Coherent Crosstalk of an Optical Add/Drop Filter with Bragg Gratings in a PLC Mach–Zehnder Interferometer for Optical LAN

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***Abstract*— The coherent crosstalk of an add/drop filter with Bragg gratings written in a planar lightwave circuit Mach–Zehnder interferometer is investigated experimentally and theoretically. The filter is used to design an optical local area network without any optical amplifiers, based on the coherent crosstalk limitation.**

***Index Terms*—Add/drop filter, Bragg grating, coherent crosstalk, optical LAN, planar lightwave circuit.**

I. Introduction

The combination of wavelength-division-multiplexing (WDM) link technology and optical add/drop multiplexers (OADM's) is promising as a next-generation optical network, because the WDM link increases the capacity of the network [1]. A WDM network with dynamic OADM enables the operation, administration, and maintenance to be based on optical path technology [2]. On the other hand, a WDM network with a static add/drop filter may provide a reliable, cost-effective, and scalable network, because the static OADM is based on a low-loss passive device and does not need any power supply. Therefore, the static OADM node can be applied to a backbone of local area networks (LAN's) without any optical amplifier elements, as well as to transport systems with optical amplifiers.

There are several types of static add/drop filter, such as a planar-waveguide-based Mach–Zehnder interferometer (MZI) with Bragg gratings [3], [4], fiber-based MZI with Bragg gratings [5], and, a fiber grating and circulator [6]. Among these devices, a planar lightwave circuit (PLC)-based add/drop filter together with the combination of a MZI and a photo-induced Bragg grating [7] is suitable for constructing LAN's, because the PLC add/drop filter is a low-cost device due to its simple structure and easy mass-producibility. The device may be made even more compact and cost effective by utilizing hybrid integration of the laser diode or photo detector [8].

Since low coherent crosstalk is indispensable for increasing the number of nodes [9] in a LAN, it is important to clarify the coherent crosstalk of the PLC add/drop filter. Polarization-insensitive Bragg gratings are important, because the Bragg wavelength shift due to birefringence degrades the extinction ratio of Bragg gratings and the coherent crosstalk for add/drop operation.

In this letter, we report an investigation of the coherent crosstalk of a PLC add/drop filter, that consisted of polarization-independent Bragg gratings written by 193-nm laser light, and discuss the filter's application to a LAN.

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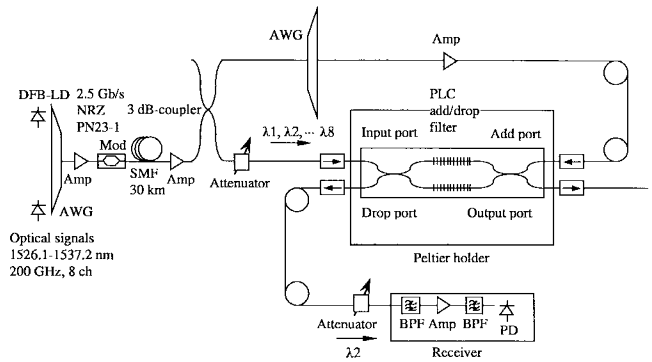

Fig. 1. Experimental setup.

II. Experimental

Polarization-independent gratings, whose Bragg wavelength was 1527.7 nm, were formed by irradiating 193-nm laser light [7], which produced identical 4-mm-long gratings on the branched waveguides of a MZI. The polarization dependence of the Bragg wavelength was below 0.05 nm. The polarization-dependent loss at the Bragg wavelength was 0.07 dB. The isolation of the Bragg gratings was 36 dB for any polarization state. The insertion loss of the fiber-pigtailed filter was 1.0 dB.

The experimental setup for measuring the bit-error-rate (BER) performance of the add/drop filter is shown in Fig. 1. The Bragg wavelength of the filter (1527.7 nm) corresponded to channel 2 in the experiment. Eight channels of WDM signals from laser diodes with 200-GHz channel separation were modulated by a $LiNbO_3$ modulator with a $2^{23}-1$ NRZ pseudorandom bit sequence at a bit rate of 2.5 Gb/s. The signals were transmitted through a 30-km single-mode fiber, which was used for bit-decorrelation, and were divided by a coupler. The main signals were led to the input port of the add/drop filter through an isolator. The added signal was simultaneously led to the add port. The input power of the

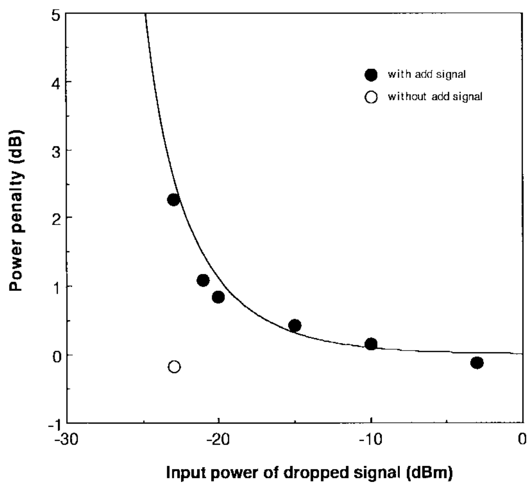

Fig. 2. Power penalty versus input power of dropped signal.

main and added signals were all −3 dBm at the connector of each fiber-pigtail of the filter. The signals from the output port, which included the main signals and the added signal, were detected by a receiver with a band pass filter through the isolator. The dropped signal was also measured with the receiver through the isolator. The BER performance was measured by optimizing the threshold of the receiver.

III. Results and Discussion

A. BER Performance

In order to investigate the condition of the input power of the add/drop operation with the filter, we measured the BER of the dropped signal by reducing its input power while simultaneously injecting an add signal at a constant power of −3 dBm. The power penalty at BER of 10^{-9} is plotted against the input power of the dropped signal in Fig. 2. The penalty was almost zero when the dropped signal input power was -3 dBm. When the input power was reduced, the penalty increased. BER of 10^{-9} was not achieved with input power of −27 dBm. In contrast, there was no penalty with input power of −23 dBm without an added signal. It is clear that the increase in penalty was due to the influence of the added signal. The degradation of BER in the filter was caused by coherent crosstalk as reported in [9] where the power penalty due to the coherent crosstalk is expressed as

$$\text{Penalty} = -10\log\left(1-\frac{\sigma_R^2 Q^2}{2}\right) \tag{1}$$

assuming an optimizing-threshold-type receiver and random polarization. Here, σ_R^2 is the power ratio between the filter's added and dropped signals, and Q is 6 for the error rate of 10^{-9}. The input power of added signal $P_{\text{add\_in}}$ (0.5 mW) and main signal $P_{\text{main\_in}}$ is given by

$$\sigma_R^2 = \frac{(P_{\text{add\_in}}/R)}{(P_{\text{main\_in}}/T)} \tag{2}$$

where the extinction ratio R and the loss T of the filter and the optical power are expressed on a linear scale.

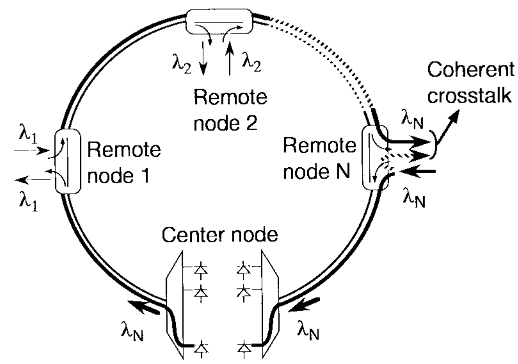

Fig. 3. Model of optical LAN.

The calculated penalty is shown in Fig. 2, using the parameters of the filter. The calculation agrees well with the experimental results. Finally, an input power of −19.6 dBm, which gives a penalty of 1 dB, was obtained as the minimum input power. Since the input power of the added signal was −3 dBm, the power ratio of the added and main signals was

$$-16.6 < 10\ \log\ \frac{P_{\text{add\_in}}}{P_{\text{main\_in}}} < 16.6. \tag{3}$$

Therefore, the input power ratio of the two signals was 33.2 dB for the add/drop operation. This input power tolerance results from the high isolation between added and dropped signals due to the polarization-independent Bragg gratings.

B. Network Design

The number of nodes and the span between neighboring nodes were designed based on the coherent crosstalk limitation. Fig. 3 shows the network model. An optical add/drop network was constructed from one center node, several remote nodes and transmission fibers. There are no optical amplifier elements such as erbium-doped fiber amplifiers in the transmission fibers, which results in a cost-effective network. The center node has signal sources, such as DFB lasers, receivers, and multiplexer/demultiplexers such as arrayed waveguide gratings. Each remote node has a Mach–Zehnder/Bragg grating PLC add/drop filter, a laser light source for the added signal, and a receiver for the dropped signal. The remote nodes can communicate with each other via the center node by using optical signals of different wavelengths, because a different wavelength is assigned to each remote node. For example, the signal wavelength of λ_1 assigned to node 1 is converted into λ_2 assigned to node 2 in the center node. For simplicity of the level diagram, the optical power of the signal light sources is 1 and −3 dBm in the center and remote nodes, respectively, when the losses of the multiplexer in the center node and that of the add/drop filter are 5 and 1 dB, respectively. This condition allows the signal levels provided to the transmission fiber from the center and remote nodes to be equal (−4 dBm). The receiver is assumed to be an optimizing-threshold-type. In this model, the number of nodes is determined by the coherent crosstalk between added and dropped signals of the filter. The minimum power level can be detected with an avalanche photo diode as a receiver.

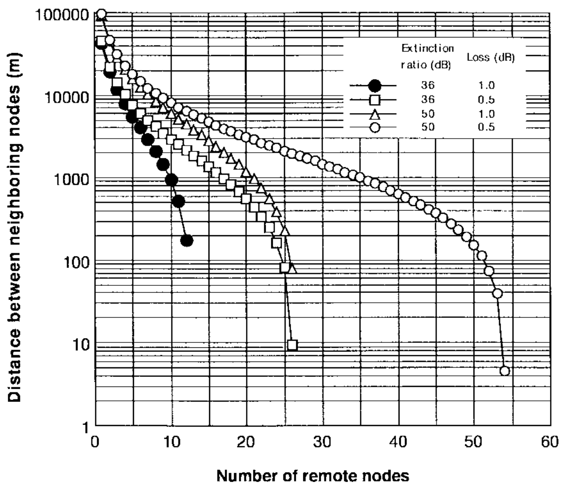

Fig. 4. Design of optical LAN.

Fig. 4 shows the calculated relationship between the number of remote nodes and the span between nodes based on the network model in Fig. 3. The span between nodes L is related to the number of remote nodes N as follows:

$$L = \frac{-\eta + 10\ \log\left(0.206\ \frac{1}{Q^2}\right) - \alpha N}{\beta(N-1)}. \tag{4}$$

Here, the extinction ratio of the filter η, the filter loss α, and the fiber loss β, is expressed on a log scale. The equation assumes, as a worst case, that the added and dropped signals in the remote node have the same polarization state in order to guarantee the network design against any polarization condition. Under the worst polarization condition, the input power ratio of the two signals is 27.2 dB. This means that the difference between the power of the added signal in the center node and the received power of 13.6 dB is allocated to the transmission fiber loss of 0.275 dB/km and remote node loss (filter loss) of 1 dB. As shown in Fig. 4, an optical signal is transported in the optical add/drop network consisting of three remote nodes with a span of 10 km, or nine remote nodes with a span of 1 km, using the Mach–Zehnder/Bragg grating PLC add/drop filter in each remote nodes. Furthermore, the number of nodes can be increased by improving the grating extinction ratio and the insertion loss of the filter, as shown in Fig. 4. An optical add/drop network having eight remote nodes with a 10-km span, or thirty-four remote nodes with a 1-km span can be constructed when the extinction ratio and the loss are improved to 50 and 0.5 dB, respectively. The extinction ratio can also be improved by writing slightly longer gratings than those used in the present experiment.

IV. Conclusion

We have designed an optical add/drop LAN using Mach–Zehnder/Bragg grating PLC add/drop filters without any optical amplifiers on the basis of coherent crosstalk limitation. The PLC add/drop filter can be used for the backbone of a WDM LAN.

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