Comparative study of all Optical Amplifiers

Prince Jain, Neena Gupta

Abstract— All Optical Systems exploiting Dense Wavelength Division Multiplexing Systems (DWDMs) have emerged through implementation of optical amplifiers. The performance of DWDM system is enhanced throgh Optical Amplifier. In this review paper several optical amplifiers have been discussed that are suitable for the low-cost, high performance applications of DWDM systems. The different amplifiers, such as Erbium Doped Fiber Amplifiers (EDFA), Raman amplifiers (RA), Semiconductor Optical Amplifier (SOA), Ytterbium Doped Fiber Amplifier (YDFA), Erbium Ytterbium Co-Doped Fiber Amplifier (EYCDFA) and Thulium Doped Fiber Amplifier (TDFA) have different properties that make them suitable for a variety of applications and their advantages can be integrated to improve the performance of all optical systems.

Index Terms— Optical Communication System, EDFA, EYCDFA, RA, SOA, TDFA, YDFA.

1 INTRODUCTION

Long distance (>100km) transmission of signal needs to compensate the attenuation losses with in fiber. In past this was done with an Opto-Electronic module, consists of an optical transmitter(laser), regeneration(repeater) system, equalization system, and an optical receiver(photo diode). Elimination of EO(Electronic to Optical) and OE(Optical to Electronic) conversions and to oppose attenuation and dispersion effects, optical fiber amplifiers(OFA's) are used [1].

Use of OFA's into the system causes additional problems, such as, Amplified Spontaneous Emission (ASE) noise and ASE noise accumulates as the number of OFA's in the signal path increases. The Range of optical fibers is really great if the all the wavelength bands: S-band (short 1460-1530 nm), C-band (central 1530-1565nm), and L-band (long 1565-1625 nm) are utilized efficiently. Hence optical fiber amplifiers must be used to amplify the signal along the fiber and OFAs needs High Gain which provides good amplification of the signal and high optical power which provides long transmission distance with less distorted signal.

OFAs have found many applications ranging from ultra-long undersea links to short links in access networks and these applications involve:

Pre-amplifier: This is used before the photo detector at the receiver end to boosts signal power in to receiver. Pre-amplifier typically has high gain (~30 dB), and have a low NF in the range of 4-5.5 dB, in order to give error-free detection of the signal channels.

Post-amplifier: This is used after the source at the transmitting end to boost its power. Post amplifier should provide low gain (in the range of 5-15 dB) and high output power (~20dBm).

In-line amplifier: This is used as a repeater to provide optical amplification for optical amplification in intervals (approx. 70 km). In-line amplifiers typically have moderate gain in the range of 15-25 dB, NF in the range of 5-7 dB and high output power (~20dBm).

- *Prince Jain is currently pursuing masters degree program in electronics and communication engineering in PEC University of Technology, Chandigarh, India, PH-09649787014. E-mail: princejain.rajjain@gmail.com*
- *Neena Gupta is currentlyHead & Prof. of ECE Deptt. in PEC University of Technology, Chandigarh, India, PH-09815503245. E-mail: ng65@rediffmail.com*

2 OPTICAL AMPLIFIERS

The optical amplifiers that find widespread use in optical networks can be classified into six main categories:

- Erbium Doped Fiber Amplifier (EDFA)
- Raman Amplifier (RA)
- Semiconductor Optical Amplifier (SOA)
- Ytterbium Doped Fiber Amplifier(YDFA)
- Erbium Ytterbium Co-Doped Fiber Amplifier(EYCDFA)
- Thulium Doped Fiber Amplifier(TDFA)

2.1 Erbium Doped Fiber Amplifier (EDFA)

EDFA avoids cross-gain saturation and provides amplification of individual channels in WDM systems. In silica fibers, spontaneous carrier lifetime is relatively long and this allows achieving high gain for a weak signal with low NF. Due to low NF the difference in signal-noise ratio at the input and output of the device under consideration. This is the main reason why EDFAs are so popular in optical amplification field.

EDFAs are also insensitive to polarization and have negligible noise for inter channel cross talk and has minimum coupling losses with requirement of lesser pump power. EDFA allow high bit rate transmission over long distances. It has a broad peak with a lower centered at 1550nm and a narrow high gain peak at 1532nm and owing to their versatility, high pumping efficiency, useful gain bandwidth and low intrinsic noise.

Electrons from Ground state [E1] are excited to higher energy level [E3] by pump laser signal as shown in Fig. 1. Excited state [E3] is not stable and Er ions dropped to meta-stable [E2] via radiation less decay process(i.e. no phonon is released)[3].

International Journal of Scientific & Engineering Research Volume 5, Issue 11, November-2014
ISSN 2229-5518

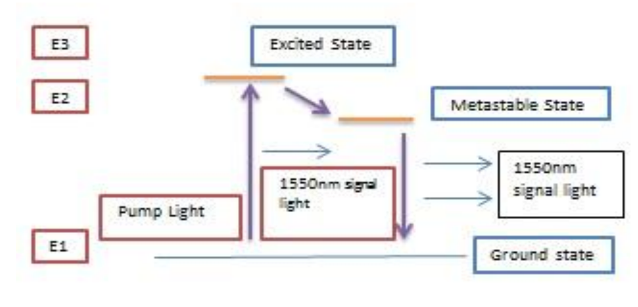

Fig. 1. Energy Level Diagram of Er^{3+}[3].

TABLE 1
COMPARATIVE ANALYSIS FOR EDFA

S.No.	Paper Name	Techniques used	Gain	Noise Figure
1.	Performance analysis of EDFA for DWDM system[3]	Input channel power, channel spacing, EDFA length and Concentration.	34±3.5dB	~7.4 dB
2.	Gain Flatness of EDFA in WDM Systems[4]	Fiber length and pump power	24±0.3dB	<6dB
3.	Analysis of Wide-Band Flat-Gain Amplifier Utilizing High Concentration of EDFA[5]	Er concentration and wavelength with input signal power, pump power and Er length	22±3dB	4dB-7.5dB

2.2 Raman Amplifier

In a Raman amplifier, the signal is amplified by a process called stimulated Raman scattering (SRS), in which light is scattered by atoms from a lower wavelength to a higher wavelength. When sufficient pump power is present at a lower wavelength, stimulated scattering can happen in which a signal with a higher wavelength is amplified by Raman scattering from the pump signal. SRS is a nonlinear interaction between the signal (higher wavelength) and the pump (lower wavelength) and can take place within any optical fiber. The efficiency of the SRS process is low in most fibers, meaning that high pump power (typically >1 W) is required to obtain useful signal gain, so in most cases Raman amplifiers cannot compete effectively with EDFAs.

The main advantage of Raman amplifier is that its gain spectrum is very wide (upto 10 nm), and its shape can be changed by varying the number of pumps and their pump wavelengths and it also has relatively low NF making it more efficient. These two aspects make Raman amplifiers the main component of optical systems, as they can be used to broadening and equalizing the gain spectrum of a particular amplifier, with addition of very little noise to the amplified signal. They can be combined with EDFAs to expand optical gain flattened bandwidth.

Disadvantages of Raman amplifiers are the pumping efficiency at lower signal power is poor, and the use of costly high power lasers capable of delivering great powers into single-mode fibers. RAs are also preferable due to negligible noise, negligible coupling loss and inter-channel cross talk makes more efficient for DWDM.

Basically two types of Raman amplifiers as given below:

Distributed Raman amplifier (DRA) is one in which the transmission fiber is utilized as the gain medium by multiplexing a pump wavelength with signal wavelength and generally length of fiber is longer(~100 km).

Discrete Raman amplifier utilizes a dedicated, shorter length of fiber (~20km) to provide amplification, reason for reduced length is highly non linear fiber with a small core is used to increase the interaction between signal and pump wavelengths.

TABLE 2
COMPARATIVE ANALYSIS FOR RAMAN AMPLIFIER

S.No.	Paper Name	Technique Used	Gain	Noise Figure
1.	Transient effects in gain clamped discrete RA cascades [6]	Channels drop/add	20dB	Less than 4dB
2.	Investigation on multipump fiber RAs on WDM in OCS[7]	1 to 7 pumps are used	Gain ripple decreases 0.87-0.42 dB	-
3.	Analysis and investigation of NF of FRA [8]	ASE and 2nd order is used	15-30 dB	2.3-3.6 dB
4.	Reduction of noise in fiber optic RA [9]	Channel and fiber length	-	NF decreases

In discrete amplifiers the amplification takes place at a single point at the end of the link and in DRA the amplification takes place along the fiber, avoids low power at the end of the link, and/or allows lower power to be launched at the starting of the link.

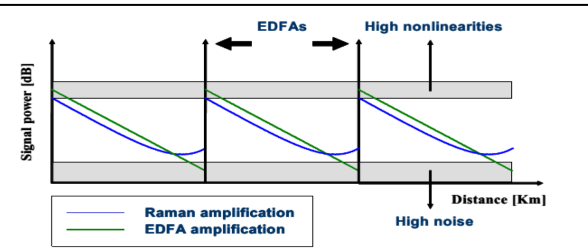

Fig. 2. Difference between DRA and EDFA amplification.

International Journal of Scientific & Engineering Research Volume 5, Issue 11, November-2014
ISSN 2229-5518

Since gain occurs along the fiber, DRA prevents the signal from being attenuated to very low powers, as shown in Fig. 2, improves the SNR of the signal.

2.3. Semiconductor Optical Amplifiers (SOA)

A semiconductor optical amplifier is based on a semiconductor gain medium. SOAs are typically constructed in a small package and they work for 1310 nm and 1550 nm systems[10].

As shown in Fig. 3, the gain of an SOA is influenced by the input signal power and the internal noise generated by the amplification process so the output signal power increases the gain decreases.

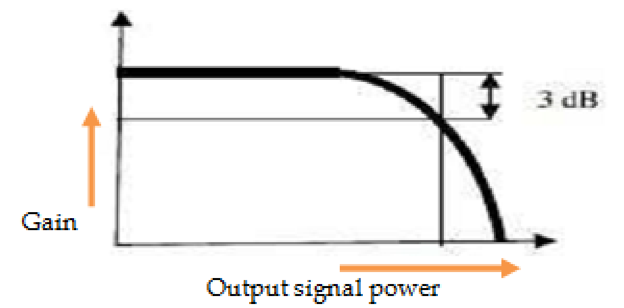

Fig. 3. Typical SOA gain versus output signal power [11].

SOA accepts a wide range of input power and delivers constant output power because it has short carrier lifetime of about several tenths to several hundreds of picoseconds compared to several hundred microseconds to several milliseconds in EDFA's, means the SOA has fast gain dynamics. This saturation of gain can cause significant distortion in signal, which becomes more severe as the modulated signal bandwidth increases. These effects are even more in multichannel systems where the saturation gain leads to inter-channel crosstalk[12].

SOA is very important in novel optical system, so the gain and noise performances are relevant in all linear and nonlinear regimes[12].

2.4 Ytterbium Doped Fiber Amplifier(YDFA)

In 1985, where the invention of erbium-doped fiber amplifier (EDFA) has attracted great interest in the field of communication, but the applications of EDFA's have not been confined to telecommunications, such as, the amplification of pulses to provide a source of very high peak powers. The particular wavelength's advantage of the EDFA for telecommunications is no longer important, so the rare-earth dopants comes into existence. Ytterbium-doped fiber lasers, provides very broad wavelength range from 975 to 1200 nm to provide amplification and is expected to generate increasing interest in the future[13].

YDFA also offers high output power and excellent power conversion efficiency and many of the complications which are well-known from erbium-doped fiber amplifiers are discarded, such as excited state absorption and concentration quenching (It comes due to high concentration doping of erbium) by interionic energy transfer do not occur. By avoiding concentration quenching high doping levels are possible, leading to high gain in a short length of fiber[14].

The wide bandwidth gives better amplification of ultrashort pulses and the high saturation fluence allows for high pulse energies. It also allowing a variety of pumping schemes because wide ranges of possible pump wavelengths (860 nm to 1064 nm) are available. Applications of YDFA's include power amplification at special wavelengths (such as 1083 nm as required for spectroscopic measurements), small-signal amplifiers in fiber sensing applications, free-space laser communications, and chirped-pulse amplification of ultrashort pulses.

Based on pump laser power, length of doped fiber and wavelength of the input signal YDFA exhibits maximum gain of 62dB around 1030nm regions with pump wavelength of 975nm, pump power=5Watt and YDF length=8m[15].

2.5 Erbium Ytterbium Co-Doped Fiber Amplifier (EYCDFA)

Optical amplifiers, which have fiber length is short and high gain, needs high concentration doping of erbium ions, operating around 1550 nm. Problem arises due to high doping of erbium ions is concentration quenching. High concentration of erbium provides high gain(>10dB) in short length fiber amplifiers. Concentration above a few hundreds parts per million(ppm) of Er causes pair induced upconversion rate reduced the erbium meta stable level and pump efficiency.

This issue has been resolved by co-doping the Er doped fiber with Yb. The presence of Yb ions gives reduction in formation of Er clusters and up conversion rate from the upper level of Er($^4I_{13/2}$ level) and this permits high erbium doping level needed for a high gain amplifier.

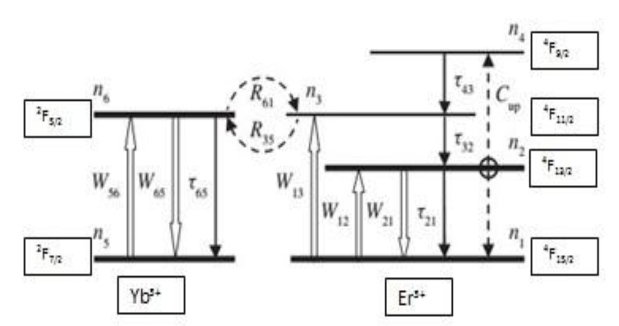

Fig. 4. Energy-level diagram of the erbium ytterbium co-doped system[16].

As shown in Fig 4, depending on the pump wavelength, pump photons can be absorbed by the Yb^{3+} in the $^2F_{7/2}$ level and/or the Er^{3+} in the $^4I_{15/2}$ level, and excite them to the $^2F_{5/2}$ level and the $^4I_{11/2}$ level, respectively. The excited Yb ions transfers energy to the neighboring Er ions in the $^4I_{15/2}$ level, exciting them to the $^4I_{11/2}$ level and the lifetime of the $^4I_{11/2}$ level is very short. Due to this short lifetime the excited Er^{3+} will quickly relax to the metastable level $^4I_{13/2}$ and the signal is amplified through the stimulated transitions between the $^4I_{13/2}$ and $^4I_{15/2}$ levels.

International Journal of Scientific & Engineering Research Volume 5, Issue 11, November-2014
ISSN 2229-5518

TABLE 3
COMPARATIVE ANALYSIS OF EYDFA

S. No.	Paper Name	Parameters	Gain	Output power/NF
1.	Experimentally and theoretical studies on Yb sensitized EDFA [17]	EYDF length(10m) and Pump power (3.5dB)	30-34dB	O/P Power >23dBm (1541-1565nm)
2.	56 dB Gain EYDFA with improved NF with dual stage partial double pass configuration [18]	inpu signal power(-50dBm) and pump power(140mW)	56 dB	NF-4.66dB
3.	37.2 dB small signal gain from EYCDFA with 20mW power[19].	Double pass	37.2 dB	NF-5.4dB
		Single pass	22.2 dB	NF-10.3dB

2.6 Thulium Doped Fiber Amplifier (TDFA)

TDFA offers more benefits over EDFA such as low fiber loss, low dispersion and low absorption loss due to OH- ions. In order to overcome the increasing demand of information traffic in DWDM systems, so the requirement is wavelength range has to be increase by using S- band with already existing optical amplifier i.e. EDFA in the C-band and L-band and for utilizing S-Band Thulium Doped Fiber Amplifier is used. An emission occurs at 1.47µm between the two excited levels $^3H_4$ and $^3F_4$ of TDFA and this emission exactly matches the range of S-Band. So TDFA provides high efficiency, high gain and low noise.

The energy diagram of TDFA shows that Tm^{+3} ions has three energy level and it has been observed that the gain and Noise Figure(NF), Amplified Spontaneous Emission (ASE) are dependant not only on Excited State Absorption (ESA) and Stimulated Emission (SE) but also on Ground State Absorption(GSA) and the GSA in TDFA reduces the efficiency of TDFA.

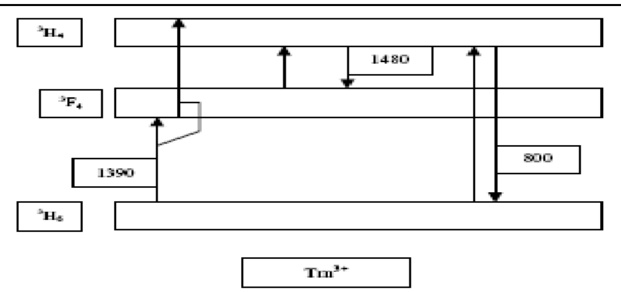

Fig. 5. Energy diagram of Tm^{3+}[20].

In Fig.5 shown the pumping scheme consists of the two step excitation of $^3H_6$ to $^3F_4$ and $^3F_4$ to $^3H_4$ with the same pump wavelength. With this upconversion pump scheme a population inversion state between $^3F_4$ to $^3H_4$ exists. To lower the ground state absorption (GSA) of TDFA, phonon energy in Tm^{3+} must be lowered and it is important to use either fluoride or aluminum is added, rather than conventional pure silica glass. By adding aluminium improvement in quantum efficiency has been observed without lowering its maximum phonon energy and the normal doping level considered was 600ppm.

The wavelength band of thulium (Tm^{3+}) around 2µm covers ~28THz (1750 nm - 2100 nm), almost a factor 2 more than that of erbium (Er^{3+}) doped fiber. Thulium-doped fiber sources having many applications such as eye safe radar, remote sensing, photo-medicine, and mid-IR generation, they have received little attention from the optical communication community apart for its S-band emission properties.

TABLE 4
COMPARATIVE ANALYSIS OF TDFA

S.No.	Paper Name	Parameters	Gain	Noise Figure
1.	Thulium-doped Fiber Amplifier for Optical Communications at 2µm[20]	Wavelength and pump power	>35dB	<6 dB
2.	An Efficient TDFA Model for Improved Gain Enhancement by Improving Doping Schemes[21]	doping concentration	32.5dB	-

TABLE 5
CHARACTERISTICS OF ALL AMPLIFIERS

Amplifiers	Advantages	Disadvantages
EDFA	High power efficiency (> 50%)	less Wavelength Range(1500-1600nm)
RAMAN	Gain BW is Pump dependent	Low Gain (~20–25 dB)
SOA	Compact, Output saturation power 5-10 dBm	High NF(~8dB), High Coupling losses
YDFA	High Output Power	Not compatible with others due to high Power
EYCDFA	High and Flat Gain (30-34 dB)	High NF(~10 dB)
TDFA	Low Fiber Loss, Low Noise	ASE – amplified spontaneous emission

International Journal of Scientific & Engineering Research Volume 5, Issue 11, November-2014
ISSN 2229-5518

3 Conclusion

Due to continuous growth in optical fiber communication technology the need of amplifiers increased and the reason being the amplifiers enhances the gain-bandwidth and also reduces the noise figure which arises in optical fiber. EDFA provides High power efficiency (> 50%) but also produces Cross-talk effects. RAs provide broad amplification spectrum, producing very little signal distortions. SOA is compact but produces high coupling losses. YDFA also offers high output power and excellent power conversion efficiency. Higher concentration of Er ions arises the problem of concentration quenching, this can be avoided by EYCDFA. TDFA offers low fiber loss, low dispersion and low absorption loss due to OH- ions. All amplifiers have their own advantages and it can be integrated to improve the performance of all optical networks.

References

[1] Govind P. Agarwal, "Fiber Optic Communication Systems", John Wiley &sons, Inc. Publication, 2003.

[2] G. Keiser, "Optical Fiber Communications", McGraw-Hill, New York, 1991, Pages 376-396.

[3] Mubashir ul zaman, shahid Iqbal and Isha, "Performance analysis of EDFA Amplifier for DWDM system" 2014 IEEE.

[4] P. NagaSiva Kumar, A. Sangeetha," Gain Flatness of EDFA in WDM Systems" International conference on Communication and Signal Processing, April 3-5, 2013, India.

[5] B. A. Hamida, S.Khan, A.W. Naji, W. Al-Khateeb, H. Ahmad and S. W. Harun," Modeling and Experimental Analysis of Wide-Band Flat-Gain Amplifier Utilizing High Concentration of EDFA"

[6] Raman Kumar, "Reduction of noise in fiber optic raman amplifier", International journal of computer science and technology, vol. 1, Issue 1, Sept (2010).

[7] Kulwinder Singh, Manjeet Singh Patterh and Manjit Singh Bhamrah, "Investigation on multipump fiber Raman amplifiers on WDM in optical communication system", International journal of computer applications, vol 39, no 4, 2(2012), p.p 8-12.

[8] Ramanpreet Kaur and Kirandeep Kaur, "Analysis and investigation of noise figure of fiber Raman amplifier", International journal of electronics and computer science engineering, 2008.

[9] G. Bolognini and F.Di Pasquale, "Transient effects in gain clamped discrete Raman amplifier cascades", IEEE, vol 16, no 1, 2004.

[10] R.Giller et al, "Analysis of the dimensional dependence of semiconductor optical amplifier recovery speeds", OpticsExpress, Vol. 1/5, No. 4, 2007.

[11] E. Ciaramella V. Donzella, and A. D'Errico "Parameters affecting the performance of WDM-DPSK systems based on SOA amplifiers" Optical Society of America 2007

[12] Eszter Udvary, Tamas Banky, Attila Hilt, Tamas Marozsak," Noise and Gain Properties of Semicunductor Optical Amplifier"

[13] R. Paschotta, D. C. Hanna, P. DeNatale, G. Modugno, M. Inguscio, and P. Laporta, "Power amplifier for 1083 nm using ytterbium doped fiber," Opt. Commun., vol. 136, pp. 243–246, 1997.

[14] Rudiger Paschotta, Johan Nilsson, Anne C. Tropper, and David C. Hanna," Ytterbium-Doped Fiber Amplifiers" IEEE Journal of Quantum Electronics, Vol. 33, No. 7, July 1997

[15] Tanvi, Neena Gupta," Comparative Gain Analysis of Erbium and Ytterbium Doped Optical Fibre Amplifiers" International Journal of Computer Applications (0975 – 8887) Volume 91 – No.16, April 2014.

[16] G. Canat, J.C. Mollier, J.P. Bouzinac, G. M. Williams, B. Cole, L. Goldberg, Y. Jaouën, and G. Kulcsar, "Dynamics of high-power erbium ytterbium fiber amplifiers,"J. Opt. Soc. Am. B, vol. 22, pp. 2308–2318, Nov. 2005.

[17] Moghaddam M.R.," Experimentally and theoretical studies on Yb sensitized erbium doped fiber amplifier" International Journal for Light and Electron Optics,122(20), pp.1783-1786, 2011.

[18] Muhd-Yassin S.Z. ," 56 dB Gain EYDFA with improved NF with dual stage partial double pass configuration", International Journal for Light and Electron Optics 123(20), pp. 1884-1887, 2012.

[19] Harun S.W. "37.2 dB small signal gain from EYCDFA with 20mW power", Optics and Laser Technology, 40(1), pp.88-91, 2008

[20] Z. Li, A.M. Heidt, J.M.O. Daniel, Y. Jung, S.U. Alam, and D.J. Richardson," Thulium-doped Fiber Amplifier for Optical Communications at 2µm" 2013 OSA

[21] Inderpreet Kaur and Neena Gupta," An Efficient TDFA Model for Improved Gain Enhancement by Improving Doping Schemes" International Journal of Computer Applications (0975 – 8887).