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Erbium-Doped Fiber Amplifier Elements for Structural Analysis Sensors

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ABSTRACT: The use of erbium-doped fiber amplifiers (EDFAs) in optical fiber sensor systems for structural analysis is described. EDFAs have been developed for primary applications as periodic regenerator amplifiers in long-distance fiber-based communication systems. Their in-line amplification performance also makes them attractive for optical fiber sensor systems which require long effective lengths or the synthesis of special length-dependent signal processing functions. Sensor geometries incorporating EDFAs in recirculating and multiple loop sensors are discussed. Noise and polarization birefringence are also considered, and the experimental development of system components is discussed.

1. INTRODUCTION

Optical fiber sensors have been developed during the past fifteen years for the measurement of strain, temperature, acoustic waves, rotation rate and other physical observables. Optical fiber sensors may be classified according to the physical observable measured, the optical property modulated by the environmental field, or whether the light remains inside the fiber (intrinsic), exits the fiber to interact with the surrounding environment (extrinsic) or depends upon evanescent field coupling outside the fiber.

One of the major potential advantages of optical fiber sensors over conventional wire-based sensors is that they may be spatially multiplexed so more than one individual sensor element may be addressed simultaneously over a single input/output fiber line. Because in-line fiber amplifiers could be used to amplify fiber sensor signals, multiplexing schemes which are typically limited by the accumulated losses at each of the sensor locations or bus interconnection nodes could be extended to incorporate large numbers of sensors. Additionally, time domain-based optical fiber sensors which rely on multi-pass sensor signal propagation in re-entrant loops to realize signal processing and filtering operations may be improved by the incorporation of fiber amplifiers within the loop path itself.

Erbium-doped fiber amplifiers (EDFAs) in particular have been demonstrated during the past several years in repeaterless long distance fiber communication systems, as well as in loop and multi-loop signal processing applications. These all-fiber devices have good in-line amplification characteristics at wavelengths required for low loss, long distance propagation, and the current amplifier limitations due to both noise and birefringence are being investigated by numerous research groups.

The objective of this student design project and workshop paper is to briefly explore the possible applications of EDFAs in optical fiber sensor systems, and to discuss work-in-progress on EDFA-based fiber sensor components and design. The paper is divided into three following sections. The individual optical fiber components of a prototype EDFA-based fiber sensor system are

discussed in detail in the following section. The next section of the paper outlines the assembly and test procedures for the proposed OTDR-based EDFA sensor system we considered in detail. Comments concerning the progress of this effort are given in the fourth section.

2. EDFA-BASED OPTICAL FIBER SENSOR SYSTEM COMPONENTS

The EDFA-augmented reentrant loop OTDR sensor system to be considered is shown in Figure 1. The first part of this student design project has been to design, fabricate and test the system components required to fabricate the system [1]. These components are briefly discussed in this section.

The wavelength-division multiplexing (WDM) coupler is required to couple together the 1550nm OTDR signal and the 980nm input pump signal. Several WDM couplers were fabricated using modified fused biconical tapered (FBT) coupler manufacturing methods. The measured spectral response of one of the fabricated couplers is as shown in Figure 2. Minimizing excess losses for this coupler is important, primarily because the amplification characteristics of the erbium-doped fiber are strongly influenced by the input 980nm pump power level.

Isolators are required to prevent 980nm pump signal components from being coupled back into the OTDR pumped laser source, or forward into the OTDR avalanche photodiode. The geometry used for these isolators fabricated is shown in Figure 3, and typical spectral transmission is shown in Figure 4. Two GRIN lenses were carefully positioned at the ends of two opposing single mode fibers and across a sharp cutoff spectral filter. Isolation of greater than 30dB has been obtained with this simple and straightforward optical design.

The special tap-off coupler shown in Figure 1 was designed and fabricated by Litton-PolyScientific using side polishing and carbon dioxide laser stitch techniques.

The erbium-doped fiber used in the following experiment was provided by AT&T Bell Laboratories. The measured spectral characteristic of the fiber, shown in Figure 5, confirms the pump absorption and laser amplification model of energy states shown in Figure 6 [2].

3. OTDR SYSTEM CONSTRUCTION AND STATUS

The system shown in Figure 1 was assembled using the components indicated below. Current status is that insufficient light is coupled into the input 980nm single mode fiber to allow efficient amplification in the erbium-doped fiber; it is estimated that 20-30mW is required for a single-trip gain of 4dB. Measurements obtained using the OTDR system and a reentrant loop which does not contain an erbium doped fiber element indicate that approximately 2.6dB is necessary per trip to cancel losses in the tapoff coupler, the in-line splices and connectors, and the losses in the fibers themselves.

4. DISCUSSION

Future work for the remainder of the Spring Semester 1992, and for continued work on an undergraduate/graduate independent study basis during Summer 1992 will involve improvement in source-to-fiber coupling and the use of a pigtailed 980nm pump laser. Further, we will work to replace the Litton coupler with a more efficient single mode tapoff device, in order to both reduce the round-trip losses, and to reduce the accumulated pulse dispersion which limits effective loop-dominated sensing and signal processing capability. With full single-mode operation, the noise and polarization effects of the EDFA will likely become the limiting factors in system performance [3]. Due to the relatively long times required to obtain averaged data from currently available OTDR strain measurement systems, and the relatively long gage lengths of OTDR-based strain sensor elements, the proposed high-resolution quasi-distributed strain measuring system would

likely be of most use in applications requiring the analysis of large civil structures such as roadways, railways, bridges and dams.

5. ACKNOWLEDGEMENTS

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6. BIBLIOGRAPHY

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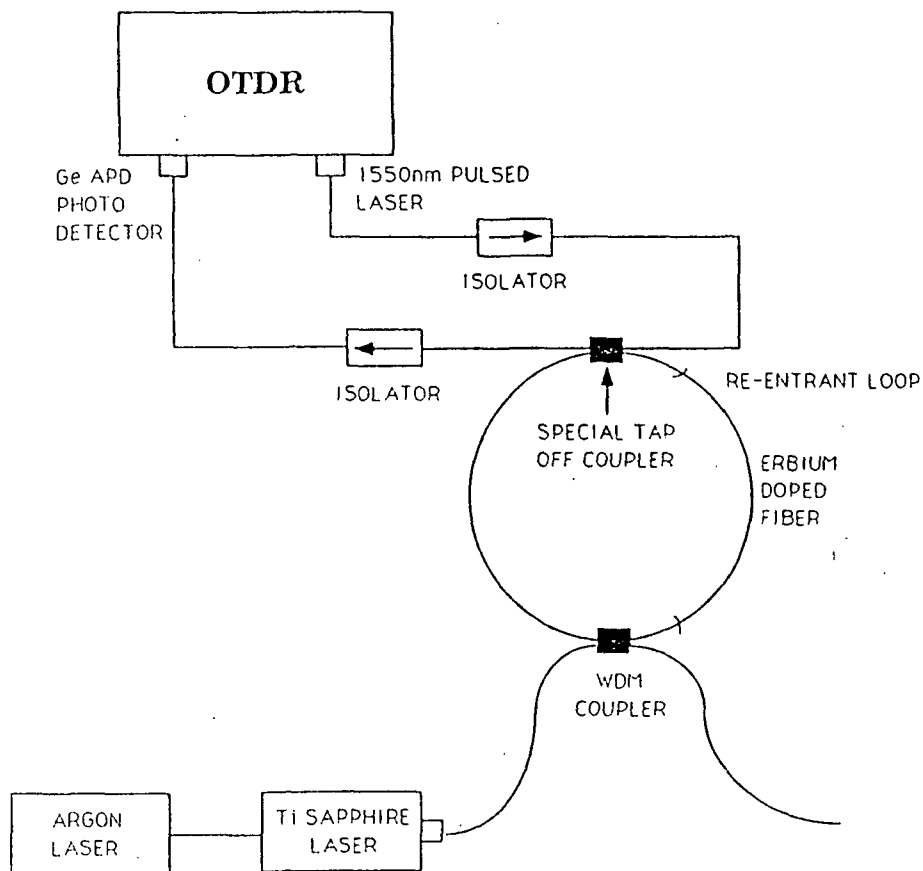


Figure 1. EDFA-augmented OTDR sensor system geometry.

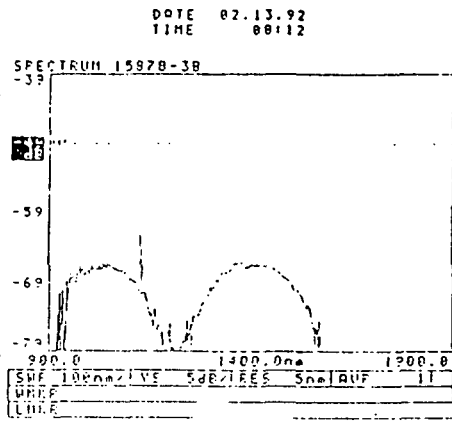


Figure 2. WDM coupler spectral response.

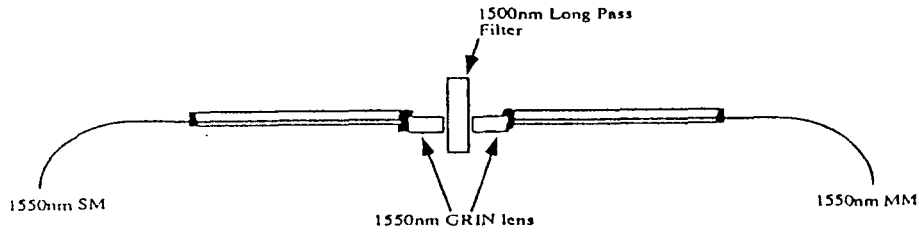


Figure 3. In-line fiber isolator geometry.

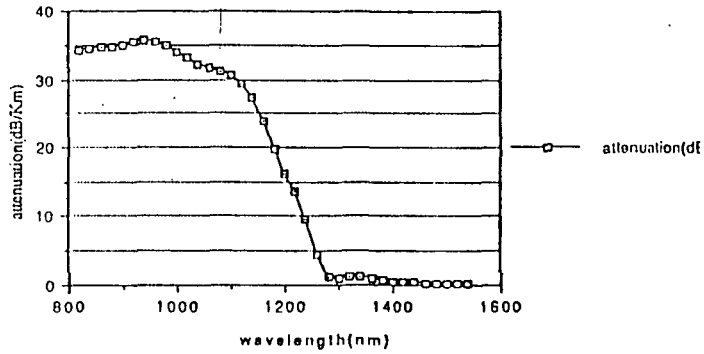


Figure 4. Fiber isolator spectral response.

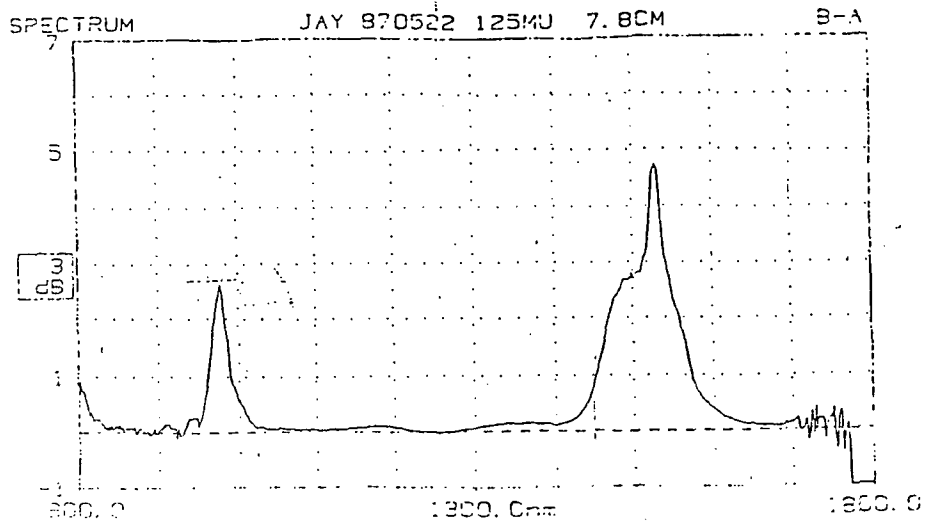


Figure 5. Erbium-doped fiber spectral response.

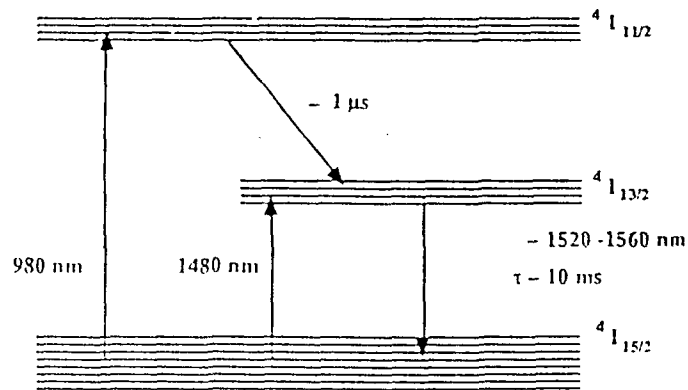


Figure 6. Erbium-doped fiber energy band level model.