Available online at www.sciencedirect.com
ScienceDirect
Optics Communications 273 (2007) 407–412
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

Investigation of the optical gain and noise figure for multi-channel amplification in EDFA under optimized pump condition

Mrinmay Pal *, M.C. Paul, A. Dhar, A. Pal, R. Sen, K. Dasgupta, S.K. Bhadra

Fibre Optics Laboratory, Central Glass and Ceramic Research Institute, 196, Raja S.C. Mullick Road, Kolkata 700032, India

Received 5 September 2006; received in revised form 8 January 2007; accepted 17 January 2007

Abstract

We present the results of an investigation of optical gain and noise figure for simultaneous multi-channel amplification of an erbium doped fibre amplifier (EDFA) under optimized pump condition. Different pump configurations with varying input signal levels show interesting features on gain flatness. In the experiment, population inversion along the fibre length which determines the gain-spectra and noise characteristics of the amplifier is adjusted through optimized fibre length and injected pump power in order to minimize the gain-tilt at C-band. It is observed that bi-directional pumping manifests the best combination of low noise and high gain of EDFA which are useful as in-line repeaters in WDM network. We obtain 30 ± 1.5 dB intrinsically flat small signal gain from 1538 nm to 1558 nm band of wavelength with noise figure <4 dB for 16-channel simultaneous amplification in a single stage EDFA without gain flattening filter.

Keywords: Multi-channel amplification; Optical gain; Gain-tilt; Noise figure; Inversion level; Pumping configurations; EDFA; WDM

1. Introduction

Erbium-doped fibre amplifiers (EDFAs) are one of the key devices for wavelength division multiplexing (WDM) application in modern optical network systems [1–4]. EDFA is the best known and most frequently used optical amplifier suited to low loss optical window of silica based fibre. Perhaps its outstanding reliability made it an ideal component for long-distance or metro network either in analog or digital mode of operation. In WDM systems by multiplexing, a stream of wavelength channels particularly in C and L-band regimes can simultaneously amplify to a desired power level where the amplification of any particular channel is dependent on the signal wavelength, the number of signals present in the system, the input signal powers and its absorption and emission cross-sections [5]. Since, the gain of a conventional EDFA is non-uniform at particular spectral segment (peak at 1532 nm and dip at 1538 nm) in C-band, it creates problem in cascading number of EDFAs or performing adding/dropping channels in real network operation. To obtain intrinsically flat gain with an efficient EDFA, high aluminium concentration in Er doped fibre (EDF) has an important role to play [5]. Some recent reported results [6–8] of modeling EDFA in terms of flat gain and noise figure (NF) in WDM operation are found to be interesting where multi-channel amplification is analyzed using approximate analytical methods and genetic algorithm. Sun et al. [9] reported the output characteristics of an EDFA by considering average inversion level along the fibre length.

The present paper reports the results of a detailed experimental investigation of simultaneous multi-channel amplification characteristics of an EDFA (optical gain and NF) in C-band regime in suitable pumped condition. The investigations are made for different pump powers at 980 nm

* Corresponding author. Tel.: +91 33 24838083; fax: +91 33 4756012.
E-mail address: mpal@cgcri.res.in (M. Pal).

0030-4018/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.optcom.2007.01.039

and configurations like co-, counter- and bi-directional modes keeping low to high input signal power levels with optimized fibre lengths. We use an Al co-doped EDF which gives a flat gain from 1538 nm to 1558 nm. We try to explain the gain and NF of EDFA for multi-channel amplification by calculating population inversion level along the fibre length which can be controlled by proper selection of fibre length and/or pump power to reduce the effect of gain-tilt (difference of gain between 1532 nm and 1538 nm).

2. Experiment

The details of fabrication of EDF is described in references [2,10]. The fibre core was co-doped with Ge–Al having Er-ion concentration of 1.0×10^{25} ions/m^3, core diameter 3.2 micron, cut-off wavelength <950 nm and numerical aperture 0.23.

The experimental set-up used for the measurements of multi-channel amplifications is shown in Fig. 1a. Sixteen numbers DFB laser sources of specifications as shown in Table 1 were multiplexed into an EDF through a multiplexer followed by a variable optical attenuator and switch. The input signal level was varied through this attenuator. The EDF was pumped by Bragg grating stabilized semi conductor laser diode pump sources at 980 nm coupled through 980/1550 WDM couplers as shown in Fig. 1b. There is option to pump the EDF bi-directionally using two pump laser diodes with suitable WDM couplers. Two polarization insensitive isolators were inserted at both ends of the system. An input optical isolator prevents ASE signals from propagating in the backward direction. Otherwise, reflected ASE would reduce the population inversion, thereby reducing the gain and increasing the noise figure. The output isolator prevents output reflections from reentering the EDFA. The optical gain and NF were measured in an optical spectrum analyzer whereas output power was measured through a power meter. The whole measurement was carried out by EXFO IQ 200 optical integrated test system.

Initially, the fibre length was optimized for obtaining maximum output signal power as it is evident from Fig. 2. The length of fibre increases as the injected pump power into the EDF increases. The population inversion along the fibre length was controlled by varying the injected pump power.

The fluorescence spectrum of the EDF used in our experiment is shown in Fig. 3. The broad shoulder of the spectrum ensures the presence of high concentration of aluminium into the EDF core.

3. Results and Discussion

The optical gain and NF for multi-channels amplification of the amplifier were measured for all three pumping configurations for varying pump powers and at different input signal levels. Fig. 4 shows one of the results where gain and NF characteristics for 16-channels simultaneous amplification of input signals of −20.0 dBm/ch with a pump power of 150 mW at 980 nm for all three different pumping configurations: co-, counter and bi-directional at optimum fibre length. In bi-directional configuration, 75 mW of pump power from both the laser diodes was injected into the EDF. We observed that bi-directional and counter-propagating pumping configurations show an improved optical gain for all the channels when compared to the co-propagating configuration as shown in Fig. 4. In the counter propagating mode the pump is strongest in the region where the signal power level is high. The most advantageous situation is to have the signal strong, where the inversion is maximum, so that the signal, not the ASE will deplete the gain. The pump configuration that yields the highest conversion efficiency is the counter-propagating mode as shown in Fig. 4. But noise figure (6–9.5 dB) is bad at counter-propagating configuration compared with (<4 dB) co- and bi-directional configurations. The reason is that in the co-propagating configuration, the portion of the fibre that the signal enters tends to be more inverted than the section by which the signal

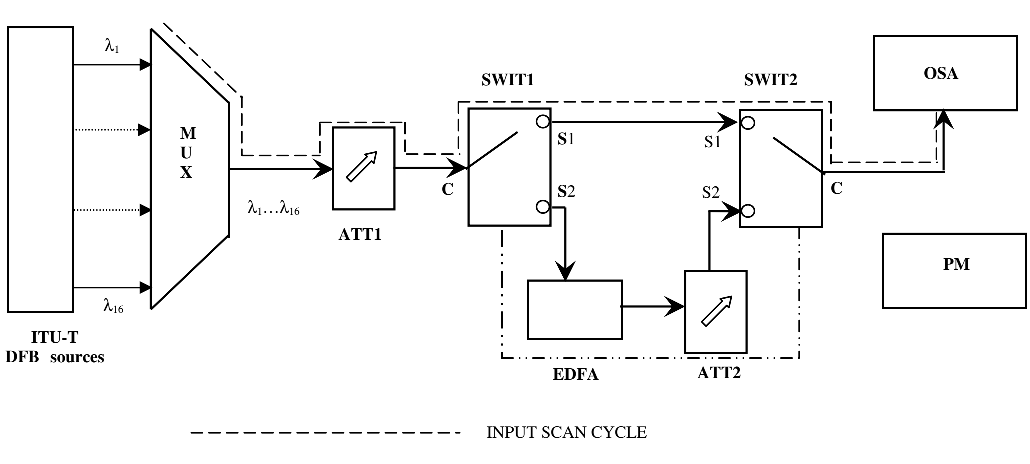

Fig. 1a. Schematic of multi-channel amplification through EDFA.