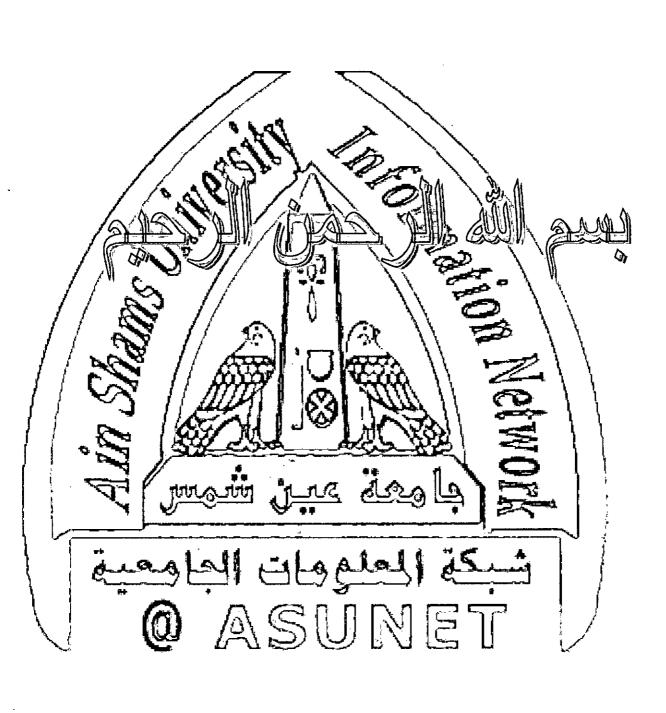


شبكة المعلومات الجامعية





شبكة المعلومات الجامعية

جامعة عين شمس

التوثيق الالكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها على هذه الأفلام قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأفلام بعيدا عن الغبار في درجة حرارة من ١٥-٥٠ مئوية ورطوية نسبية من ٢٠-٠٤% To be Kept away from Dust in Dry Cool place of

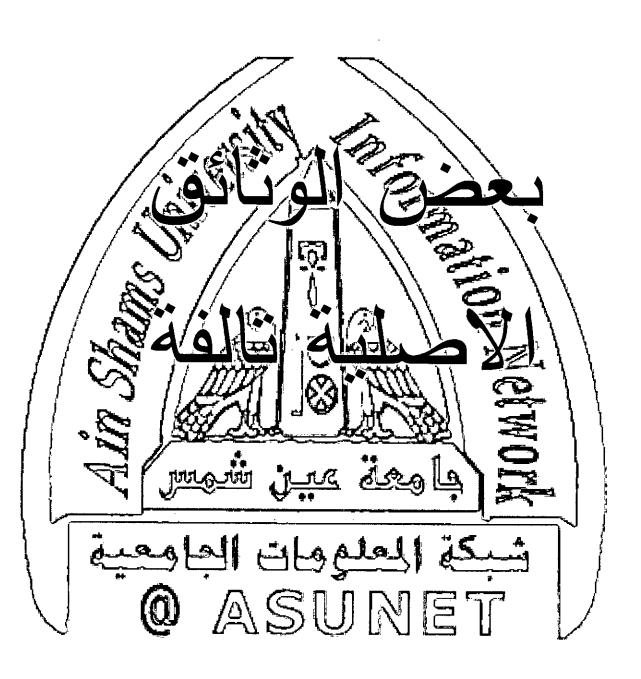
15-25- c and relative humidity 20-40%





شبكة المعلومات الجامعية التوثيق الالكتروني والميكروفيلم













Tanta University Faculty of Engineering Electronics and Electrical Communications Department

Thulium Doped Optical Fiber Amplifiers

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Electrical Engineering

(Electronics and Electrical Communications Engineering)

By

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Tanta University Faculty of Engineering Electronics & Electrical Communication Dept.

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Thesis Title **Thulium Doped Optical Fiber Amplifiers**

Degree Master of Science in Electrical Engineering

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إن الرق الرق



صِياقِ الله المظيم

سوبهةطه الآية: ١١٤.

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ABSTRACT

Like any communication system, the signal in optical fibers suffers from attenuation. So, the use of amplifiers is so important to increase the optical signal power. Optical fiber amplifiers based on rare earth elements play an important role in the telecommunications. Recently, efforts are in progress to extend the wavelength bands of optical telecommunication beyond the conventional C-band (1530–1565 nm) into the S-band (1440–1530 nm), L-band (1565–1625 nm) and U-band (1625–1675 nm). Also, to realize the practical application in these new communication bands, efficient optical amplifiers must be developed for each band using a proper combination of host glasses and dopant rare-earth ions.

Thulium doped fiber amplifiers (TDFAs) for S (1480-1530 nm) / S⁺ (1450-1480 nm) bands have been studied extensively in recent years, as the candidates for the next generation amplifiers. The present work contains a comparative study for the signal gain of TDFA in the S-band using different doping profiles and different host materials. These hosts include: silicate, bismuth, fluoride, tellurite, chalcohalide, and heavy metal oxide.

Different doping techniques are used to obtain different concentration profiles in silica fibers. The optimal one is found to be the step like profile. The effect of the different parameters on signal gain of the optical amplifiers is also studied including the amplifier length and emission cross section.

Results showed that the highest gain can be provided by bismuth (Bi) based glass host with a broad band gain from 1450 nm to 1520 nm having its peak wavelength around 1480 nm. A maximum gain above 28.5 dB is obtained with 11 m long Bi-TDFA. It is indicated also that Bi-TDFA is a very promising candidate for S-band amplifiers because the Bi₂O₃-based glass is fusion-spliceable to silica fibers using conventional fusion splicing machines. This spliceability of TDFA to conventional SiO₂ fibers is a practical requirement to obtain mechanical reliability, low loss and low cost.

PUBLICATIONS

[1] M. H. Ali, M. E. Nasr and H. E, Seleem, "Thulium Doped Fiber Amplifier in the S/S* Band Employing Different Concentration Profiles," Academy of Science Research and Technology in Affiliation The National Institute of Laser Sciences, Cairo University, The Fifth Workshop on Advanced Photonics 10 May 2005, Cairo, Egypt.

LIST OF SYMBOLS

A	Spontaneous emission rate
$A_{\it eff}$	The transverse area occupied by the thulium ions
A_i^{nr}	Multiphonon non radiative decay rate of level i
A_{ij}^{r}	The radiative decay rate between energy levels i and j
a_{x}	The value of the spreading length of the lateral distribution
a_y	The tail width of semi-Gaussian ion depth distribution
$a_{_{ym}}$	The tail-width of semi-Gaussian ion depth distribution toward the surface
a_{yp}	The tail-width of semi-Gaussian ion indepth distribution toward the surface
c	Speed of light
d	Diffusion depth
d_x	Lateral diffusion width
E(r , φ)	The transversal distribution of the electric field
G_{max}	Maximum gain of the amplifier
G	Single-pass gain in the absence of light in SOA
g ₁ , g ₂	Degeneracies of levels
g	Overall gain per unit length
g _m	The material gain coefficient of SOA
h	Planck's constant
$I_e^{peak}(\lambda)$	The measured peak emission intensity
$I_e(\lambda)$	The emission intensity at λ
I_s	An intensity of incident signal of wavelength λ_s
I(z)	Intensity of the field at point z
Inv	The relative medium inversion
L	Amplifier length
L_{opt}	Optimal amplifier length
$N_{1.}$	Ground level atomic population
N_t	The average concentration of thulium

N_{i}	Atomic population density of energy level i
n _c	The core refractive index
P_{λ}^{\pm}	Forward and backward signal power
PCE	Power conversion efficiency
PCE_{ove}	Overall conversion efficiency
$P_p^{\prime\prime\prime}$	Input pump power
P_f^{p}	Forward pump power
P_b^p	Backward pump power
P_s^{in}	Input signal power
P_s^{out}	Output signal power
$P_{amp;sat}$	The amplifier saturation power
P(z)	The power of the field at point z
QCE	The quantum conversion efficiency
\mathbf{W}_{ij}	Transition rate of absorption (i < j)
\mathbf{W}_{ij}	Transition rate of emission $(i > j)$
W_{pi}	Transition rate of absorption $(i < j)$ or pumping rate at λ_{pi}
W_{se}	Transition rate of stimulated emission
W_{se}	Transition rate of stimulated absorption
W_{18}	Transition rate of amplified spontaneous emission (ASE) at 1.8 µm
W_8	Transition rate of amplified spontaneous emission (ASE) at $0.8 \mu m$
w	Diffusion width
α	The fiber background loss
$ec{lpha}$	Effective absorption coefficient of the material in the optical path in SOA
$oldsymbol{eta}_{ij}$	Branching ratio
$\Delta \lambda_{\mathbf{k}}$	Spectral width of the partial wave
ΔΝ	Population inversion
$ abla \omega_{ij}$	The spectral line width of an optical transition ij
$\nabla \lambda_{e}$	The effective line width
η	Ratio between emission and absorption cross sections
λ_p	Pump wavelength

λ_{s}	Signal wavelength
\mathcal{V}_{S}	Optical signal frequency
$ u_{ m p}$	Optical pump frequency
$\sigma_{_a}$	Absorption cross section
$\sigma_{_{ m e}}$	Emission cross section
$\sigma_{\epsilon}^{\it peak}$	Peak emission cross section
$oldsymbol{\sigma}_{ij}$	Transition cross section of absorption or emission between level i to j
σ^a_{ij}	Absorption cross section area between level i to j
$\sigma^a_{\scriptscriptstyle pi}$	Absorption cross section area of pump signal i
τ	Fluorescence life time
$arphi_p^{\scriptscriptstyle in}$	Photon flux of the input pump signal
$oldsymbol{arphi}_p^{out}$	Photon flux of the output pump signal
$oldsymbol{arphi}_s^{in}$	Photon flux of the input signal
$oldsymbol{arphi}_{x}^{out}$	Photon flux of the output signal
Γ	Optical confinement factor or Overlap factor
ρ	Thulium concentration profile
$ ho_d$	Dopant ion density
$ ho_o$	Surface concentration
$ ho_{avg}$	The average concentration of thulium

LIST OF ACRONYMS

ASE Amplified spontaneous emission.

BER Bit error rate.

Bi - TDF Bismuth based glass thulium doped fiber

b/s Bit per sec

CET Cooperative energy transfer

CW Continuous wave.

DFA Doped fiber amplifier

DSFs Dispersion shifted fibers.

EL Electroluminescence

Er Erbium.

EDFA Erbium doped fiber amplifier.

EDWA Erbium doped waveguide amplifier.

ESA Excited state absorption.

FPA Fabry perot amplifier

FWHM Full width at half maximum

GSA Ground state absorption.

GS-TDFA Gain shifted thulium doped fiber amplifier.

HMF Heavy metal fluoride.

HMO Heavy metal oxide glasses

Ho Holmium

Inv Local inversion of the rare earth ions.

LASER Light amplification for stimulated emission of radiation

LD Laser diode.

LED Light emitting diode

LTT lithium-titanium-tellurite glass

MCVD Modified chemical vapor deposition technique.

MPR Non radiative multi- phonon relaxation

NA Numerical aperture

Nd Neodymium

NDFA Neodymium doped fiber amplifier.