Performance characteristics of interferometric Bragg grating based OADMs in WDM transmission systems

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Abstract: The performance of a coupler/Bragg grating interferometric OADM is studied theoretically at 40Gb/s. Employment of such filters with typically degraded spectral responses can result in at least 0.15 dB higher Eye-Opening Penalty compared to fully optimized OADMs.

OCIS codes: (060.4510) Optical Communications, (060.2340) Fiber Optics Components, (060.1810) Couplers, Switches, and Multiplexers.

1. Introduction

Wavelength Division Multiplexing is a very promising solution for the successful construction of the next generation of Broadband Optical Networks. A special class of WDM components on great demand is the Optical Add-Drop Multiplexers-Demultiplexers. To date Arrayed Waveguide Gratings (AWG or PHASARs) and Bragg Grating Based devices form two of the main classes. In the later, narrow-band reflective Bragg gratings for the wavelength selection, in conjunction with coupled waveguide structures to achieve the channel routing, have been used for the construction of four-port devices with the fundamental functions of Adding or Dropping of a particular WDM channel. This four-port device gives an essential optical processing function and can serve as building block for more complicated modules such as switch matrices. Such OADMs have been proposed and implemented in interferometric [1,2] or non-interferometric [3,4,5] waveguide structures. An OADM device which theoretically can give ideal overall performance is based on a perfectly matched Mach-Zender Interferometer (MZI) [1], but unfortunately it is very susceptible to any imbalances of the order of light wavelength (~1μm) which can severely degrade its performance. An alternative compact interferometric configuration [2] based on symmetric full (100%) couplers (SFC-OADM) with the grating placed in to the coupler waist, suggests a much more fabricationally robust and environmentally stable solution. However the grating has to be placed precisely in the correct position for optimum operation. The paper analyses the implications of the inherently non-optimum spectral characteristics of this device, in the frame of high-bit-rate WDM systems.

2. Full-Coupler-Based-OADM Principle of Operation

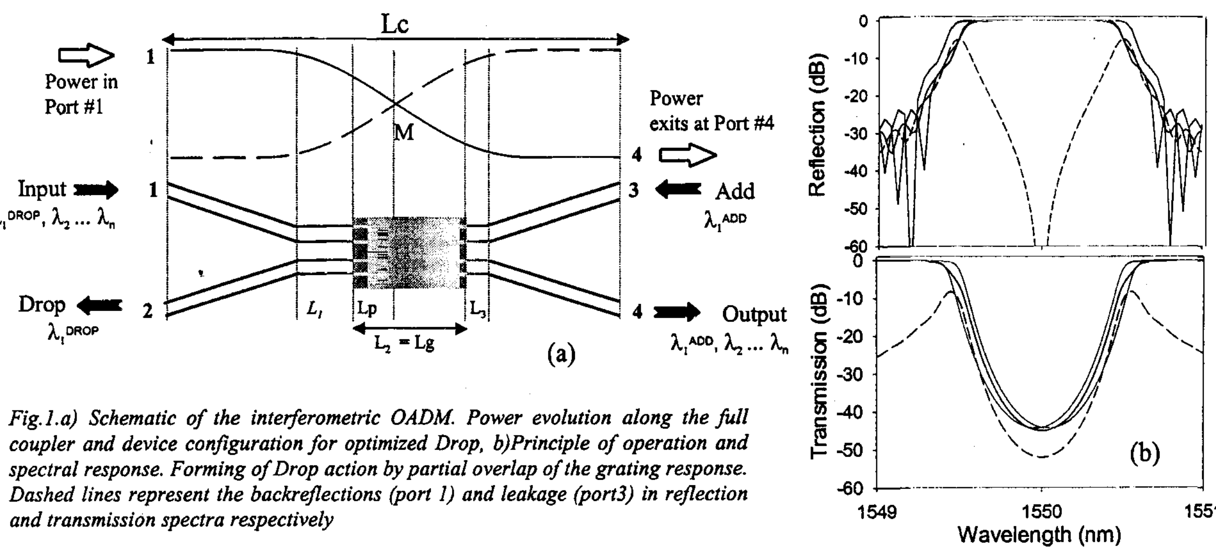

Fig.1.a) Schematic of the interferometric OADM. Power evolution along the full coupler and device configuration for optimized Drop, b)Principle of operation and spectral response. Forming of Drop action by partial overlap of the grating response. Dashed lines represent the backreflections (port 1) and leakage (port3) in reflection and transmission spectra respectively

For the optimised Drop or Add action of this OADM the grating should be placed asymmetrically in the coupler waist -taking into account its penetration depth- in order to make the reflecting point of the grating at the central operating wavelength (here 1.55μm) coincident with the 3-dB point M of the coupler. In Figure 1a the device is configured for optimised Drop action of wavelength λ_1. For this arrangement is clear that the Add action cannot be implemented optimally. By placing the grating at the centre of the coupler waist ($L_1=L_3$) the device exhibits a symmetric operation with equivalent but compromised Add and Drop actions. In the simulated device here, the waist length of the full coupler is $Lw=L_1+L_2+L_3=10$mm. The considered typical grating of reflectivity 35 dB has length $Lg=5200\mu m$, amplitude of refractive index modulation $\Delta n \sim 3.65*10^{-4}$, and Sine-apodisation profile. The penetration depth at the operating wavelength $\lambda_1=1.55\mu m$ is $Lp \sim 965\mu m$ and is taken into account for the optimum configuration of the device (Fig 1a).

Using local normal mode analysis and coupled mode theory we simulate the device response. The reflection spectra for the *optimised [O]* Drop, the *degraded [D]* Add corresponding to the optimised Drop-configuration, and the *compromised [C]* -for symmetrical grating placement- are concluded in Figure 3a. For comparison the spectral response of the employed grating (BG) is shown. Due to the partial overlap (Fig. 1b) of the even & odd normal modes by the grating the formed Drop action is slightly narrower than the grating's bandwidth.

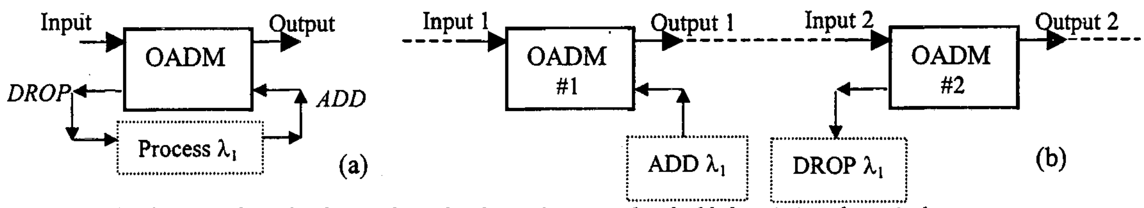

Fig. 2. a) Schematic of a node where a channel is dropped processed and added again into the optical stream.
b) Schematic of physical realization of cascaded Drop and Add actions in an optical network.

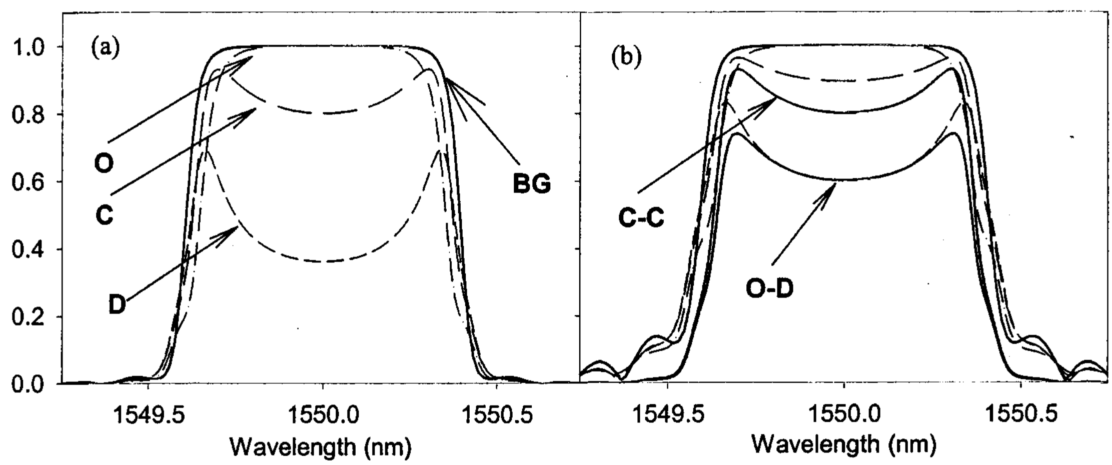

Fig. 3. a) Filters reflectivity for optimised Drop (O), degraded Add (D), compromised Add/Drop (C)
and employed Bragg grating (BG), b) Magnitude of the reflection coefficients for single passes and cascaded ADD/DROP actions.

The transfer function of the filters contain both the amplitude and phase response, but here we show only the amplitude (Figure 3b). In Figure 2a is introduced the *Drop & Add* cascaded operation for an OADM, which forms a processing node for a single channel. Figure 2b demonstrates the physical arrangement of two OADMs where their combined actions gives the fundamental *Add-and-Drop* function for a specific WDM channel in an optical network. For the aforementioned OADM we study all the possible combinations of Add and Drop actions between the two employed OADMs depending on their individual configurations and *also* the relative orientation of these modules into the network. The combinations of optimised *(O)*, degraded *(D)* and compromised *(C)* filter responses are examined in the next section regarding their performance in a high-bit-rate system. Of special interest for the characterization of a specific OADM are the *'optimised Drop & degraded Add' (O-D)* and the *'compromised Drop and Add' (CC)* and their overall response is shown in Figure 3b. We can notice that despite their different average level –which should lead to different overall insertion loss- the shape of the *(O-D)* and *(C-C)* responses are equivalent. Consequently is expected that they have identical intra-band distortion effects and this preliminary conclusion will be confirmed rigorously later using system simulations –by taking also the phase response of the filters into account-.

In this study we concentrate on the distortion effects due to the spectral shape characteristics neglecting the effect of the different insertion loss that different transfer functions can give.

3. Performance evaluation of the OADMs using communication system simulations

The quality of the spectral characteristics of an OADM is very critical in high-speed WDM systems where the dense packing of channels requires the bandwidth (BW) of these selective filters to be the minimum possible in order to accommodate the bandwidth of a modulated signal at a specific employed Bit-Rate. We study here those effects by quantifying the resulted Eye Opening Penalty (EOP) in an Intensity Modulation/Direct Detection (IM/DD)

Communication System. The simulated system is based on the SONET standards. The bandwidth of the WDM filters we modeled in the previous section is ~0.7nm and the distortion effects are examined here for the compatible NRZ modulation format and 40Gb/s transmission speed. The results obtained here could be transferred to any bit-rate and equivalent employed filters, which satisfy the same filling factor.

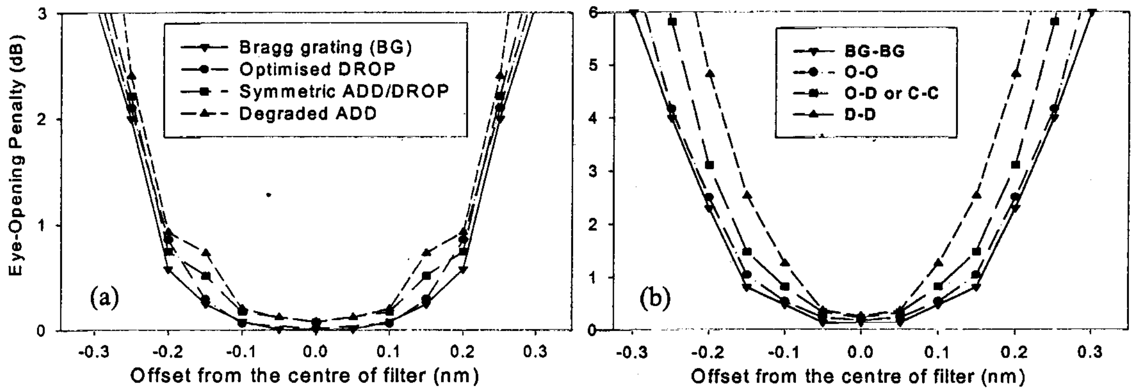

Fig. 4. a) EOP for the four different OADM responses. b) EOP for the DROP–and-ADD operations

Figure 4a gives the EOP for the three different single-pass spectral responses as a function of the signal offset from the centre of the filter. We can notice that for the misalignment range [-0.2,0.2]nm the non-optimum OADM responses leads to an EOP higher by at least 0.15dB. Figure 4b shows the EOP for the *Add-and-Drop* operation described in Figure 2. The *'optimised Drop & degraded Add' (O-D)* and the *'compromised Drop and Add' (C-C)* configurations exhibit *exactly the same EOP relation* versus the filter misalignment, as predicted from the discussion in section II. So, the overall *Drop-and-Add* operation of a particular OADM is independent of the individual responses and consequently insensitive to the grating arrangement in the coupler waist.
In a large scale network the *wrong* relative-orientation of both considered OADMs is likely to happen leading to the worst case *degraded Drop-degraded Add (DD)* operation, which suffers *considerably higher EOP.* The *optimised Drop -optimised Add (O-O)* EOP curves can be further used to compare those interferometric OADMs with another class of devices with optimised overall performance. Typical representative is the well-known bulk configuration with the two optical circulators [6], which exhibits equivalent Add and Drop actions, identical to the spectral characteristics of the employed fiber Bragg grating. We have shown recently [5] that the same superior flat-spectral characteristics can be obtained by another non-interferometric configuration based properly designed mode-converting tilted Bragg grating. Therefore the curve *(O-O)* and *(BG-BG)* in Fig. 4b could be associated with the employment of this type of fully optimized OADM. In the second case the employed single Bragg grating filter has slightly wider bandwidth leading thus to better characteristics.

4. Conclusions

We have studied the Intra-Band characteristics of the full coupler interferometric OADM in the frame of High-Bit-Rate applications in Dense WDM networks. We have shown that a typical degraded response of the full coupler based OADM exhibits an excessive EOP of 0.15 dB compared with the case of an optimised flat response. Also in the case of an *Add-and-Drop* operation the allowed range of filter misalignment in order to keep the EOP less than 1dB is almost *half* of the range, which corresponds to the employment of fully optimised OADMs

5. References

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