Applications of Bragg Gratings in Optical Amplifiers

(Invited paper)

Martin Guy[1,2], Jocelyn Lauzon[1], Martin Rochette[1,3] and François Trépanier[1,2]

[1]INO, 2740 Einstein, Sainte-Foy, Québec, Canada G1P 4S4

[2]TeraXion, 360 Franquet suite 20, Sainte-Foy, Québec, Canada, G1P 4N3

[3]COPL, Université Laval, Electrical Engineering Department, Québec, Canada, G1K 7P4

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ABSTRACT

In this paper, we show that Bragg gratings can greatly contribute to enhance the performances of today's optical amplifiers. Some of the applications of Bragg gratings in optical amplifiers such as gain equalization, gain stabilization and dispersion compensation will thus be reviewed.

1. INTRODUCTION

For the last five years, WDM communication systems have been widely deployed by a large number of long-distance carriers. This technology is now very well accepted not only to increase the transmission capacity of the fiber link but also to allow channel management and routing at the wavelength level. WDM communication systems are now migrating into metropolitan networks and this penetration could soon reach the access network.

Optical amplifiers have greatly contributed to the successful deployment of WDM systems. For one, those amplifiers allow simultaneous optical amplification of multiple channels. This greatly reduces the cost of the overall system eliminating the need to individually amplify each channels.

Bragg gratings is another technology that greatly enhances the performances of high density WDM systems. The filtering capabilities of Bragg gratings combined with its all-fiber configuration make them an ideal candidate for high channel count density components such as multiplexer/demultiplexer, optical interleaver and add/drop filter. Moreover, due to its great flexibility, Bragg gratings can also performed other functions such as spectrally-designed complex filter and dispersion compensator.

Nowadays, we can say that almost all field-deployed optical amplifiers have at least one Bragg grating built in. In fact, Bragg gratings and optical amplifiers can be gracefully combined to improve the gain and noise performances of the amplifiers and/or to increase the number of functions that an optical amplifier can performed. This paper will review some of the applications of Bragg gratings in optical amplifiers. We will limit the discussion to Bragg grating (or short-period grating) although long-period grating can also be used for numerous functions [1].

2. PUMP LASERS

The principle of operation of an optical amplifier is based on the transfer of energy from a high power pump signal to the signal carrying the information. It is thus cleared that the performances of the pump laser directly translate to the performances of the overall optical amplifier. The most commonly used optical amplifiers are the erbium-doped fiber amplifiers (EDFA) which depending on the configuration, can cover both the C-band (1530-1560 nm) and/or the L-band (1565-1620 nm). EDFAs are pumped by lasers operating at 980 or 1480 nm. Power and wavelength stability of those pump lasers are crucial for the good performances of the EDFA. One way used commercially to improve the spectral characteristics of the pump lasers is to use a low-reflectivity (1-10%) Bragg grating at a distance from the laser to avoid that the reflected signal interfere coherently with the electric field of the laser [2,3]. This stabilization technique is called coherence collapse. With this technique, the output power and wavelength stability which is dictated by the Bragg grating of the pump laser are greatly improved. Moreover, Bragg gratings stabilized pump lasers are also less affected by external reflections. Bragg grating stabilized high-power 980 nm pump modules without thermo-electric cooler have also been demonstrated [4].

In order to expand beyond the amplification window of erbium-doped fiber amplifiers, cascaded Raman amplifiers can be used. These amplifiers are based on stimulated Raman scattering which is a nonlinear process occurring in all optical fibers. In [5], a 1.3 μm Raman amplifier is obtained from a simple cascaded Raman resonator. This Raman resonator (consisting of pairs of Bragg gratings) converts the pump light at 1060 nm to signal at 1240 nm through a cascading effect; light at 1310 nm can then be amplified since a pump at 1240 nm is available.

Numerous configurations using Bragg grating for pump and/or signal reflector have also been proposed to enhance the performances of optical amplifiers [6].

3. GAIN EQUALIZATION

Flat-gain amplifiers are needed to ensure proper amplification of every channel in WDM communication systems. Such amplifiers can be realized by combining a precisely tailored filter with an EDFA. There are many gain-flattening filter technologies presently offered on the market: acousto-optic, long and short period gratings, all-fiber Mach-Zehnder, thin film dielectric filters, etc. The technology that will prove to be best should be low-cost, flexible (easy adaptation to the spectral response), made to fit as precisely as possible with the needed spectral response and not dependent on a unique technology (not dependent on a special fiber for example). Spectrally designed short period gratings (blazed and unblazed gratings) offer all those possibilities. Long period gratings can also be used to perform gain equalization [7]. However, these gratings suffer from strong temperature sensitivity and are difficult to package in an athermal passive module.

Blazed Bragg gratings used as gain flattening filters [8,9,10] have the main advantage of having a low residual back reflection level. For low enough back reflection level, this avoid the use of an optical isolator when the filter is incorporated in the amplifier. Although these gratings have shown adequate gain equalization performances, they may be difficult to reproduce in a control manner.

Gain equalization using unblazed fiber Bragg gratings (FBG) have also been successfully demonstrated [11,12]. These filters are easily reproducible in a production environment and can be easily packaged in a passive athermal module. Figure 1 [12] shows gain equalization of +/-0.3 dB when an unblazed Bragg grating used in transmission is placed in the middle of a two-stage EDFA. Moreover, in this experiment, no significant noise figure degradation was observed. For efficient operation, these type of filters are combined either with an isolator or a circulator. Since EDFAs are associated with isolators, unblazed Bragg grating technology could prove to be an optimal choice.

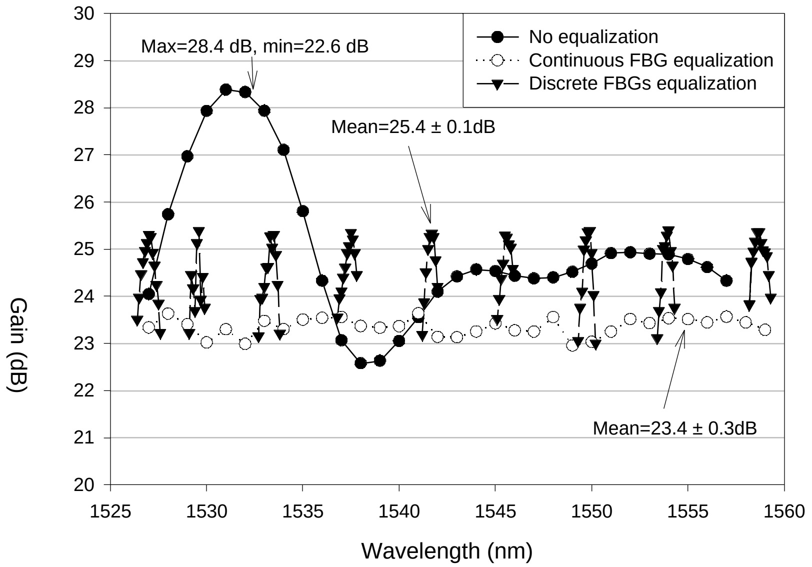

Figure 1: Gain equalization performances (with respect to the non-equalized case) for continuous and discrete FBG equalization [12].

While the previous discussion address gain equalization using a filter covering a wide bandwidth (continuous FBG equalization), gain equalization can also be performed using discrete Bragg gratings associated with each channel [13-16]. Figure 2 proposes such a configuration where the reflectivity of each Bragg grating in the mid-stage section is adjusted to perform gain equalization at the output of the amplifier [13]. Regarding output gain (25.4 dB) and flatness (±0.1 dB), the discrete filters approach gives the best performances compared to the continuous FBG equalization. All the ASE from stage 1 is rejected at port 2 with the exception of ASE reflected by the gratings. Also, back-propagating ASE from stage 2 is blocked by the optical circulator. Such processes leave more energy available for signal amplification. However, continuous FBG equalization is probably better suited when WDM system upgrade is a concern.

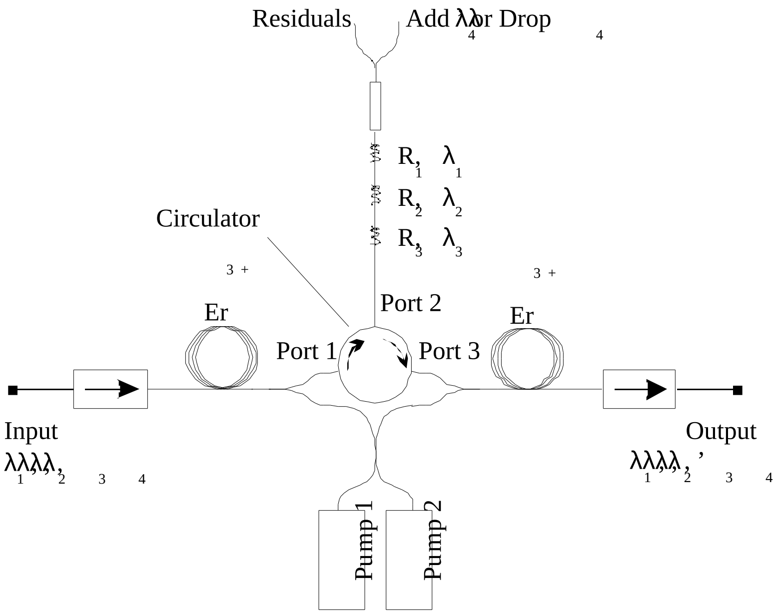

Figure 2: Proposed EDFA configuration with discrete gain equalization [13].

4. GAIN STABILIZATION

To avoid gain spectrum distortion or a variation of the obtained gain per channel value when adding or dropping channels is performed, a gain locking scheme has to be implemented. Two gain locking possibilities can be proposed: 1) gain clamping [17,18] and 2) residual pump power gain locking [19]. Gain clamping is an automatic gain control scheme; a laser channel, slightly outside the DWDM transmission window, is created by inserting spectrally overlapping Brag gratings at each end of the amplification section. This laser channel uses the excess gain available when DWDM channels are dropped. In order, for this method to be implemented efficiently, the reflectivity of the Bragg gratings has to be adjusted very precisely. The second approach uses a comparison between the pump residual power at the output of the EDFA and the pump power launched into the amplifier fiber. By keeping the ratio between these two values constant using a feedback loop, one can obtain a constant gain spectrum and gain per channel value.

5. DISPERSION AND PMD COMPENSATION

Chromatic dispersion is a predictable phenomenon for a given fiber cable and can thus be compensated. Chromatic dispersion creates a cumulative optical pulse width broadening along the fiber cable. Dispersion leads to inter-symbol interference which increases the bit error rate, thus reducing the quality of the transmission. Dispersion can be managed by using specially designed fiber cables where one can obtain zero dispersion at a specific wavelength. However, if the zero dispersion wavelength of the cable falls within the DWDM transmission window, nonlinear effects can arise and deteriorate the signal quality.

Presently, the main dispersion compensating component is known as the Dispersion Compensating Fiber (DCF). Such a fiber offers opposite dispersion compared to the transmission fiber cable and is inserted periodically along the communication link. DCF is very lossy compared to standard fiber and has a low nonlinear effect threshold.

Linearly chirped Bragg gratings have been proposed to perform dispersion compensation [20,21]. Using a circulator in combination with such dispersion compensating gratings, losses are not a major concern, neither are nonlinear effects. However, unlike DCF, dispersion compensating gratings are not yet considered a qualified practical solution and proven technology by DWDM system manufacturers. So far, the communication system manufacturers are mainly questioning the ripples in the delay curves of those gratings. However, it is known that if a perfectly apodized grating can be made, no ripples would be present on the delay curve [22]. However, delay curve ripples should also be put in a proper perspective; system demonstrations at 10 Gb/s have shown that chirped gratings with 10 ps peak-peak ripples on the delay curve gave results similar to dispersion compensating fiber [23]. Bandwidth of the gratings in the context of WDM systems may also be a concern. However, recent developments in writing techniques may soon allow the fabrication of commercial-grade long gratings operating over a large bandwidth [24,25].

Dispersion compensators based on chirped Bragg gratings can be gracefully combined with optical amplifiers [13,14]. These proposed configurations are similar to the one presented in figure 2. In that case, the Bragg gratings are chirped while keeping the reflectivities to a predetermined value in order to equalize the gain of the amplifier. In [26], such a configuration was used to compensate the dispersion of a 1895 km fiber link simulated by a recirculating loop. In addition to chromatic dispersion, chirped Bragg gratings induce deterministic PMD which can be detrimental for the overall system performances [27,28]. Although writing techniques exist to reduce the UV-induced birefringence in the gratings [29], simple PMD compensators may prove to be a better solution. The deterministic PMD found in chirped Bragg gratings can easily be compensated using another component of opposite deterministic PMD. In [26], PMD compensation of chirped Bragg grating is obtained using a short length of highly birefringent fiber. Figure 3 presents the proposed dual-stage amplifier. With this configuration, complete PMD compensation of the chirped Bragg grating was demonstrated after 25 successive reflections corresponding to a propagation distance of 1895 km in a recirculating loop.

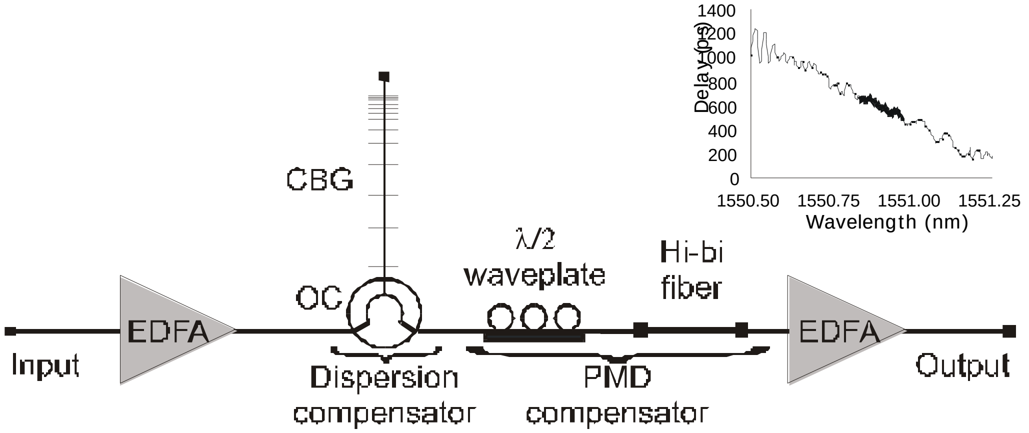

Figure 3: Dual-stage amplifier comprising a chirped Bragg grating (CBG) for chromatic dispersion compensation and its PMD compensator (λ/2 waveplate and HiBi fiber). The inset shows the delay curve of the grating. OC: Optical Circulator.

6. CONCLUSIONS

Fiber Bragg gratings technology is perfectly suited to improve the performances of optical amplifiers. This all-fiber, compact, low-cost technology with unequalled spectral filtering potential can be used to fulfill a very large number of functions such as gain equalization, gain stabilization, dispersion compensation, etc. Moreover, applications such as pump recycling [30], pump power monitoring [31] and C and L-band combiner [32] can also be fulfilled by Bragg gratings.

With the ever increasing quality of commercially available Bragg gratings, there is no doubt that Bragg gratings will keep on playing an essential role in the development of high performance optical amplifiers.

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