiles supported by these structures for different regions of the dispersion curve, including the flat bands. Implications of these results for emissive microcavity devices such as LEDs will be discussed.

1. A. Dodabalapur, L.J. Rothberg, R.H. Jordan, T.M. Miller, R.E. Slusher, J.M. Phillips, J. Appl. Phys. **80**, 6954–6964 (1996).
2. P.T. Worthing, R.M. Amos, W.L. Barnes, Phys. Rev. A **59**, 865–872 (1999).
3. P.T. Worthing, W.L. Barnes, J. Opt. A **1**, 501–506 (1999).
4. R.E. Slusher, Solid State Commun. **92**, 149–158 (1994).
5. I. Abram, G. Bourdon, Phys. Rev. A **54**, 3476–3479 (1996).

CMR 1:30 pm–3:15 pm

Rooms 270–276

Novel Modulation Techniques

Nick J. Doran, *Aston Univ., UK, Presider*

CMR1 1:30 pm

Interferometric crosstalk suppression using polarization multiplexing technique and an SOA

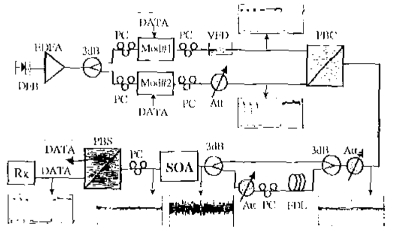
F. Liu, X. Zheng, R.J.S. Pedersen, P. Jeppesen, *Res. Center COM, Tech. Univ. of Denmark, Lyngby, DK-2800, Denmark; E-mail: LF@com.dtu.dk*

Interferometric cross talk is one of the biggest issues in transparent wavelength-division-multiplexing (WDM) networks, and should be overcome by either decreasing the crosstalk level from the components, or employing effective techniques to suppress its impact.[1]

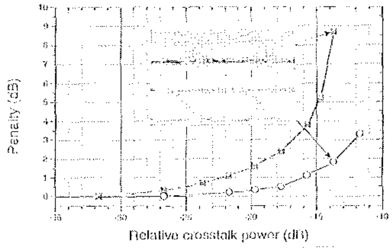
A gain-saturated laser diode amplifier has been reported to suppress cross talk, but it can't be used for high-speed signals and the output signal suffers from extinction ratio degradation and waveform distortion.[2]

In this paper, we use a gain-saturated semiconductor optical amplifier (SOA) to suppress the impact of interferometric cross talk, and show that 6 dB more cross talk can be tolerated for 1 dB penalty at 10 Gbit/s. Using polarization multiplexing of optical signals modulated by data and the complementary, impairments like waveform distortion and extinction ratio degradation are eliminated, and the method is also bit rate transparent.

Figure 1 shows the experimental setup and waveforms at different points. Light from a distributed feedback (DFB) laser is divided into two parts after being amplified by an erbium-doped fiber amplifier (EDFA). Each part is modulated by data or the complementary in an external modulator, and then set to one of two orthogonal polarization states. The two parts are combined in the polarization beam combiner (PBC). A variable fiber delay line and a variable optical attenuator are used before the PBC, in order to obtain a constant power of the combined signal without bit transition patterns. Cross talk is added to the com-



CMR1 Fig. 1. Experimental setup. 3 dB: 3-dB coupler; PC: polarization controller; Mod: Lithium Niobate modulator; VFD: variable fiber delay line; PBC: polarization beam combiner; Att: variable optical attenuator; FDL: fiber delay line; SOA: semiconductor optical amplifier; PBS: polarization beam splitter; Rx: optical receiver.

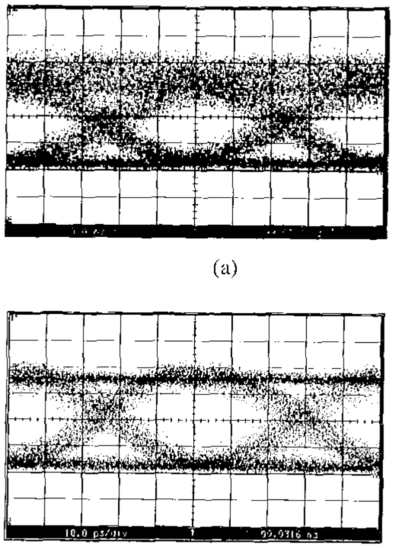


CMR1 Fig. 2. Penalty vs. relative crosstalk power with (circles) and without (squares) gain saturated SOA.

bined signal by adding a fraction of the original signal delayed by 500 m of fiber. The signal-crosstalk beat noise causes amplitude fluctuations, but these fluctuations are significantly suppressed after the SOA because of the gain saturation. The 3-dB saturation input power of the SOA is −10 dBm, and the input power into the SOA is −2 dBm in our experiment. The two orthogonally polarized signals are separated by the polarization beam splitter, and one of them is detected.

Because the SOA only experiences constant optical power of the combined signal, no waveform distortions will be generated by the SOA. Furthermore, because amplitude fluctuations are suppressed by the saturated SOA, crosstalk-induced penalty can be reduced. Figure 2 shows the penalties versus relative crosstalk power with and without the SOA; it can be seen that 6 dB more crosstalk power can be tolerated using the SOA at 1-dB penalty (BER = 10^{-9}). The inlets show eye-diagrams of the 10-Gbit/s signal before and after the SOA when −13.8 dB cross talk is introduced. A clear eye is restored after the SOA.

Because of the constant optical power in the SOA, this method is pattern independent and bit rate transparent, and there is no extinction ratio degradation. Figure 3 shows the eye-diagrams at 20 Gbit/s before and after the SOA when the relative crosstalk power is −17.8 dB; also here a clear eye can be found after the SOA. Due to lack of a 20-Gbit/s receiver, no BER curves are measured in this case.



(a)

(b)

CMR1 Fig. 3. Eye-diagrams before (a) and after (b) gain-saturated SOA at 20 Gbit/s. Relative crosstalk power is −17.8 dB.

We successfully demonstrate that the impact of interferometric cross talk can be suppressed using a saturated SOA and a polarization-multiplexing technique. The method is pattern independent and bit-rate transparent and gives no waveform distortion or extinction ratio degradation. A 6-dB higher crosstalk level can be tolerated at 1-dB penalty using this method.

1. P.J. Legg, M. Tur, I. Andonovic, "Solution paths to limit interferometric noise induced performance degradation in ASK/direct Detection lightwave networks," J. Lightwave Technol. **14**, 1943–1954 (1996).
2. K. Inoue, "Suppression of signal fluctuation induced by crosstalk light in a gain saturated laser diode amplifier," IEEE Photonics Technol. Lett. **8**, 458–460 (1996).

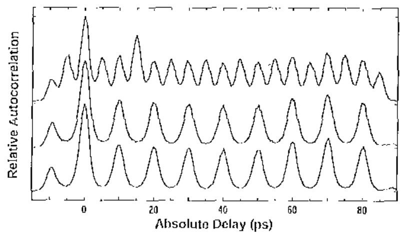
CMR2 **1:45 pm**

200-Gbit/s polarization-multiplexed transmission over 100 km of dense-dispersion-managed fiber

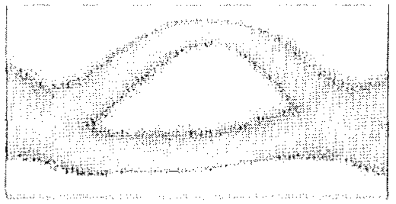
W.I. Kaechele, M.L. Dennis, T.F. Carruthers, I.N. Duling III, *Advanced Lightwave Applications Section, Code 5654, NRL, 4555 Overlook Ave., SW, Washington, D.C. 20375, USA; E-mail: kaechele@nrl.navy.mil*

High-rate time-division-multiplexed return-to-zero transmission has been demonstrated using both linear and nonlinear transmission in systems employing dispersion-shifted fiber as the transmission medium.[1,2] Dense-dispersion-managed transmission links, in which the local nonlinearity is utilized to balance the average dispersion of the system, provide another avenue for high-bit-rate communication. Theoretical studies have demonstrated the feasibility of transmitting 100 Gbit/s over distances greater than 1000 km.[3,4] Using a dense-dispersion map we have successfully transmitted an error-free 200 Gbit/s return-to-zero data stream over 100 km.

The details of the experimental configuration are described in Ref. 5. A mode-locked fiber laser capable of producing 1.5–2.5 ps soliton-like pulses served as the source of a 12.5-GHz pulse train.[6] The pulses were encoded with a pseudo-random binary sequence (2^{31}-1 bits, 1:2 mark ratio) at 1561.6 nm. The encoded stream is then split, delayed and recombined sequentially using 3-dB polarization-maintaining couplers to produce a 100-Gbit/s time-division-multiplexed data channel. To achieve an aggregate data rate of 200 Gbit/s, the 100-Gbit/s channel was multiplexed using the walkoff between the orthogonal polarization axes in high birefringence fiber. The pulse trains were delayed by one and a half bit periods to avoid nearest-neighbor interactions during transmission. The autocorrelation trace of the 200 Gbit/s pulse train at launch is illustrated in Fig. 1.



CMR2 Fig. 1. Autocorrelation traces of the 200 Gbit and the individual 100 Gbit streams. The largest peak at zero delay corresponds to the autocorrelation trace, while the large pulse at 15 ps delay in the 200 Gbit stream is the cross-correlation resulting from the polarization multiplexed delay of 1.5 bit period. Rolloff of the traces at the edges is due to the time limit of the correlator.



CMR2 Fig. 2. An error-free, received eye diagram of 2^{31}-1 bit word after transmission over 100 km.

To facilitate clock recovery, a cw signal at 1555.0 nm, modulated at the data base rate, was transmitted along with the data signal. The clock wavelength was filtered from the data using a fiber Bragg grating and optical circulator; the clock frequency was then extracted via a phase-locked loop scheme. Operation of the clock recovery was robust and provided an absolute timing reference for the received channels. The presence of the clock recovery signal necessitates the removal of all filters from the link, reducing the signal-to-noise ratio at the receiver.

The transmission span has a zero-dispersion wavelength of 1560.9 nm and an average dispersion of 0.05-ps/nm/km at the operating wavelength. The pulses are 1.8-ps full-width at half-maximum, which corresponds to a dispersion length of approximately 15 km. To overcome the deleterious dispersive effects over the total transmission distance (107 km), the output power levels of the in-line amplifiers were set to nonlinearly balance the dispersion. Optimal performance was obtained with a pulse energy of 150 fJ after amplification, which corresponds to a peak pulse power of 83 mW.

At the end of the span, the 200 Gbit/s stream is polarization demultiplexed, then time-division-demultiplexed to 12.5 Gbit/s using a $LiNbO_3$ modulator based demultiplexer.[7] The received bit error-ratio was measured to be better than 10^{-10}. A typical error-free eye pattern using a 2^{31}-1 bit word is shown in Fig. 2.

This experiment demonstrates the feasibility of using dense-dispersion management for transmitting rates as high as 200 Gbit/s over