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Analysis of temperature based power spectrum in EDFA and YDFA with different pump power for THz applications

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ABSTRACT

The indispensible output power spectrum for optical amplifier system in the presence of temperature using EDFA and YDFA is numerically investigated. The notion of temperature suggested as −30 °C, 30 °C, 60 °C, 90 °C. Each output spectrum has been analyzed at −30 °C, 30 °C, 60 °C, 90 °C in both EDFA and YDFA systems. The output power at the point of two maxima as 26.829 dBm and 23.260 dBm at wavelengths 1530 nm and 1550 nm for EDFA, maximum output power as −6.499 dBm at wavelength 1043 nm for YDFA system are examined keeping 900 mw pump power and 60 °C temperature. Similarly, the maximum output power is analyzed as −6.499 dBm at the wavelength of 1043 nm for the same pump power and temperature in YDFA system. Also the results have been plotted for various pump power and temperature.

Introduction

In any fibre optic communication systems the transmission distance is limited by the fibre losses. The recent approach to overcome the loss limitation is the use of optical amplifiers which ensures the accomplishment of fibre optic communication systems for long distances efficiently. Different categories of optical amplifiers found for widespread use such as Erbium Doped Fibre Amplifier (EDFA) [1], Raman Amplifier (RA) [2], Semiconductor Optical Amplifier (SOA) [3], Ytterbium Doped Fibre Amplifier (YDFA) [4], Erbium Ytterbium Co-Doped Fibre Amplifier (EYCDFA) [5] and Thulium Doped Fibre Amplifier (TDFA) [6]. Among these amplifiers, we consider about EDFA and YDFA which are made by doping the fibre core with rare-earth elements of Erbium and Ytterbium respectively. EDFA operates in the wavelength region from 1530 nm to 1565 nm with semiconductor laser pump wavelengths of 980 nm and 1480 nm. YDFA operates in a broad wavelength range from 975 nm to 1200 nm with pump wavelengths of 910 nm and 975 nm. In this paper, the temperature effect on output spectrum have been analyzed to incur the variation presence in the application scenario such as optical network, WDM mesh network and mode division multiplexing system [7] etc.

Theoretical background

Erbium ions having molecules with quantum power is doped with core of the optical fibre. It is stimulated by least power associated with Erbium ions. This is one of the main properties to construct an optical amplifier. Those ions can be processed by two kinds of emission with or without pump power. The main amplification process could be done by both signal power and pump power. The emission can be categorized by spontaneous as well as stimulated emission. Here, the spontaneous emission can be considered as non-radiative process which means it does not produces any radiation whereas it produces radiation as heat. The pumping of Erbium ions is taken over at 980 nm and 1480 nm wavelength. In general, the pumping power could be as 24–26 dBm for single system application.

Gain spectra of Erbium doped fibre amplifier

The gain spectrum of Erbium ions is seemed by both homogeneous and in-homogeneous broadening, here the homogeneous broadening arisen by the interaction of Erbium ions with applying external photons at 1550 nm and 980 nm wavelength and in-homogeneous spectrum broadening arisen by doping of Erbium with glass of the fibre. The main

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characteristics of gain spectrum are gain-bandwidth which has been considered as unique and useful in WDM as well as DWDM application.

The temperature dependence of the Erbium doped fibre amplifier gives the variation in gain spectrum and this could be happened by the variation of absorption and emission spectrum. The gain and absorption equations are expressed by Eqs. (1) and (2)

$$g^*(\lambda) = \sigma_e(\lambda)\ \Gamma(\lambda)\ n_t(r, \varphi, z) \tag{1}$$

$$\alpha(\lambda) = \sigma_a(\lambda)\ \Gamma(\lambda)\ n_t(r, \varphi, z) \tag{2}$$

where $\sigma_a(\lambda)$, $\sigma_e(\lambda)$ are known as absorption and emission cross section, $\Gamma(\lambda)$ is overlap factor between the erbium ion core and excited modes in fibre core and (r,φ,z) is the cylindrical geometry of the fibre with distribution of erbium ion density.

In case of YDFA, Yr^{+3} as rare earth elements are doped with glass material of the optical fiber. The gain spectrum of YDFA is also changed with temperature as in case of EDFA. The variation is analyzed by considering absorption and emission cross section with changing of temperature. The overlap factor for YDFA is given by,

$$\Gamma(\lambda) = 1 - e^{0.1 - v},$$

v is the normalized frequency.

Energy level diagram of EDFA and YDFA

The simplified energy level diagram of Erbium in silica glass is a shown in the Fig. 1. The energy transition from metastable state ($^4I_{13/2}$) to ground state ($^4I_{15/2}$) is responsible for the photon emission of 1550 nm wavelength.

EDFA pumping is necessary to achieve gain through population inversion which is possible efficiently by using semiconductor lasers operating at 980 nm and 1480 nm. Pumping at 1480 nm requires high power than 980 nm pumping because of it is in the tail of the absorption band.

The fractional densities of ions in two states N_1 and N_2 satisfy the following rate equations,

$$\frac{\partial N_2}{\partial t} = (\sigma_p^a N_1 - \sigma_p^e N_2)\varphi_p + (\sigma_s^a N_1 - \sigma_s^e N_2)\varphi_s - \frac{N_2}{T_1} \tag{3}$$

$$\frac{\partial N_1}{\partial t} = (\sigma_p^e N_2 - \sigma_p^a N_1)\varphi_p + (\sigma_s^e N_2 - \sigma_s^a N_1)\varphi_s + \frac{N_2}{T_1} \tag{4}$$

where, σ_j^a and σ_j^e are absorption and emission cross section at w_j frequency with j = p,s. T is the spontaneous lifetime of excited state. φ_p and φ_s are the photon flux for pump and signal waves respectively.

Ytterbium in silica is a system of two main levels having four stark levels in the lower manifold $F_{7/2}$ and three stark levels in upper manifold $F_{5/2}$ as shown in the Fig. 2.

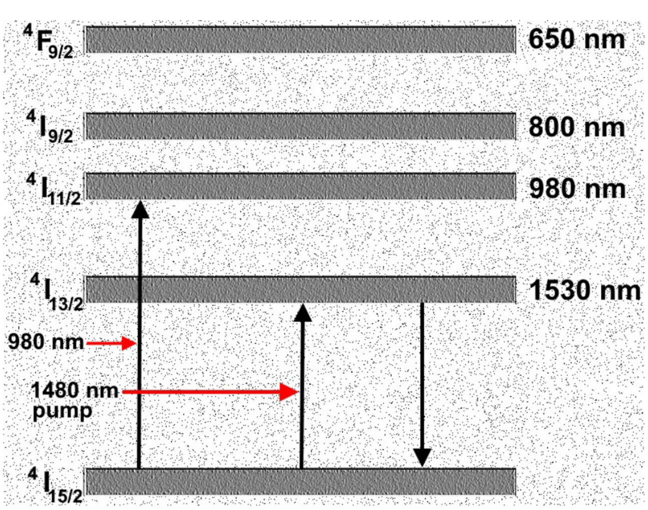


Fig. 1. Energy level diagram of EDFA.

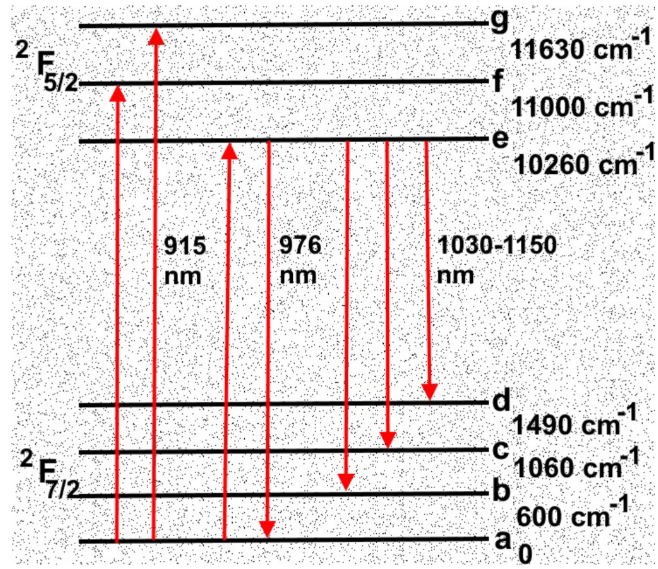


Fig. 2. Energy level diagram of YDFA.

Since Ytterbium has small energy gap between ground and excited state, it produces low quantum effects which results in pronounced quasi-3-level behavior. Consequently ytterbium offers high output power, power conversion efficiency and reduced detrimental effects such as excited state absorption and concentration quenching.

The rate equations for the ground and excited state ion populations are,

$$\frac{dN_1}{dt} = -W_{sa}N_1 + W_{se}N_2 + A_{21}N_2 - W_pN_1 \tag{5}$$

$$\frac{dN_2}{dt} = W_{sa}N_1 - W_{se}N_2 - A_{21}N_2 + W_pN_1 \tag{6}$$

where, W_p is the pump transition, W_{sa}, W_{se} are the signal transition for absorption and emission respectively. A_{21} is the spontaneous emission co-efficient.

System setup

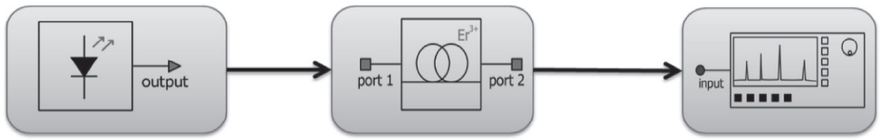
Fig. 3 shows the simulation model of temperature dependence EDFA and YDFA with and without pump power.

It consists of CW Laser as input source, Erbium doped fibre and Ytterbium doped fibre for signal transmission, Pump Laser for giving pump power in case of pumping configuration and Optical spectrum analyzer to visualize the output signal power. In this paper, CW Laser ranges from 1450 nm to 1650 nm wavelength for EDFA and from 975 nm to 1200 nm wavelength for YDFA with −20 dBm input power. EDF and YDF Lengths have been considered as 20 km each. The parameters is listed in Table 1.

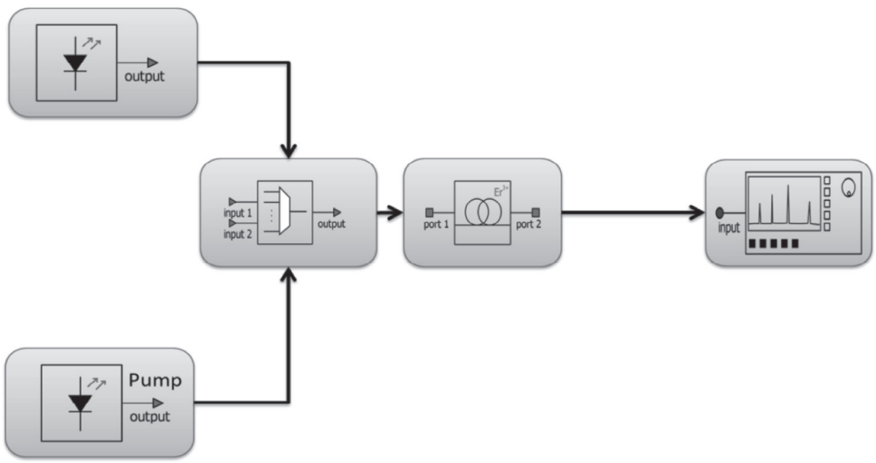
Without giving pump power, the output spectrum with various temperatures −30 °C, 30 °C, 60 °C and 90 °C have been analyzed. Also by applying various pump power of 100 mW, 300 mW, 600 mW and 900 mW with constant temperature, the output power spectra are analyzed.

Result and discussion

The output power spectrum is plotted with and without pump power. Figs. (4) and (5) shows the output spectra of EDFA and YDFA respectively with various temperatures when no pump power is applied. EDFA power spectrum decreases gradually with wavelength and



(a)



(b)

Fig. 3. Experimental setup of doping fiber system. a. without pump power, b. With pump power.

Table 1
Different parameters of EDFA and YDFA.

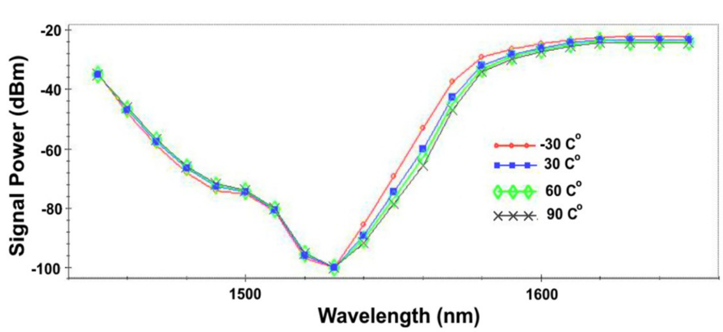
Parameter	Erbium doped Fibre	Ytterbium doped Fibre
Core radius	1.27 µm	3.4 µm
Excited state lifetime	10 ms	0.8 ms
Doped ion density	$2.2 \times 10^{24}\,m^{-3}$	$1 \times 10^{25}\,m^{-3}$
Numerical Aperture	0.266	0.2
Pump wavelength	980 nm	910 nm

has minimum power of −100 dBm at 1530 nm at all temperatures and then increases rapidly. YDFA power increased rapidly and is been constant after 1110 nm for all the temperatures. YDFA does not have changes in power with varying temperature. Figs. (6) and (7) shows output spectra of EDFA and YDFA respectively with various temperatures and constant pump power of 300 mW. EDFA output power increases drastically and reaches maximum of 22 dBm power for all temperatures at 1530 nm wavelength. It is only due to the absorption of erbium ions when launching the input laser power. The energy absorption of erbium ions then changed as emission energy as its does not capable of holding the energy absorbed. Later it decreases with the second maxima of 17 dBm at 1550 nm. YDFA increases rapidly and reaches maximum of −18.5 dBm at 1042 nm and further it is been constant with slight decrease in maximum power. And it does not have change in power with temperature changes.

Figs. (8) and (9) shows the output spectra of EDFA and YDFA respectively with varying pump power and constant temperature of 60 °C. For EDFA all the curves has maximum output power at 1530 nm and second maxima at 1550 nm 900 mW pumped signal has maximum of 26.5 dBm output power at 1530 nm and second maxima of 20.5 dBm at 1550 nm. YDFA power increases gradually and been constant after 1110 nm. Power spectrum varies with various pump power and it has maximum power of −7 dBm at 900 mW pump.

Conclusion

The system has been designed to analyze the temperature and pump power dependence of the optical amplifiers EDFA and YDFA. Both the



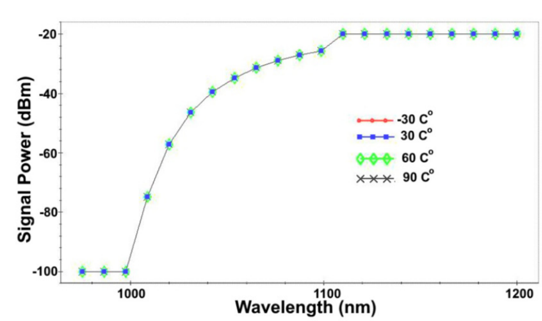


Fig. 4 & 5. Output spectrums of EDFA and YDFA without pumping power at different temperature.

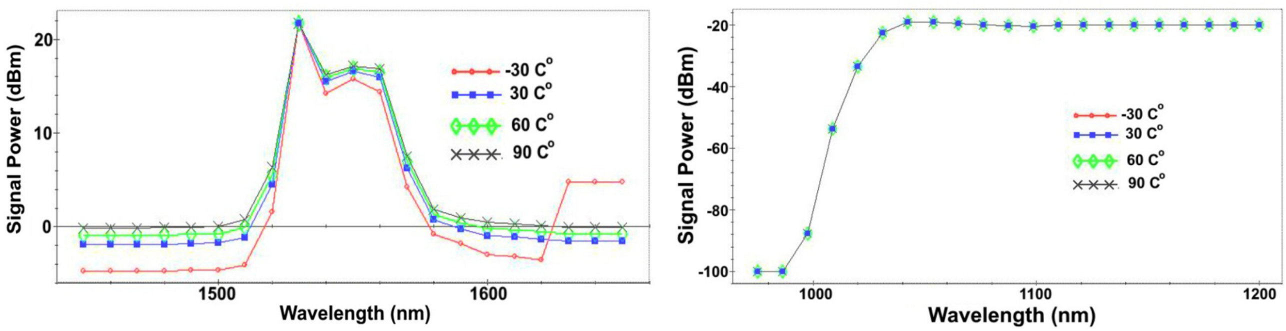


Fig. 6 & 7. Output spectrums of EDFA and YDFA with pumping power at different temperature.

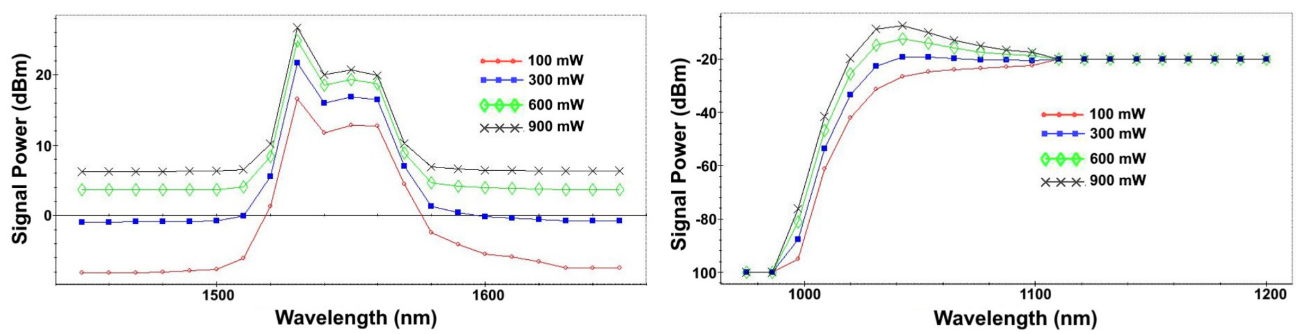


Fig. 8 & 9. Output spectrums of EDFA and YDFA with different pumping power at temp 60 °C.

amplifiers have increased power spectrum with increase in pump power and have maxima at amplification region. When temperature increases, EDFA has little increment in power and YDFA's output spectrum is independent of temperature.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.rinp.2018.05.040.

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