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Thulium Doped Optical Fiber Amplifiers

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

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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 Bi_2O_3-based glass is fusion-spliceable to silica fibers using conventional fusion splicing machines. This spliceability of TDFA to conventional SiO_2 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_{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
$E(r, \varphi)$	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
$P_\lambda^\pm$	Forward and backward signal power
PCE	Power conversion efficiency
PCE_{ove}	Overall conversion efficiency
P_p^{in}	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
W_{ij}	Transition rate of absorption (i < j)
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 μm
w	Diffusion width
α	The fiber background loss
$\overline{\alpha}$	Effective absorption coefficient of the material in the optical path in SOA
β_{ij}	Branching ratio
$\Delta\lambda_k$	Spectral width of the partial wave
ΔN	Population inversion
$\nabla\omega_{ij}$	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
ν_s	Optical signal frequency
ν_p	Optical pump frequency
σ_a	Absorption cross section
σ_e	Emission cross section
σ_e^{peak}	Peak emission cross section
σ_{ij}	Transition cross section of absorption or emission between level i to j
σ_{ij}^a	Absorption cross section area between level i to j
σ_{pi}^a	Absorption cross section area of pump signal i
τ	Fluorescence life time
φ_p^{in}	Photon flux of the input pump signal
φ_p^{out}	Photon flux of the output pump signal
φ_s^{in}	Photon flux of the input signal
φ_s^{out}	Photon flux of the output signal
Γ	Optical confinement factor or Overlap factor
ρ	Thulium concentration profile
ρ_d	Dopant ion density
ρ_o	Surface concentration
ρ_{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.