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GC-EDFA for a Burst Packet Mode Optical Switching System

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A two-stage gain-clamped erbium doped fiber amplifier (GC-EDFA) using a pump laser diode and a 16 channel wavelength division multiplexing (WDM) with 0.8 nm spacing in C band of 1,545 ~1,560 nm wavelength is experimentally demonstrated for a burst packet mode optical switching system.

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I. INTRODUCTION

Erbium-doped fiber amplifiers (EDFA's) have been intensively studied for wavelength-division-multiplexing (WDM). If the optional channels are added/dropped from the WDM network for the reconfiguration or partial failure of the network, the input signal power, which is transmitted to an EDFA from the WDM network, is varied, which in turn causes an undesirable power transient or output variation [1] to take place in the surviving channels. Therefore, the WDM packet mode optical switching system, where the traffic input condition is varied in a burst, is required to have an amplifier having a characteristic of amplifying the signal constantly irrespective of the transient due to any variation in some channels. A conventional EDFA would experience gain transients for the addition or deletion of one or more channels due to channel failure or burst traffic. These transients are reflected the remaining channels and may cause substantial degradation in the system's bit error rate. Transient effects as well as gain fluctuation resulting in degradation of signal quality in the surviving channel should be suppressed, and thus a gain clamping is required. This configuration is referred to as the GC-EDFA. GC-EDFA is provided with a dynamic gain and flatness control arrangement that is fast enough to ensure reliable services continuously in the surviving channels, when one or more channels are suddenly dropped or added, as may be experienced when a system reconfiguration or fault interrupts some of the channels. The conventional EDFA, which is generally used in the transmission system, is subject to the characteristic definition that the input signal traffic is kept uniform or constant, and it is, therefore, unavailable for the burst packet mode WDM optical switching system. We have demonstrated that the GC-EDFA comprising a double pump laser diode (LD) and an electrical automatic gain controller (AGC) is available for the packet mode optical switching system.

II. PROPOSED GC-EDFA

The problem of dynamic gain saturation dependent on the input power has been successfully overcome by using either optical or electronic stabilization approaches. The optical approach involves establishing lasing action at a desired wavelength to clamp the amplifier's average population inversion. But degradation may occur owing to the relaxation oscillations in the laser [2]. In the electrical control approach, a probe signal is launched to the input through a low splitting ratio coupler, the optical gain is controlled by adjusting the pump power while monitoring the output power of a probe signal through a low splitting ratio coupler at a fixed wavelength and input power. This configuration is referred to as the pump controlled EDFA. A fast pump control EDFA basis rather than dummy link basis does not increase the complexity of the network's EDFA and is simple, less expensive, and well suited to the packet switching system.

Recently, a fast pump control method has become available to limit the power excursions of surviving channels against fast power transients. For the packet mode switching system, a fast pump control circuit in an EDFA with several μs of response time was required to maintain the constant power. In the conventional electronic gain control approach, the optical gain is controlled by adjusting the pump power while monitoring the output power of a probe signal at a fixed wavelength and input power through a two stage pump laser control [3].

In this paper, we proposed and demonstrate a new scheme to protect surviving channels by controlling the pump power while monitoring the total input power and the total output power. And we experimentally investigated the power transient of the GC-EDFA and demonstrated the feasibility of the proposed scheme.

Fig. 1 is a block diagram of the proposed gain-clamped EDFA. To achieve both a low noise figure and a high pump efficiency, it has been recognized that the use of a two stage configuration has been advantageous. The GC-EDFA removes 1,530~1,544 nm band by using the amplified spontaneous emission (ASE) filter, and uses 1,545~1,560 nm band for the purpose of designing 16 WDM channels with a wavelength spacing of 0.8 nm in the C band. The maximum strength of the entire input signal in the GC-EDFA is -4 dBm, and the power per channel for 10^{-12} BER (bit error rate) is equivalent to -16 dBm. The GC-EDFA represents a case where the gain is saturated at 20 dB. In this case, during the input, power is varied in the range of -4 dBm to -19 dBm, the gain is maintained at 20±0.5 dB in the gain band of 15 nm without any variation in the gain spectrum in the C band of 1,545~1,560 nm, and a very flattened gain spectrum of 1~1.2 dB is realized. After tapping the optical signal by using two tap couplers of 95:5 and 99:1 at the input and the output end of the EDFA, respectively, the data monitored through the input monitor PD and the output monitor PD are transmitted to the micro-controller to control the output of the 980 nm pump LD. The input optical signal of the GC-EDFA and the pumping optical signal of the 980 nm pump LD are combined through the WDM with the optical isolator attached thereto, and further are amplified through the EDF.

Fig. 2 illustrates the output spectra of the GC-EDFA depending on the input power. As shown in the figure, we can see that the GC-EDFA has a uniform gain of 20 dB even though the input power is varied from -19 dBm to -4 dBm.

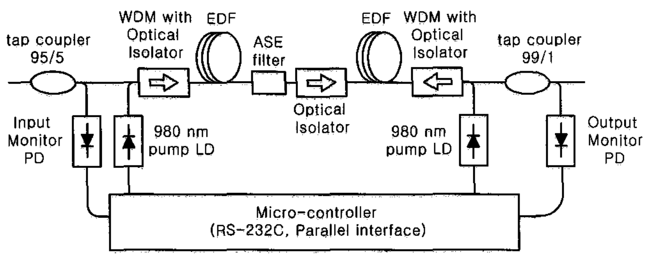

FIG. 1. Structure of two-stage GC-EDFA using a pump power control method

III. EXPERIMENTAL SETUP

Fig. 3 describes the experimental setup for measuring the dynamic eye pattern and any power transient occurring in other survival channels in case some channels are dropped when the GC-EDFA transmits an optical signal having 16 channels of a uniform size at an interval of 0.8 nm (100 GHz) in the wavelength area of 15 nm from 1,545 nm to 1,560 nm. A distributed feedback laser diode (DFB-LD) having 2 wavelengths of λ_1 = 1,545 nm and λ_2 = 1,555 nm were used as a light source, and any channel in the network was added/dropped by using acousto optic modulators. We can obtain the eye pattern on the oscilloscope by supplying external modulated data of the 2.5 Gbps using the pulse pattern generator (PPG) at the stage following the DFB-LD 1. In case 15 channels are dropped in the 16 channels WDM networks, and in order to measure the power transient of such one operating channel, the power value of one channel was assigned to the DFB-LD 1, the operating channel, while the power value of other 15 channels was applied to the DFB-LD 2. The two light sources were coupled by using a 3 dB coupler. Then, any output port was connected with the GC-EDFA to amplify the signal,

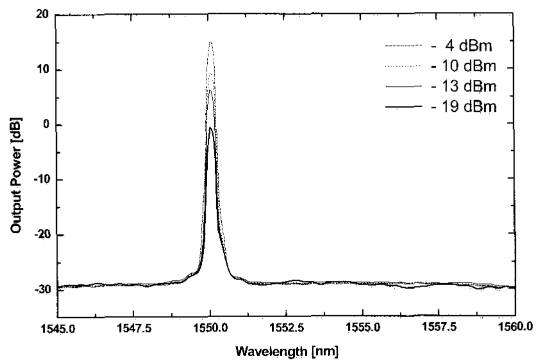

FIG. 2. Output spectra according to the input power

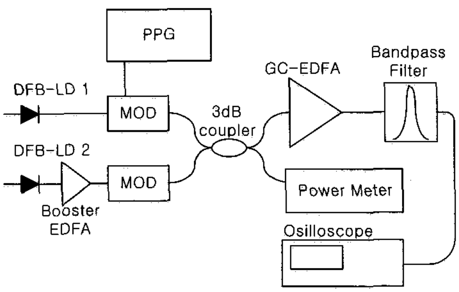

FIG. 3. Experimental setup

and in order to measure the power transient of the operating channel, an optical bandpass filter having

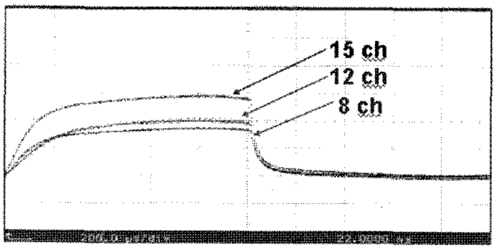

FIG. 4 (a). Power transient characteristics of GC-EDFA due to variation in channel; in case of 500 Hz modulation frequency when 8 ch's, 12 ch's and 15 ch's are dropped

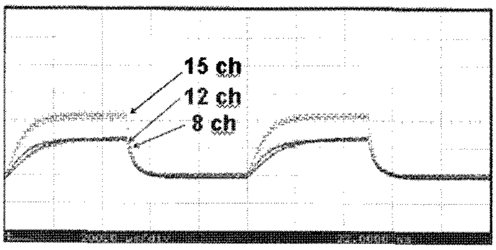

FIG. 4 (b). Power transient characteristics of GC-EDFA due to variation in channel; in case of 1 kHz modulation frequency when 8 ch's, 12 ch's and 15 ch's are dropped

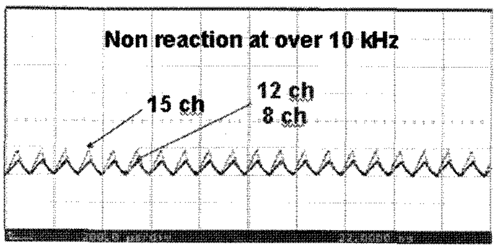

FIG. 4 (c). Power transient characteristics of GC0-EDFA due to variation in channel; in case of 10 kHz modulation frequency when 8 ch's, 12 ch's and 15 ch's are dropped

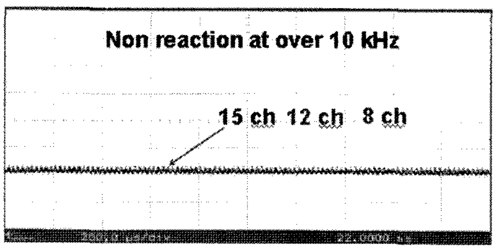

FIG. 4 (d). Power transient characteristics of GC-EDFA due to variation in channel; in case of 50 kHz modulation frequency when 8 ch's, 12 ch's and 15 ch's are dropped

the center wavelength of 1545 nm to transmit was used and it was measured with a sampling oscilloscope (30 GHz), while in the other output port, the input power to the GC-EDFA was measured by using an optical power meter. In order to measure the power transient taking place in the other operating channel under the worst case, we considered that 15 channels of all 16 channels were dropped and it was modulated with the square wave (~5 MHz) from the AOM. Thereby, the power transient of the operating channel was measured.

IV. RESULTS AND DISCUSSION

Fig. 4 and Fig. 5 show the power transient characteristics occurring in the survival channels after the power pass through the GC-EDFA. Fig. 4 depicts the power transient occurring in the survival channels when 8 channels, 12 channels and 15 channels of all 16 channels are dropped respectively. The modulation frequencies of AOM are 500 Hz, 1 kHz, 10 kHz and 50 kHz. As shown in this figure, we can see that the more channels that are dropped, the larger the power transient. Fig. 5 depicts the power transient occurring in the survival channels depending upon respective

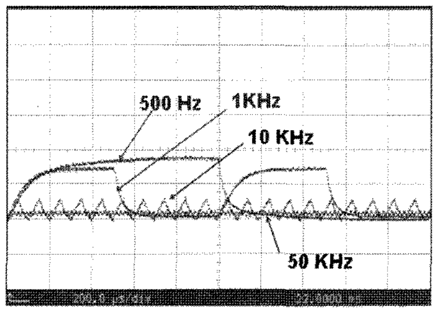

FIG. 5 (a). Power transient characteristics of GC-EDFA due to variation in frequency under the worst case; in case of 500 Hz, 1 kHz, 10 kHz and 50 kHz modulation frequency when 8 ch's are dropped

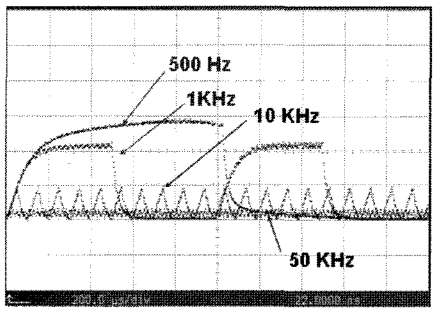

FIG. 5 (b). Power transient characteristics of GC-EDFA due to variation in frequency under the worst case; in case of 500 Hz, 1 kHz, 10 kHz and 50 kHz modulation frequency when 15 ch's are dropped variations of the modulation frequency to 500 Hz, 1 kHz, 10 kHz and 50 kHz. We considered the worst cases that the 8, 15 channels of all 16 channels are dropped. As shown in the figure, we can see that the higher the modulation frequency is, that is, the faster add and drop of channels occurred, the slower the response time of EDF is, and consequently, the power transient becomes gradually smaller.

The characteristics as shown in Fig. 4 and Fig. 5 illustrate that the GC-EDFA used in the experiment determined a speed that is required for protecting the operating channel through such characteristics and further responded to the input signal up to about 10 kHz. And, since the EDFA has slow dynamics (several 10 ms lifetime), for the input power was modulated at 10 kHz or over (below 100 μs), an infinitesimal power transient took place. In this case, the inter-optical packet spacing (the responding speed of a driver) needs to be faster than 100 μs. Fig. 6 (a) and Fig. 6 (b) illustrate the dynamic eye pattern obtained from 2.5 Gbps data that are supplied from Gbps PPG of experimental setup shown in Fig. 2. The measurements of dynamic characteristic were repeatedly carried out at 5 Hz, 50 Hz, 500 Hz, 10 kHz and 50 kHz while 1 channel, 8 channels and 15 channels of all 16 channels were dropped.

The characteristics as shown in Fig. 6 (a) illustrate that Power transient characteristics of GC-EDFA due to variation in channel under the 1 kHz modulation frequency when 8 ch's, 15 ch's are dropped. The characteristics as shown in Fig. 6 (b) illustrate that Power transient characteristics of GC-EDFA due to variation in frequency under the 500 Hz, 1 kHz and 10 kHz modulation frequency when 15 ch's is dropped.

Fig. 7 (a), Fig. 7 (b), Fig. 7 (c), Fig. 7 (d), and Fig. 7 (e) depict the power transient measured in case of 1 channel of all 16 channels at 5 Hz and 8 channels of all 16 channels at 10 kHz, respectively. From these test results, we found clamping frequency of the GC-EDFA was less than 5 Hz, and the reaction frequency of GC-EDFA was greater than 10 kHz. We can see that for modulation frequency below 5 Hz, the power transient never occurs in survival channels because the response time of the operating circuit for the gain clamping of this GC-EDFA is 200 ms. However, we also can see that if the modulation frequency is over 5 Hz,

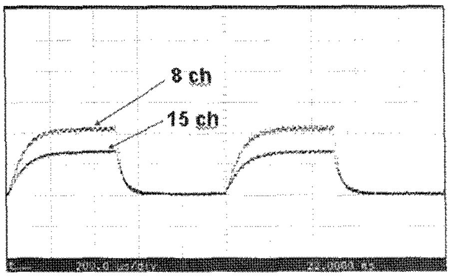

FIG. 6 (a). Power transient characteristics of GC-EDFA due to variation in channel under the 1 kHz modulation frequency when 8 ch's, 15 ch's are dropped

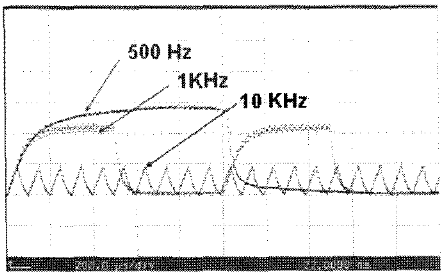

FIG. 6 (b). Power transient characteristics of GC-EDFA due to variation in frequency under the 500 Hz, 1 kHz and 10 kHz modulation frequency when 15 ch's is dropped

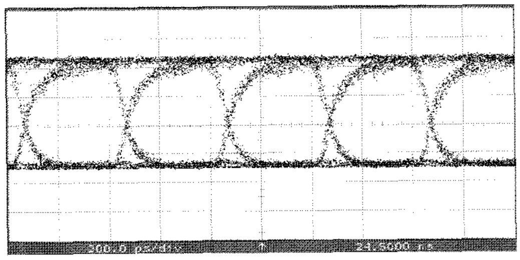

FIG. 7 (a). Dynamic eye at 2.5 Gbps data, when 1 ch of all 16 ch's is dropped with 5 Hz modulation frequency

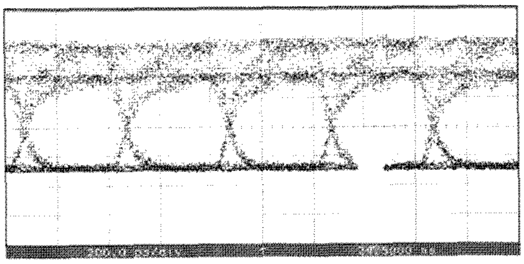

FIG. 7 (b). Dynamic eye at 2.5 Gbps data, when 1 ch of all 16 ch's is dropped with 500 Hz modulation frequency

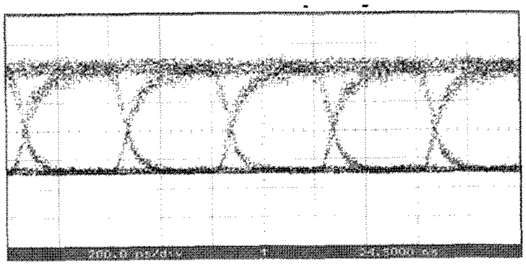

FIG. 7 (c). Dynamic eye at 2.5 Gbps data, when 1 ch of all 16 ch's is dropped with 10 kHz modulation frequency

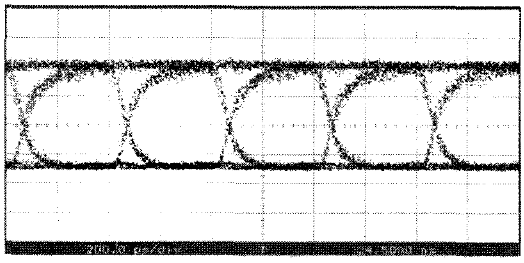

FIG. 7 (d). Dynamic eye at 2.5 Gbps data, when 1 ch of all 16 ch's is dropped with 50 kHz modulation frequency

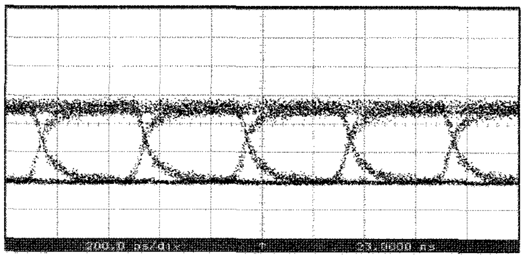

FIG. 7 (e). Dynamic eye at 2.5 Gbps data, when 8 ch's of all 16 ch's are dropped with 10 kHz modulation frequency

the power transient occurs in the upper part of the eye pattern because the GC-EDFA fails to clamp any gain. Further, we can see that the modulation frequency is 10 kHz and 50 kHz respectively, channels are inserted and extracted fast, that is, the reaction time of EDF is slow, and consequently, the power transient does not occur. Through Fig. 6 (a) and Fig. 6 (b), we can see that the fast the modulation frequency is, i.e., the fast add and drop of channels occurred, the response time of EDF becomes slow, and consequently, the power transient does not occur.

V. CONCLUSION

We have newly designed a gain-clamped EDFA for providing a uniform gain across 16 WDM channels at an intervals of 0.8 nm (100 GHz) in the C band range from 1545 nm to 1560 nm using the two stage pump power control method. An experimental setup has been configured to measure the power transient of the GC-EDFA, and the use of the AOM has been to take the effect of insertion and extraction of channels. This experimental setup has confirmed that the EDFA adopting the pump power control method have been available for the optical packet switch system. We demonstrated that GC-EDFA overcomes the output variation and the power transient impact resulting from the added/dropped channels, and further had a characteristic of maintaining the optical signal amplification gain uniformly under the burst mode packet traffic, and therefore, it is available for the burst packet mode optical switching system. We have confirmed the feasibility of the GC-EDFA to the packet switching system through the dynamic eye pattern, which was demonstrated at 2.5 Gbps optical data signal in WDM network. GC-EDFA is also suitable for multiwavelength networks using the internet packet (IP) or packet switching. A further study is being conducted for embodying a pump power driver with a high-speed response time of 100 μs or over to a high-speed power transient. The WDM burst packet mode GC-EDFA with the aforementioned characteristics would be available for the packet switching system and the IP-based system as well.

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REFERENCES

[1] S. Y. Park, *et al.*, "Doped fibre length and pump power of gain-flattened EDFAs," *IEEE Electron Lett.*, vol. 32, 1996, pp. 2161-2162.

[2] G. Luo, *et al.*, "Experimental and Theoretical Analysis of Relaxation-Oscillations and Spectral Hole Burning in All-Optical Gain-Clamped EDFA's for WDM Networks," *IEEE J. Lightwave Technol*, vol. 16, 1998, pp. 527-533.

[3] A. K. Srivastava, *et al.*, "Fast-Link Control Protection of Surviving Channels in Multiwavelength Optical Networks," *IEEE Photon Technol Lett.*, vol. 9, 1997, pp. 1667-1669.