Low-threshold amplification at 1.5μm in Er:Y_2O_3 IO-amplifiers

H.J. van Weerden, T.H. Hoekstra[a], P.V. Lambeck, Th.J.A. Popma

MESA Research Institute, University of Twente

P.O. Box 217, 7500 AE Enschede, The Netherlands

Phone X-31-53-4892816, Fax X-31-53-4893343, E-mail: h.j.vanweerden@el.utwente.nl

[a]AKZO Nobel Central Research

P.O. Box 9300, 6800 SB Arnhem, The Netherlands

Phone X-31-26-3663574, Fax X-31-26-3662193, E-mail: t.h.hoekstra@akzo.nl

Due to their low pump power requirement, Er:Y_2O_3 IO-amplifiers are especially suited for loss compensation in complex IO-circuits used in telecommunication systems. Experimental results presented show a net gain at 1536nm of 5.7dB at only 10dBm launched pump power.

Introduction

Erbium-doped integrated optical amplifiers play an important role in fiber-optic telecommunication networks operating in the third window around 1.55 μm, due to their wide gain band and excellent noise behaviour. Applications can be found in e.g. amplifiers for loss compensation[1], lasers for signal generation in WDM-based systems [2] and cross-phase modulators for all-optical switching[3]. Driven by the rapid development of erbium-doped fiber amplifiers, a lot of research has been done on planar erbium-doped amplifiers, in a number of different host materials. Good results have been demonstrated in e.g. silica [4,5] and $LiNbO_3$ [6], where high amplification values of 10-15dB have been demonstrated.

In most reported amplifiers however, the required pump power for maximum gain is considerable: typically in the order of 20dBm. The pumping threshold is typically around 10dBm. Pump power requirements can be significantly reduced by increasing the confinement of the pump mode, i.e. reducing the dimensions of the waveguide core. This approach is especially suited for waveguide configurations with a high refractive index difference between core and cladding. This is the case for Er:Y_2O_3 amplifiers where the refractive index contrast between the (Er:)Y_2O_3 (n=1.90) core layer and the surrounding SiO_2 (n=1.44) layers is high, while scattering losses in the near-infrared are limited (<1dB/cm). From simulations we expect the required pump power for maximum gain to be of the order of 15dBm and pump threshold of the order of 5dBm. Such low-threshold amplifiers may be of great interest for application in integrated optical circuits for telecommunication systems. A number of amplifiers for signal loss compensation in e.g. a 1xN splitter, or a number of signal lasers on a WDM transmitter chip may be powered using a single pump source.

In this paper, the feasibility of obtaining low-threshold amplification in planar Er:Y_2O_3 amplifiers is demonstrated using experimental results on fabricated amplifiers.

Experimental

Fabricated Er:Y_2O_3 amplifiers have been studied experimentally to gain insight in their practical performance and to verify the correspondence between experimental and numerical results. Samples were prepared on 3" silicon {100} wafers. A 3μm thick SiO_2 buffer layer was created by steam oxidation to prevent optical power leakage into the high-index silicon substrate. A 0.2At% ($1.3\cdot10^{26}$ m^{-3}) uniformly doped Erbium-doped Y_2O_3 film was deposited by reactive co-sputtering using sputterguns[7]. Ridge waveguides were defined using photo-lithography and ion-beam etching. A 2μm thick SiO_2 cladding was sputter-deposited in order to reduce losses related to interface scattering. To enable fiber butt-end coupling, the samples were cleaved perpendicular to the waveguides. The samples used for testing are 43mm long, with a cross section as shown in figure 1.

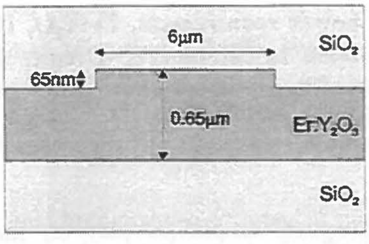

Fig. 1 Geometry of fabricated amplifiers

Amplifier properties have been studied using spectral transmission measurements in a fiber butt-end coupling setup as shown in figure 2. Pump and signal source were a 1.48μm semiconductor laser, with a maximum available power of 14.5dBm, and a tunable (1.46-1.59μm) narrowband semiconductor laser. Pump and signal were combined into a single-mode fiber and launched in the amplifier. At the amplifier output, they were collected, separated by a second WDM and detected. The signal laser was modulated at 280Hz to separate the signal from ASE present at the amplifier output.

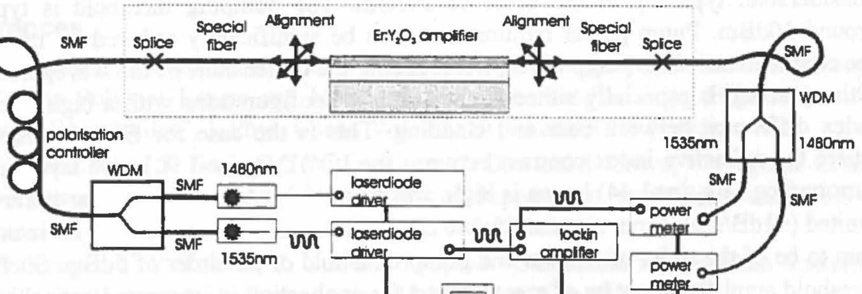

Fig. 2 Experimental setup

Spectral transmission measurements were conducted using a relative measurement technique. First, the signal power transmitted through the system including the amplifier section, as indicated by the dashed square in figure 2, was measured as a function of wavelength. Next, the measurement was repeated with the amplifier section replaced by single-mode fiber (SMF). From these measurements, assuming negligible losses in the SMF, the signal transmission spectrum of the amplifier section was obtained. To determine the actual transmission spectrum of the $Er:Y_2O_3$ amplifier the measured splice losses and estimated coupling losses, as obtained from field overlap and reflection calculations, were subtracted. Using this method, unpumped signal loss and gain spectra were determined. The polarisation used in the experiments was TE, the launched signal power was kept below -25dBm to avoid bleaching of absorption.

Results and discussion

The amplifier attenuation spectrum shown in figure 3 was determined using the unpumped signal loss spectrum. By subtracting the Erbium-related attenuation spectrum, as calculated using the absorption cross-sections obtained in earlier experiments, the background attenuation was determined to be 0.9 dB/cm, as indicated by the dashed line.

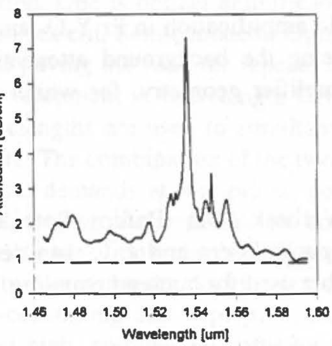

Fig. 3 Attenuation spectrum

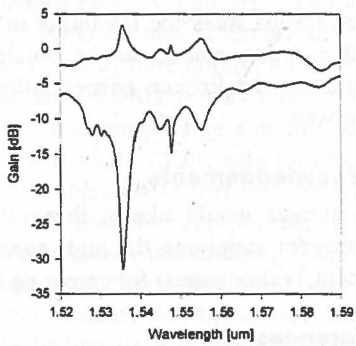

Fig. 4 Gain spectrum

The small-signal gain spectrum was measured at maximum pump power, as shown in figure 4 together with the unpumped loss spectrum. A population inversion was created, as can be seen from the inversion of the Erbium absorption peaks. One peak around 1585nm is not inverted, which may be evidence of excited state absorption from one of the higher-lying energy states. Net gain was obtained at 1536, 1548 and 1555nm. Maximum gain was 3.4dB at 1536nm. The maximum pump power launched in the waveguide was determined to be 8dBm.

To verify the coherence between experimental and theoretical result, the amplification at 1536nm was measured as a function of pump power, as shown in figure 5. Here, the circles indicate the measured data, the solid line a model calculation[8]. The measurements agree remarkably well with calculated results, except for a slight deviation near maximum pump power. This is due to reflection of pump light back to the pump laser, resulting in a red-shift of the laser wavelength and a decreased gain. From these results, the pump threshold was determined to be 5dBm.

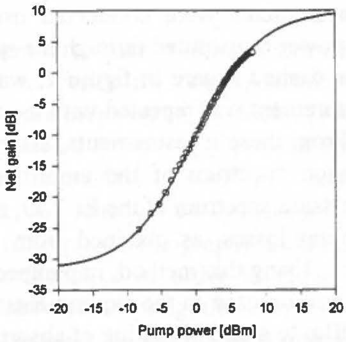

Fig. 5 Gain as a function of pumppower

From figure 5, it can be seen that maximum gain has not been reached due to lack of sufficient pump power. For that reason, a high-power 1.48μm semiconductor laser is being installed with at present a maximum available power of 17.5dBm. Preliminary gain measurements at the 1536nm peak resulted in a small-signal gain of 5.7dB at a launched pump power of 10dBm.

These results show the feasibility of low-threshold amplification in Er:Y_2O_3 amplifiers. Further improvement can be obtained by reducing the background attenuation and optimising the Erbium concentration and the amplifier geometry, for which work is underway.

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