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Optimum Position of Isolators within Erbium-Doped Fibers

Ole Lumholt, Kim Schüsler, Anders Bjarklev, Svend Dahl-Petersen, Jørn H. Povlsen, Thomas Rasmussen, and Karsten Rottwitt

Abstract—An isolator is used as an amplified spontaneous emission suppressing component within an erbium-doped fiber. The optimum isolator placement is both experimentally and theoretically determined and found slightly dependent upon pump power. Improvements of 4 dB in gain and 2 dB in noise figure are measured for the optimum isolator location at 25% of the fiber length when the fiber is pumped with 60 mW of pump power at 1.48 μm.

INTRODUCTION

THE development within the field of optimizing the gain efficiencies of erbium-doped fibers [1] has revealed in a tremendous increase to more than 10 dB/mW for fibers with gain optimized designs [2]. Even for these fibers most of the pump photons are still lost to amplified spontaneous emission (ASE) yielding gain saturation as the ASE becomes comparable with the pump power at the fiber ends. The ASE at the signal input end is especially unwanted, as a low noise figure is depended upon a high population inversion in this part of the fiber. Obviously, a way to reduce the accumulation of backward traveling ASE is to insert an isolator within the active fiber [3]. Numerical calculations have shown [3] that for favorable locations of the isolator, a remarkably improved gain and a noise figure close to the theoretical lower limit can be obtained. Recently, a work was presented [4] with an isolator inserted among two pieces of erbium-doped fiber, pumped with 0.98 and 1.48 μm light, respectively. However, the purpose with that configuration was totally different, as the isolator was employed as a necessity to prevent gain saturation by the 0.98 μm light amplifying the 1.48 μm pump light.

THEORY

Consider the situations where the length of an erbium-doped fiber is gain optimized. If an isolator is inserted at the input end of this fiber, a gain reduction and a noise deterioration arises because both signal and pump are attenuated by the isolator insertion loss. Also a location at the signal output end will reduce the gain, as in this case, the output signal power

is attenuated by the insertion loss. If counter propagating pump is present for this placement of the isolator, a further deterioration of both gain and noise figure occur, as the pump power is affected by both the isolation and the insertion loss. Looking next at the situation with the isolator placed within the active fiber, in a distance $L1$ from the signal input end, less pump power is lost in the isolator and the signal gain in the first part of the erbium-doped fiber increases because backward ASE is reduced by the isolator. This exemplifies the existence of an optimum placement of the isolator within the active fiber.

EXPERIMENTAL SETUP

The experimental setup for evaluating the gain characteristics is shown in Fig. 1. The pump and signal laser diodes are emitting at 1.48 μm and 1.55 μm respectively. An ordinary bidirectional pumping scheme is adapted and regulated so exactly the same amount of pump power is launched into the erbium fiber ends. To determine the launched pump power, a 1:99 coupler is inserted between the pump and the WDM-coupler at each fiber end. All free fiber ends in these, as well as in the other couplers, are cleaved in angles of 10° to prevent unwanted reflections. The erbium doped Al_2O_3–SiO_2 fiber has a numerical aperture of 0.31, a cutoff wavelength of 0.98 μm and has further been described in [5]. The isolator, which is inserted within the erbium fiber has an insertion loss of 1.5 dB, including the splice losses to the erbium fiber, and an isolation of 40 dB. The ASE spectrum around the signal and the total ASE spectrum, recorded by a double monochromator, are calibrated by a power measurement of the total ASE, and used to evaluate the noise figure.

RESULTS AND DISCUSSION

The length of the erbium-doped fiber has been gain optimized when inserted in the above mentioned pumping configuration, but without any isolator located between the fiber ends, and receiving a total of 60 mW launched pump power. The measured maximum gain of 37.9 dB and the corresponding noise figure of 7.4 dB are used and denoted as reference measurements in the remaining of this communication.

Corresponding measurements of gain and noise figure for a variety of total pump power levels are shown in Fig. 2 versus the relative location of the isolator within the reference fiber. That is the ratio between the erbium fiber length among the signal input end and the isolator, and the total length of the erbium-doped fiber. The predicted existence of an optimum location of an isolator within the fiber is clearly verified in
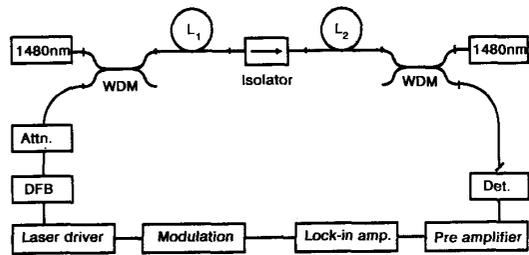
Fig. 1. Experimental setup. Not shown in the figure are monitor couplers at the signal input end of the two pump inputs.
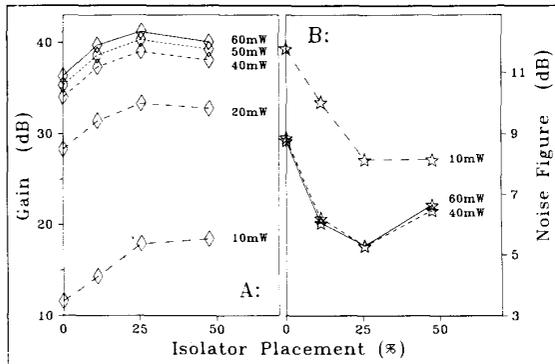

Fig. 2. Measured gain and noise figure versus the relative isolator placement between 0 and 50% of the total fiber length. Shown for pump power levels between 10 and 60 mW.
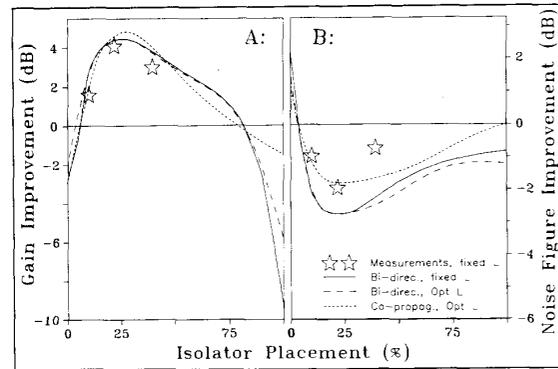

Fig. 3. (a) Gain versus relative isolator placement among 0 and 100% of the total fiber length. (b) Noise figure versus relative isolator placement. Measurements illustrated by stars. Calculations corresponding to the experiment are shown as solid lines. Calculations at gain optimized lengths in a bidirectional and copropagating pumping scheme are shown as dashed and dotted lines, respectively.

the figure, showing a pump power dependent optimum placement between 25 and 40%. The optimum relative location is slightly decreasing for increasing pump power. It is seen that the noise figure also improves with increasing pump power until a noise floor is reached for a pump power higher than 40 mW. The noise figure is constrained by the presence of stimulated emission at the pump wavelength giving a fundamental lower noise figure limit that very closely is reached in this situation. Using 60 mW of pump power, a maximum gain of 41.2 dB, and a noise figure of 5.3 dB are measured. This is an improvement of 3.3 dB in gain and 2.1 dB in noise figure compared to the reference and it is respectively 5 dB and 3.5 dB better than the situation with the isolator placed at the signal input end of the amplifier.

Along with the reduced ASE, the gain optimized fiber length will increase. For a total use of 60 mW pump power, the overall highest gain of 42.0 dB and a corresponding noise figure of 5.4 dB are measured when both the isolator location and the fiber length are optimized. Compared to the reference, the improvements are 4.1 dB in gain and 2 dB in noise figure and the increase in optimized fiber length is 25%. In comparison with measurements for two other isolator placements (10 and 40%) of this fiber length, the improvements are shown as stars in Fig. 3(a) and (b).

Numerical calculations are made by use of an accurate model [6] which has been extended in [3]. Numerous measured data for the considered fiber, in a pumping scheme similar to the experiment, are used as input parameters to the

model. Calculations are shown in Fig. 3 for various relative placements of the isolator. The solid lines correspond to the measured data. The fiber length is gain optimized with the isolator at the optimum position, and this total fiber length is kept unchanged for other relative locations of the isolator. The dashed lines illustrate the situation when the total fiber length is gain optimized for each relative location of the isolator. To generalize the analysis, corresponding calculations are made for a copropagating pumping scheme (dotted lines).

Looking first at the gain, the difference between measured and calculated improvements are less than 1 dB, and the optimum isolator placement in the bidirectional pumping scheme is both calculated and measured to be 25% of the fiber length. For the copropagating scheme, the optimum placement is a few percent larger. Although the improvement is largest for this configuration, the overall highest gain is obtained by the bidirectional scheme, as the reference gains are 34.9 and 36.1 dB, respectively. A net gain is obtained for both configurations, as long as the isolator is placed within 10–80% of the fiber length. The large gain penalty observed for an isolator at the output end of the bidirectional pumping scheme, is caused by the attenuation of the backward pump power by 40 dB isolation and the splice losses to the isolator. In the copropagating scheme, only the output signal power is reduced by the 1.5 dB insertion loss when located at this position.

Looking next at the noise figure, it is seen that the measured improvement is up to 1.5 dB less than predicted (solid line), but still the course in both cases is very similar. It is seen that the optimum isolator location with respect to noise figure is a few percentages lower than the gain optimized. Although the improvement for the bidirectional case is 1 dB better than for the copumped, both configurations result in the same low noise figure. This is due to the noise figures for the reference fiber, which in the bidirectional configuration is 1 dB higher than for copumped scheme (7.2 and 6.2 dB, respectively).

Conclusion

The use of an isolator has experimentally been verified to be a simultaneous gain and noise figure improvement component, when inserted within the erbium-doped fiber. The optimum location of the isolator is determined in the range of 25–40% of the fiber length, decreasing for increased pump power, for both copumped and bidirectional pumped amplifiers. For this location, the noise figure comes close to the theoretical lower limit. For 60 mW pump power at 1.48 μm, an increase of 25% in the gain-optimized fiber length was determined when the isolator was inserted at the optimum location of 25% of the fiber length. Compared with a gain optimized fiber without any isolator, improvements of more than 4 dB in gain and 2 dB in noise figure were measured, yielding 42 dB gain and a 5.4 dB noise figure.

Acknowledgment

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Amplified Distributed Reflective Optical Star Couplers

Y. K. Chen

Abstract—We present a practical configuration of an amplified distributed reflective N-star coupler using 2×2 3-dB fiber couplers and minimum numbers of erbium-doped fibers, pump lasers, and standard fibers. The constitution and characteristics of this coupler are investigated. Besides a tremendous saving of the required standard fibers, this distributed coupler is more efficient, more reliable, more flexible for future expansion, and more cost-effective for application in optical networks.

I. Introduction

OPTICAL star networks have the potential to provide very large throughput, and they are expected to find widespread application in upgrading existing networks and photonic networks [1], [2]. In many practical networks, users are geographically distributed in clusters such as several buildings on a campus. Hence, using a distributed star coupler is better than a centralized one [3]. The numbers of fibers and components required to implement a star network

can be reduced to a half by using a reflective N-star coupler instead of a transmissive $N \times N$ star coupler [4]. However, the inherent $1/N$ splitting and excess losses may limit the ultimate size and throughput of the star network [5]. Some researches with incorporation of erbium-doped fiber amplifiers (EDFA's) for accommodating more users, N, had been shown in centralized star couplers [6]–[8]. So the distributed reflective star coupler incorporating EDFA's is expected to have better performance and applications in practical networks.

In this letter, we present a configuration for constructing the amplified distributed reflective N-star fiber coupler using 2×2 3-dB fiber couplers and minimum numbers of erbium-doped fibers (EDF's), pump lasers, and standard fibers. The constitution, characteristics, and features of this coupler are investigated.

II. Configuration

The amplified distributed reflective N-star coupler with $N = m^2$ and $N = 2 m^2$ is similar to the centralized reflective active star coupler, but it is divided into small parts and these parts are distributed over n nodes (i.e., locations) uniformly around a circle of diameter D of the network