# High-Gain Short-Length Phosphate Glass Erbium-Ytterbium-Doped Fiber Amplifiers*

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## Abstract

Er-Yb co-doped fiber lasers and optical amplifiers are becoming popular due their high-gain, compact size, and efficient pump utilization. Several reports can found in the literature on such devices highlighting their strength, benefits and associated issues. We have conducted various test experiments on optical amplifiers utilizing co-doped active fiber ~ 8 cm to 40 cm length that were mechanically spliced with WDM couplers (980/1550 nm). Initial tests show that for the certain pump level and doping densities the optical amplifier shows a strong fluorescence in long wavelength regime (L-band). A broadband tunable laser source in C+L band was used to simulate the DWDM signals-comb experiences a moderate gain. We believe with a strong pump and gain flattening filters, it will make a compact, high-gain and an efficient L-band optical amplifier.

## Introduction / Background

Over the past decade, the demand for high-speed data transmission has increased tremendously. With the new development of the Internet applications, the demand for more and more bandwidth continues to grow. Although EDFA (Erbium Doped Fiber Amplifier) is a mature technology and is the workhorse for dense wavelength division multiplexing (DWDM) and all optical networks, yet its relatively large size requires further research and development efforts to achieve the ever-wanted small, compact, and efficient fiber amplifiers. In this paper, initial investigations on a high-gain, short-length Phosphate glass Erbium-Ytterbium-doped fiber amplifier are presented.

Phosphate glass is an attractive material for optical amplifiers, because it exhibits a high solubility for rare-earth ions. This allows a high concentration of those active-ions into a small volume of the phosphate glass. High number density of active-ions results in small size optical devices such as fiber lasers and optical amplifiers with higher gain per unit length [1,2]. In addition, phosphate glass combines several good material properties such as high-gain, wide-band tunability, and good chemical stability and durability. High solubility allows co-doping of Yb with $Er^{+3}$ that broadens the pump absorption and leads to an efficient pump coupling while relaxing the stringent requirements on the pump wavelengths around 980 nm.

A demonstration of experimental setup and preliminary results are presented from the studies conducted on the new high-gain phosphate glass Er-Yb doped fiber amplifier. We investigated the gain characteristics of the active-fiber used in this amplifier. Using a tunable laser, the performance at different signal wavelengths and strength (in the1550 nm band), and influence of various pump powers was studied. The tunable laser spanned both C- and L-bands (1525 to 1610 nm) and tuning over the ITU-grid simulated a WDM signal condition in order to investigate the spectral response of the amplifier.

Various test signals (wavelength, power) and different pump configurations were used to evaluate the performance and efficiency of the new fiber-amplifier. Previous experimental testing showed that a 26dB gain could be achieved using 1480nm pump with an only 8.8cm fiber length [1]. We have investigated 20-cm length of a single-mode fiber with its outer diameter ~ 180 μm, and 6-8 μm Er-Yb doped core, spliced and connectorized with WDM coupler (980/1550 nm) for different pump configurations. From the fluorescence at various pump levels it seems that for the available pump conditions the gain peak is shifted towards long wavelength side. Therefore, gain performance in the L-Band regime was studied and experimental results are presented.

## Active Fiber

This samples of the amplifier were derived from an active fiber that is an uncoated single mode configuration with a core containing $Er_2O_3$ and $Yb_2O_3$ [3]. Its typical length was ~20 cm with cross-sectional view shown in figure-1 below.

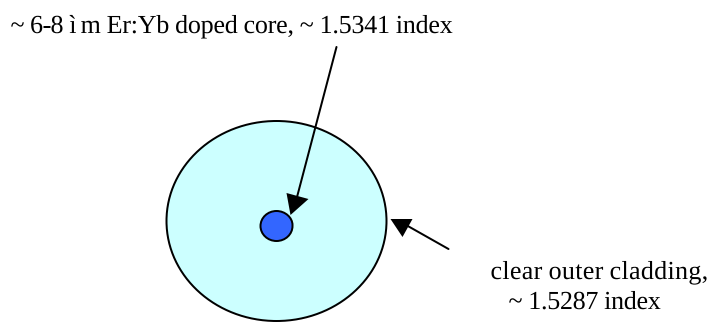


**Figure 1**

## Experimental Setup

In a simple rudimentary setup we used 980-nm pump laser module (ADC, Corp.) with a single-mode fiber (SMF) pigtail with a universal connector and a C+L Band (1510-1610 nm) tunable laser (EXFO IQ-203) as an agile signal source. The pump couples straight through a universal connector in WDM fused fiber coupler, and the signal is multiplexed with the pump through the second arm. The pump and signal then together travel through SMF the other end of coupler, which is spliced mechanically with the active fiber. The other end of the active fiber is also spliced mechanically with a SMF that has a FC-connector for optical spectrum analyzer (OSA). Fig.2 illustrates the main set up.

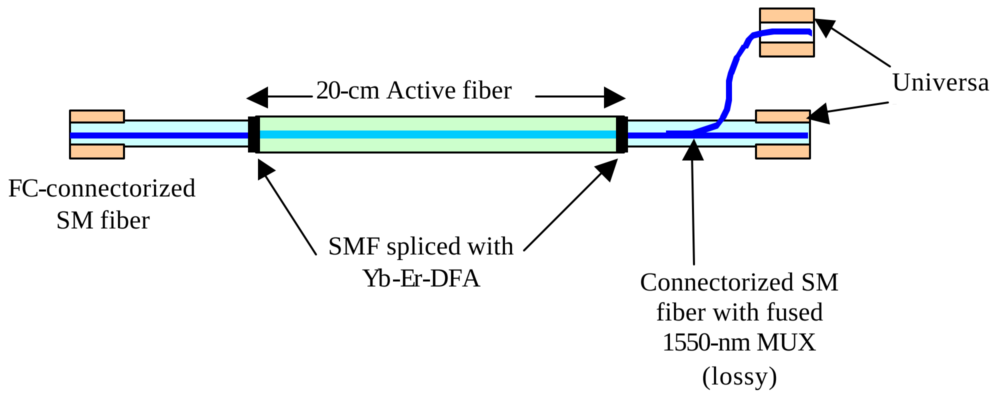


**Figure 2**

We used two different pump configurations, forward pumping and backward pumping, the results are discussed below.

### *a- Backward Pumping*

In this configuration we pumped the fiber using 980-nm pump, from the "output side", and connected the OSA to the input side. First we pumped it in the absence of signal at different pump powers, 110, 150 and 180 mW, in order to see the fluorescence of the active fiber. The configuration is shown in figure 3, and the results are shown in figure 4.

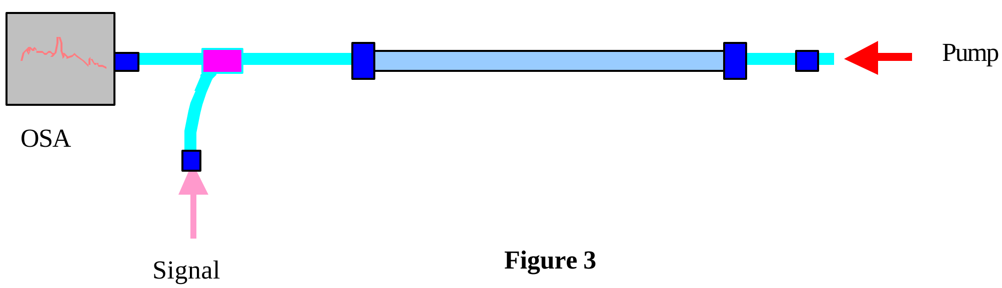


**Figure 3**

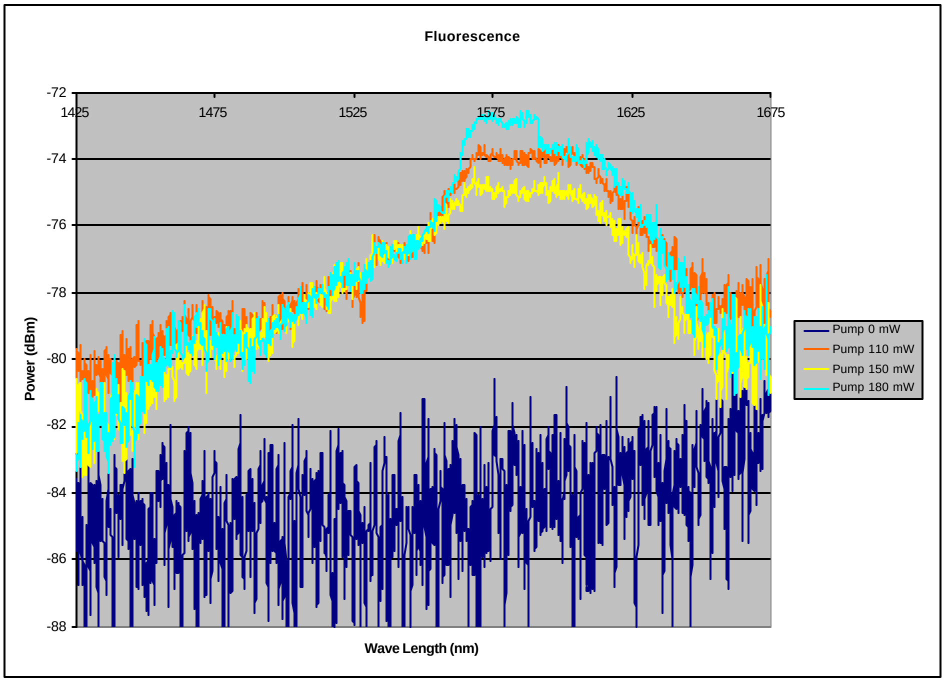


**Figure 4**

From the graph it is evident that the fluorescence is strong in 1575 to 1630 nm regime. Therefore this fiber has its gain in the L-band range, with maximum gain about 10-dB in the 1575-nm wavelength, for pump power 180 mW.

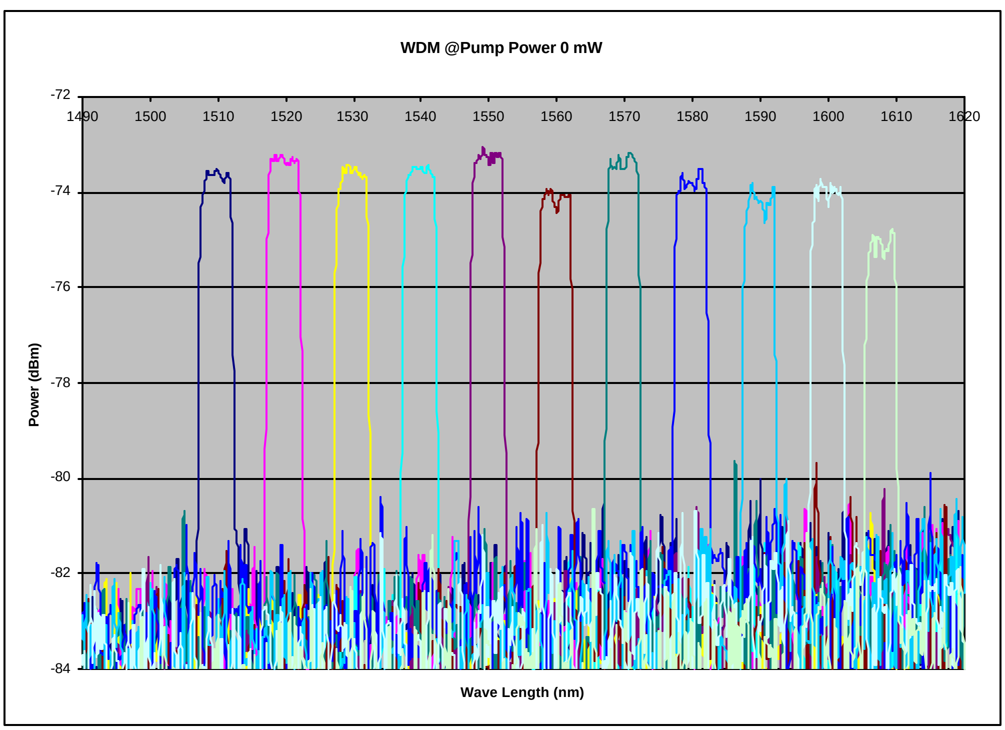


**Figure 5**: Simulated WDM signals from a tunable laser after passing through Amplifier with the pump laser turned off.

After that different WDM signals were simulated by tuning the signal laser from 1510 to 1610 nm with a step of ~10 nm in order to span the full spectral region of the test amplifier. For different pump powers, the results are shown in figures 5, 6 and 7, respectively.

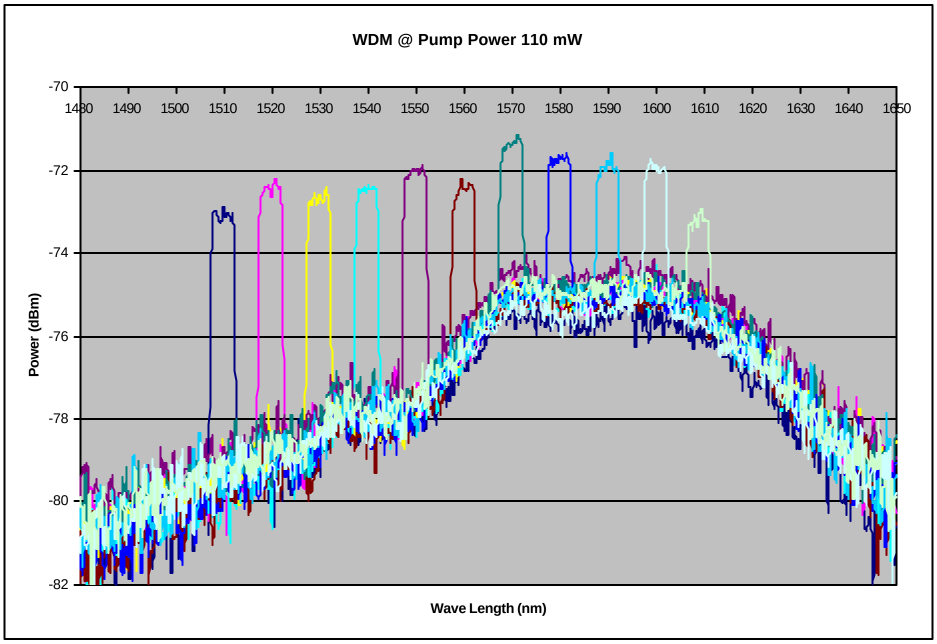


**Figure 6**: Simulated WDM signals from a tunable laser after passing through Amplifier with pump laser operating at 110 mW.

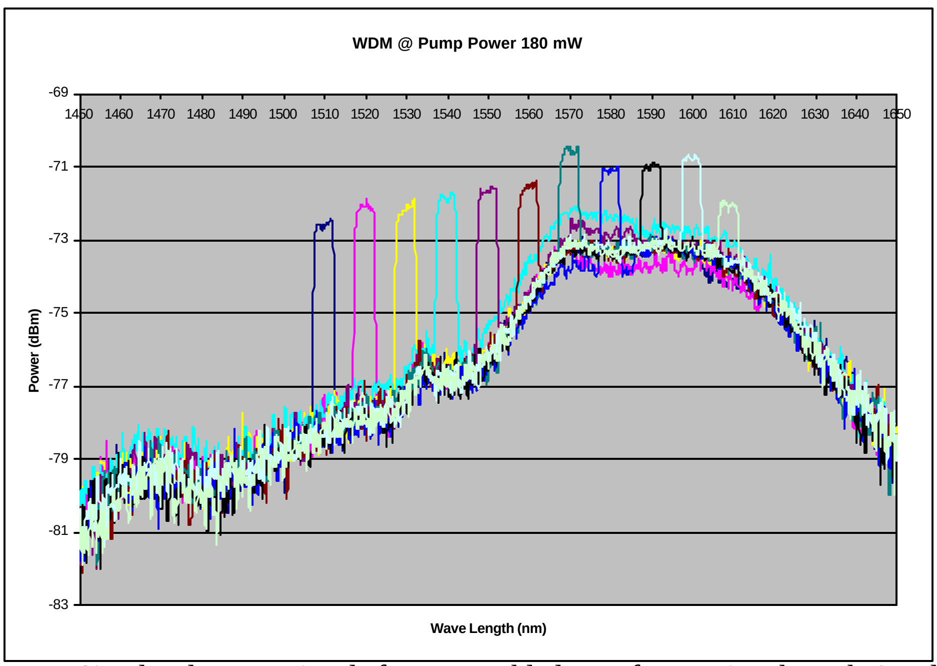


**Figure 7**: Simulated WDM signals from a tunable laser after passing through Amplifier with pump operating at 180 mW

The data shows a gain in the L-band regime. The main limitation here was the maximum pump power, which is 180 mW because of that we couldn't achieve the full gain of this amplifier.

### *b-Forward Pumping*

In this configuration the pump and the signal are coupled into the fiber from the same direction and the signal is collected from the other side, as shown in figure 8.
The results are shown in figure 9 using ~180 mW power of the pump laser.

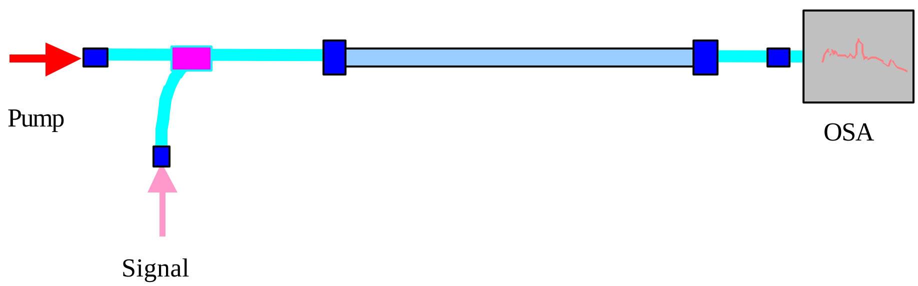


**Figure 8:** Co-directional /forward pumping

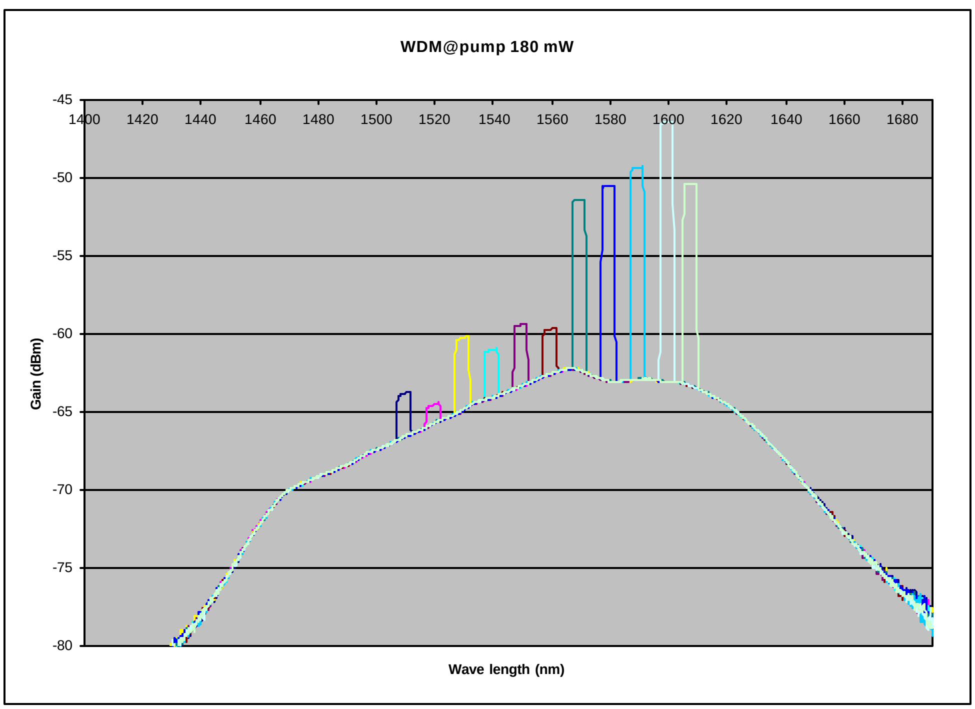


**Fig. 9:** Simulated WDM signals from a tunable laser after passing through Amplifier with forward pump ~180 mW.

More gain can be achieved by using this configuration, again the main limitation is the pump power.

**Conclusion and Future Work**

In summary, we have demonstrated preliminary results using the new high-gain phosphate glass Er-Yb doped fiber amplifier. It was shown that by applying certain pump levels and doping densities the optical amplifier shows a strong fluorescence in long wavelength regime (L-band), with maximum gain in 1575 to 1630 nm regime, satisfying the goal of making a compact, high-gain and an efficient L-band optical amplifiers.

More tests will be conducted on different samples of the active fiber using higher pump powers > 300mW at 980 nm, and different pump wavelengths (1480 nm, 850 nm ), for different lengths of the fiber in order realize an optimized amplifier.

**Acknowledgement**: The authors would like to thank Scott Williams and the staff of the International Fiber Technologies (IFT), Inc. for the technical help in fabrication and connectorization of WDM (pump and signal) for various L-band amplifiers samples. EXFO America, Inc. is acknowledged for providing a wideband (C+L) tunable laser system used in these studies. The support of Kigre, Inc. in the form of special active samples is also much appreciated.