90-nm Wideband Optical Amplifier Including an Semiconductor Optical Amplifier and a DCF-based Raman Fiber Amplifier with Gain Clamping and Dispersion Compensation

Chia-Hsiung Chang [1] **Hermann Lin** [2]

Department of Electronics Engineering and Computer Science, Tung-Fang Institute of Technology, Kaohsiung, 829, Taiwan[1]

Information & Communication Engineering Department, National Kaohsiung Normal University, Kaohsiung, 802, Taiwan[2]

bongioviochang@yahoo.com.tw[1]

Abstract

A 90-nm wideband (1500-1590nm) optical amplifier consisting of a dispersion-compensated-fiber-based Raman fiber amplifier and a semiconductor optical amplifier with gain clamping and dispersion compensation is demonstrated for wide bandwidth amplification with gain flatness as well as dispersion compensation. 10Gb/s DWDM transmission over 100-km conventional single-mode fiber link with low bit-error-rate power penalty of 0.4 dB is achieved for such gain-clamped amplifier with a lasing light at 1508 nm, which suppresses the cross-gain modulation effect of the used SOA. This amplifier will play an important role in metropolitan area network (MAN) for high speed and broadband delivery between city interconnection.

Keywords**:** *Optical Amplifier, DWDM, Raman Amplifier, Semiconductor Optical Amplifier.*

1. Introduction

The wideband optical amplifier through the combination of Raman amplifier (RA) and erbium-doped fiber amplifier (EDFA's) as well as parallel configurations for the three gain-bands of the EDFA's have been intensively studied for increasing the long-haul transmission capacity in the 1.5-1.6 μm region [1]-[2]. On the other hand, the semiconductor optical amplifier (SOA) is promising for in-line amplification of DWDM transmission [3]-[4]. However, those experiments have not yet utilized the full gain bandwidth of the SOA to effectively satisfy the urgent need of bandwidth for future metropolitan area network.

1.1 Experimental Setup:

Fig. 1 shows the experimental setup. The proposed dispersion-compensated gain-clamped wideband amplifier includes three parts: an RA, an SOA, and the gain-clamped ring cavity. The RA using a 15-km dispersion compensation fiber (DCF), which is pumped by four 1.48 μm pump LDs through a 1.48/1.55-μm WDM coupler, simultaneously achieves Raman amplification and dispersion compensation of the DWDM channels. The counter-clockwise gain-clamped ring cavity is composed of one 70/30% and 95/5% coupler, an optical isolator, and an optical bandpass filter (OBPF). The OBPF with 20-dB down bandwidth of 4.5 nm is used to choose the lasing wavelength (λ_c) for gain clamping operation separately at 1508 nm or 1565 nm. The 15-km DCF (Lucent Technologies Type: DK-80) has a dispersion of –1369 ps/nm, and a loss of 8 dB at 1550 nm. Four pumping LDs with wavelengths of 1460, 1470, 1480, and 1490 nm, combined together by a coarse WDM coupler, are adjusted to provide a total input power of

250 mW to launch into the DCF. The bi-directional SOA (without built-in optical isolators) is a bulk-tensile InGaAsP device with a gain peak at 1520 nm and has a very wide gain spectrum, which allows operation at 1500-1560 nm. The polarization dependence of optical gain and the noise figure are less than 1.5 and 8 dB, respectively, and the saturation output power is approximately +13.3 dBm.

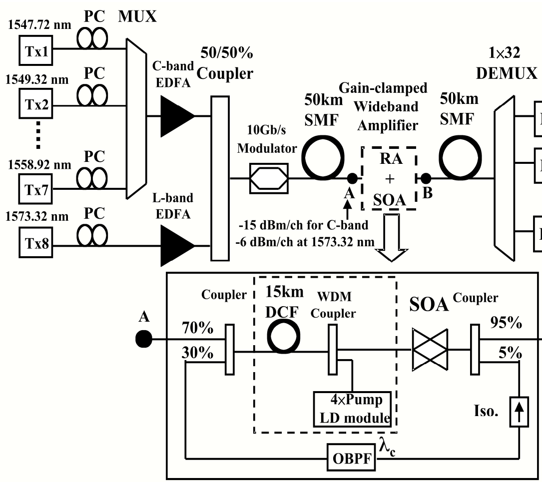

Fig. 1: Experimental setup.

The first transmitter set is composed of seven DFB laser diodes in ITU grid, spaced by 200 GHz in the wavelength range 1547-1559 nm, and amplified simultaneously by a C-band (1530-1560 nm) EDFA to compensate for the component loss. The second transmitter set is composed of only one external cavity laser with central wavelength of 1573.32 nm and amplified by an L-band (1565-1600 nm) EDFA, which acted as a saturation tone with an output power equivalent to the total output power. All channels are combined through a 50/50% coupler, and modulated simultaneously by a $LiNbO_3$ modulator with a pseudo-random bit sequence (PRBS) of length 2^{31}-1 NRZ at 10Gb/s. The signals are transmitted over two 50-km SMF spans, in which the proposed gain-clamped wideband amplifier is located in the middle position to compensate the link loss. The 200 GHz spaced optical demultiplexer (1×32 DEMUX) has a 3-dB bandwidth of 0.8 nm, an insertion loss of 2.5 dB, and an adjacent channel isolation of > 45 dB. At receiving end, each PINFET receiver (Rx) with a sensitivity of –17.5 dBm at a BER of 1×10^{-9} is used.

1.2 Results and Discussions:

Fig. 2(a) shows the gain spectra of Raman amplifier, SOA, the combination of both Raman amplifier and SOA (hereafter, the non-GC amp.), and the gain-clamped (GC) wideband amplifier (hereafter, the GC-amp.). The signal channel power launched into the Raman amplifier was –15.0 dBm/ch. The Raman gain curve has a gain peak of 17 dB at 1580 nm. The SOA was driven into gain saturation operation to yield a gain of > 20 dB in 1500-1560 nm region. The gain bandwidth of both of the non-GC amp. and the GC-amp. is almost the same with a wide bandwidth of 90 nm from 1500 to 1590 nm. The optical gain of the non-GC and GC amplifiers is ≥ 28 dB and ≥ 18 dB, respectively. Fig. 2(b) also shows the gain and noise figure comparison between the non-GC amp. and the GC-amp. case with the measured wavelength (λ_s) at 1550 nm. The gain spectrum of the non-GC amp. will be saturated while a high input power was launched. However, the optical gain of the GC-amp. with lasing light λ_c at 1508 nm keeps ≥ 17 dB while the input power was launched from –20 to +2 dBm. Noise figures for the non-GC amp. and the GC amp. were measured about 7~8 dB.

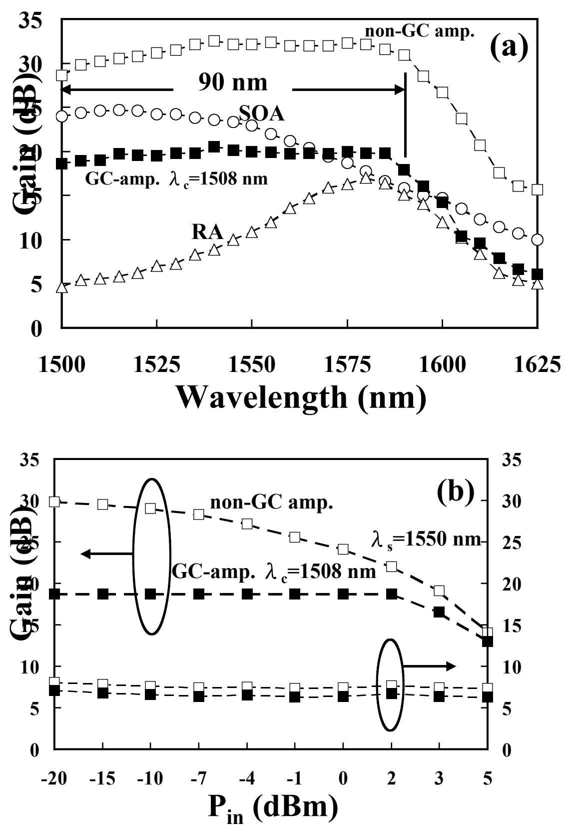

Fig. 2: (a) Gain spectra of SOA, Raman amplifier (RA), non-gain-clamped amplifier (SOA+RA: non-GC amp.), and gain-clamped amplifier (GC-amp.), and (b) optical gain and noise figure characteristics of non-GC amp. and GC-amp. as a function of input power.

The measured BER performance of this 100-km SMF link is shown in Fig. 3. The power penalty of the system with non-GC amp. case (indicated as ○) compared with the baseline case (indicated as ×) was 2.0 dB at a BER of 10^{-9}. Such power penalty is attributed to the cross-gain modulation (XGM) effect of the used SOA [5]. For the gain-clamped lasing wavelength at 1508 nm or 1565 nm, the BER performance of seven signal channels in 1547-1559 nm and the saturation-tone channel at 1573.32 nm were then measured. The power penalty of the system using the GC-amp. with lasing lights at 1508 nm or 1565 nm is 0.4 or 0.9 dB as compared with the baseline case. The improvement of power penalty is about 1.6 dB for the system using the GC-amp. with lasing light at 1508 nm. This is due to the suppression of XGM effect by injecting an extra wavelength (i.e., the 1508-nm lasing light) in the SOA.

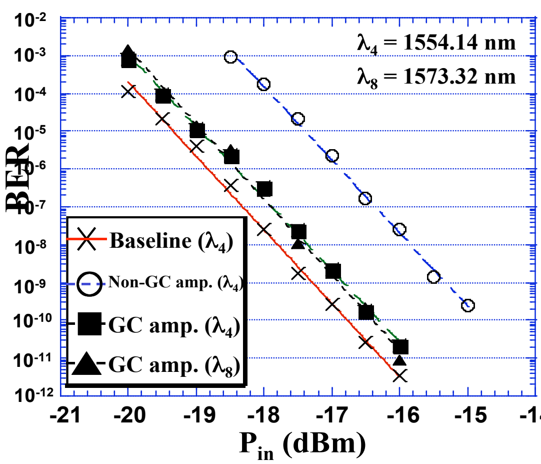

Fig. 3: The measured bit-error-rate curves after 100-km SMF transmission.

1.3 Conclusions:

We have experimentally demonstrated the gain-clamped wideband optical amplifier using a DCF-based Raman amplifier and an semiconductor optical amplifier for 90-nm wide bandwidth amplification with good gain flatness (of 3 dB) as well as dispersion compensation of 10Gb/s DWDM signals over 100-km SMF link. The power penalty of 0.4 dB for the gain-clamped amplifier with lasing light at 1508 nm has been achieved as compared with the non-gain-clamped amplifier case. Such gain-clamped light within the SOA suppresses the cross-gain modulation (XGM) effect of the SOA and therefore the XGM-induced power penalty dramatically reduced. This amplifier may play an important role in MAN for high speed and broadband delivery between city interconnection.

2. References

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