UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A BROADBAND ERBIUM DOPED FIBER AMPLIFIERS

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By

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Abstract of thesis presented to the senate of University Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

DESIGN AND DEVELOPMENT OF A BROADBAND ERBIUM DOPED FIBER AMPLIFIER

By

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June 2003

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This thesis presents the research work that was carried out on the development, characterization and analysis of broadband Erbium doped silica fiber amplifier (B-EDF).

Erbium doped fiber amplifiers provide advantages over regenerative repeaters as well as other amplification systems. For example, better crosstalk characteristics, higher power operation, lower insertion loss than semiconductor laser amplifiers, higher efficiency than Raman amplifiers and low noise figure than Brilloun amplifiers. In addition, EDFAs are the only amplifier, that can be used as both distributed and lumped amplifier in telecommunications.

Currently, optical communication technology is moving from point-to-point systems to optical networking. The exponential growth in data communications and the internet places urgent demands on high-capacity communication networks. To increase the total capacity, amplifier bandwidth has commanded much attention. However, the

spread and expansion of dense wavelength division multiplexing (DWDM) systems are keeping pace with various technology developments of optical amplifiers and, in particular, the bandwidth broadening of EDFAs. For this thesis, a novel EDFA structure is developed to increase the amplifier bandwidth by combining the conventional band and long wavelength band (C+L). This will offer more efficient use of optical fiber networks and it will satisfy the demand of higher transmission capacity.

The design and development of EDFA is viewed particularly from engineering perspective through double pass technique. Single pass and double pass silica based Erbium doped fiber amplifier, (SP-EDFA , DP-EDFA) have been discussed in this thesis. The performance of both systems is compared and presented thoroughly.

There are two approaches used in this thesis: simulation and experiment work. Simulation is designed to check and optimize the design parameters of the amplifier. Efforts, costs and time can be saved through software simulation process, which are the benefits that makes the simulation as an absolute option in the amplifier design. Experiment is implemented after the optimization stage with both, SP-EDFA and DP-EDFA, systems.

As a conclusion, results of both approaches will be presented in this thesis. A bandwidth amplification of 90nm is obtained through a double pass technique. This bandwidth can support more than 100 WDM channels with standard channel spacing of 100 Gbps. All analysis and discussion will be presented.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

REKABENTUK DAN PEMBANGUNAN PENGUAT GENTIAN OPTIK BEREBIUM JALUR LEBAR

Oleh

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Ogos 2003

Pengerusi: **Profesor Madya Mohamad Khazani Abdullah, PhD**

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Tesis ini mengenai penyelidikan yang melibatkan pembangunan, pencirian, penggunaan, dan analisa mengenai penguat gentian optik Silika berebium (EDFA).

Penguat gentian optik berebium mempunyai banyak kebaikan berbanding menggunakan pengulang dan juga sistem penguat yang lain. Sebagai contoh, pemalar cakap silang adalah lebih baik, tenaga operasi yang tinggi, kehilangan masukan yang rendah berbanding penguat laser pengalih separuh, kecekapan yang tinggi berbanding penguat Brilloum. Tambahan pula, EDFA adalah satu-satunya penguat yang boleh dipergunakan sebagai penguat teragih dan penguat terhimpun di dalam sistem telekomunikasi.

Pada masa kini, teknologi komunikasi telah berkembang dan berubah daripada sistem nod-ke-nod kepada rangkaian optikal. Pembangunan yang mendadak dalam komunikasi data dan internet ini, telah menyebabkan permintaan yang tinggi terhadap

rangkaian komunikasi berkapasiti tinggi. Oleh itu, untuk menambah jumlah kapasiti lebar jalur di dalam rangkaian, tumpuan terhadap penguat kian bertambah. Tambahan pula, perkembangan di dalam permultiplek pelbagai gelombang (DWDM) sistem telah mengambil tempat dalam perkembangan komunikasi dengan diisikan oleh perkembangan teknologi penguat optikal terutamanya dalam perlebaran-jalur EDFA. Di dalam tesis ini juga, kebaharuan stuktur EDFA telah dibuat untuk pembaharuan lebar jalur penguat dengan mengabungkan jalur-C dan jalur-L. Ini akan menambah kecekapan penggunaan rangkaian gentian optik dan menambah kapasiti penghantaran.

Rekabentuk dan pembangunan EDFA adalah berlandaskan prespektif kejuruteraan melalui teknik dua laluan. Penguat gentian optik berebium satu laluan (SP-EDFA) dan dua laluan (DP-EDFA) berunsurkan silika telah dibincangkan di dalam tesis ini. Perbandingan mengenai dua teknik ini telah dibincangkan di dalamnya.

Dua cara telah digunakan di dalam tesis ini iaitu: simulasi dan ekperimen. Simulasi digunakan untuk merekabentuk dan mencari perkala-perkala yang boleh menoptimumkan rekabentuk penguat. Dengan mengunakan simulasi ia telah menjimatkan kos, masa dan juga tenaga kerja yang diperlukan untuk merekacipta penguat. Selepas menemui pemalar optimum didalam simulasi bagi kedua-dua sistem iaitu SP-EDFA dan DP-EDFA, ekperimen pengaut dilakukan.

Sebagai kesimpulan, keputusan bagi kedua-dua cara ini telah ditunjukkan di dalam tesis ini iaitu 90nm jalur lebar penguat DP-EDFA telah diperolehi. Lebar jalur ini boleh menampung 100 WDM bahagian iaitu setiap bahagian memuatkan 100Gbps.

Semua analisa dan perbincangan ditunjukkan di dalam tesis ini.

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LIST OF ABBREVIATIONS

DWDM	Dense wavelength division multiplexing
WDM	Wavelength division multiplexing
EDFA	Erbium doped fiber amplifier
SP-EDFA	Single pass- erbium doped fiber amplifier
DP-EDFA	Double pass-erbium doped fiber amplifier
C-EDFA	Conventional-erbium doped fiber amplifier
L-EDFA	Long wavelength erbium doped fiber amplifier
SMF	Single mode fiber
SOA	Semiconductor optical amplifier
FOA	Fiber optical amplifier
REDFA	Rare earth doped fiber amplifier
TDFA	Tellurite doped fiber amplifier
ASE	Amplified spontaneous emission
BER	Bet error rate
NF	Noise figure
FWM	Four wave mixing
DSF	Dispersion shifted fiber
EDF	Erbium doped fiber
EDFFA	Erbium doped fluoride fiber amplifier
F-EDFA	Floured-based erbium doped fiber amplifier
EDTFA	Erbium doped tellurite fiber amplifier

LD	Laser diode
WSC	Wavelength selective coupler
SE	Spontaneous emission
SHB	Spectral hole burning
OC	Optical circulator
WDA	Wavelength add/drop
CATV	Cable television
DMUX	Demultiplexer
B-EDFA	Broadband erbium doped fiber amplifier
UEDFA	Unidirectional erbium doped fiber amplifier
TBF	Tunable band filter
ITU	International telecommunication union

CHAPTER 1

INTRODUCTION

1.1 Optical Fiber Communication Systems

Optical communication systems have moved very rapidly from research labs into commercial application. When attenuation, inherent to the optical fiber was reduced to levels that made fibers economically attractive for long-haul communications, these first generation systems were based on silicon devices, operating at wavelength in the 800-900 nm range.

Fiber attenuation is lower at long wavelength, therefore fiber with lower attenuation and large bandwidth, as well as laser and photo detectors for wavelengths on the 1250 nm - 1350 nm range, were intensively used. Second generation systems, based on the 1300nm technology and improved optical fiber with attenuation around 0.4dB/km with maximum bandwidth through single mode fiber at 17.7THz. Third generation or 1500nm window, ranging from 1450nm to 1620nm with fiber attenuation at approximately 0.2dB/km has a maximum bandwidth of 19.5THz.

Therefore, the total available bandwidth (250nm) of the second and third generation provides potential capacity of around 37THz. These two windows, used by single mode fibers as the working horse for transporting tremendous signals in long-haul systems, and have a huge potential in through put capacity.

However, the subdivision of the third wavelength window into the small bands, S̀- band, ranging from 1450-1480 nm, S–band from 1480-1530 nm, C band from 1530-1570nm and L-band from 1570-1620nm, is for compatibility purposes, among which are fiber loss, light source, receiver and optical components.

Two recent major technological advances, wavelength division multiplexing (WDM) and Erbium doped fiber amplifier (EDFA) have boosted the capacity of existing systems and have brought about dramatic improvements in the capacity of systems. In WDM systems, the overall transmission capacity depends significantly on the spectral characteristics of the optical amplifier, such as flatness, bandwidth, and magnitude of the gain. EDFAs have provided efficient optical gain in the 1500nm communications window in conventional signal-mode fibers (SMF).

1.2 Optical Amplifier

In long haul systems, light propagating along fibers for certain distances will suffer from power losses caused by fiber attenuation, connections and signal distortion in networks. This leads to the need of an amplification of the signal at certain stages of the transmission link.

Prior to the advent of optical amplifiers, electronics regenerators were periodically placed along the line to cope up with the attenuation of light signals. In regenerator scheme, optical signal is converted into an electrical signal and then converted back into an optical signal. The drawback of this process is that bit-rate of telecommunication networks are limited by how fast the electronics can reach. There are two major classes of optical amplifiers in use today; semiconductor optical amplifiers (SOA) (M.J.O'Mahony, 1988 and B.Merstali et al, 199 [1,2]) and fiber optical amplifier (FOA) (Koester et al, 1964 [3]). A semiconductor optical amplifier is, in essence, an active medium of a semiconductor laser without or with very low optical feedback.

On the other hand, SOAs have their advantages as electrical pumping, small size, large gain over a large bandwidth, and easy integration with other semiconductor devices. The disadvantages however, are cross-talk between channels, large noise factor, large coupling losses, polarization–dependent gains, and temperature sensitivity.

A fiber optical amplifier is quite different from a semiconductor optical amplifier, the former is essentially a piece of special fiber spliced with a transmission fiber and connected to a pump laser. A FOA works on the principle of stimulated emission. Energy from a pump laser is used to excite atoms at the upper energy level, where they are stimulated by the photons of an information signal to fall to a lower level. Fiber amplifiers especially EDFA's are the workhorse in today's WDM networks. Another difference between SOA's and EDFA's is that an EDFA operates only in the 1550nm window while SOA covers both the 1300nm and 1500nm transparent windows.

Moreover, there is another type of an optical amplifier (Raman amplifier)along with SOA's and EDFA's using non linear effects for amplification rather than stimulated emission. Raman amplifier is based on a third-order nonlinear process. It exhibits low noise close to quantum limit, which can be advantageous in long-haul applications. However, the drawbacks of using Raman amplifier are the need of long fibers (several kilometers). Therefore, high pump powers are required, and large crosstalk between different channels in the saturation region. In contrast, EDFA's can achieve all the advantages at once: polarization insensitivity, temperature stability, quantum limited noise figure and immunity to inter channel crosstalk even at saturation region (E.Desurvire, 1994 [4]).

1.2.1 Functional Types of Optical Amplifiers

Optical amplifiers are categorized in terms of the function according to their performance into three basic types, which are; *boosters, inline amplifiers*, and *preamplifiers* as illustrated in Figure1.1

A *booster*, also called a post–amplifier, is a power amplifier that magnifies a transmitter signal before sending it down a fiber, Figure 1.1 a. The main requirement of this amplifier is to produce maximum output power, not maximum gain.

An *inline amplifier* operates with a signal in a fiber optical link, as shown in Figure 1.1 *b*. It's primary function is to compensate for power losses. Hence, stability over the entire WDM bandwidth is the main requirement of this type of amplifier.

A *preamplifier* magnifies a signal immediately before it reaches the receiver. As it shown in Figure 1.1 *c*. This type of amplifier operates with a weak signal. Thus, a good sensitivity, high gain, and low noise are the major requirements for this type. Noise will become an extremely important feature, since the receiver performance is limited not by it's own noise but by the noise of the preamplifier. As shown above, three amplifiers, meet different requirements. The system to be designed, meets all the above requirements and there fore can be applied for inline, boost and preamplifier.

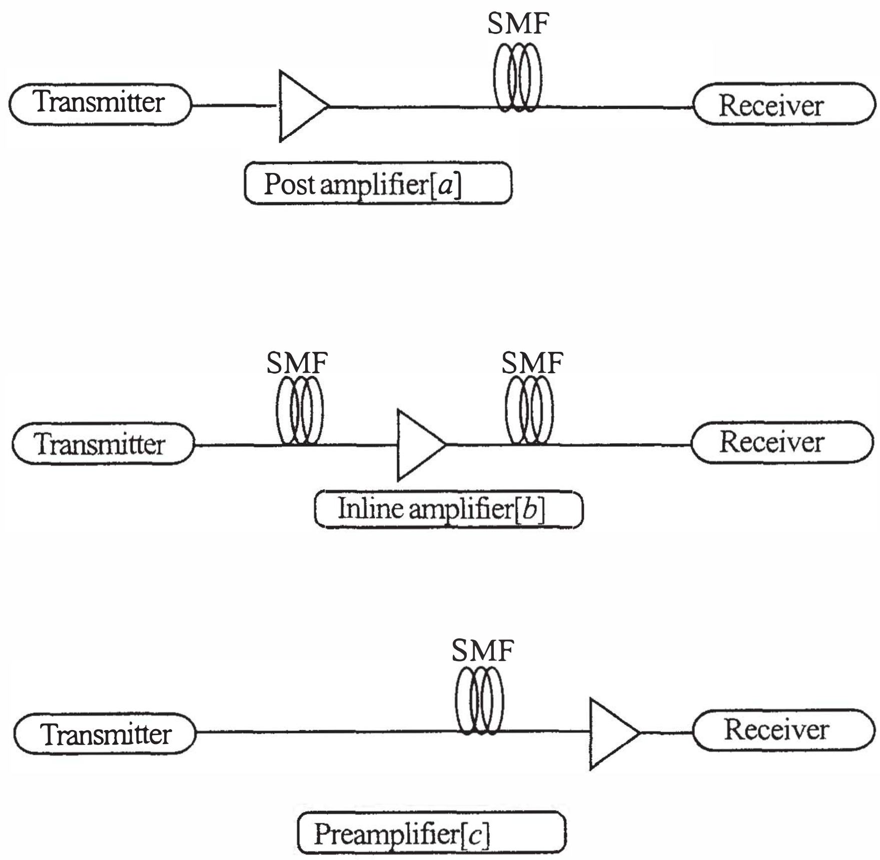

Figure1.1 Functional of optical amplifiers; booster, inline and preamplifier.