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FIBER OPTIC SENSOR FOR BENDING MEASUREMENT

BY

RAMONA GĂLĂTUŞ[*], E. VOICULESCU and MARINA ŢOPA

Technical University of Cluj-Napoca

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Abstract. The paper introduces a simple system based on a bendable large mode area (LMA) fiber, meant for a sensing accuracy of the microns order. The simulation shows that for a 1…3 m length of active fiber the 1 μm difference in fiber bending radius is quite well discerned. A power variation of the fundamental mode in excess of 10 μW (–20 dB.m) up to 48 μW has been obtained. The signal was 1550 nm (typical), and the pump wavelength 980 nm, also typical for telecommunication links. The performance is optimized by varying the bending radius, index/doping profile, and the LMA fiber core diameter.

Key words: fiber optic sensor; bending loss; EDFA (Erbium Doped Fiber Amplifier); YDFA (Ytterbium Doped Fiber Amplifier); LMA (Large Mode Area); highly doped fiber.

1. Introduction

The technology of optical sensors presents itself as advantageous for a diverse range of uses – from on-site monitoring sensors to distributed sensor arrays. Its great adaptability to today's competitive industrial landscape is achieved by improving the technological base of manufacturing and also

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[*] Corresponding author: *e-mail*: ramona@bel.utcluj.ro

satisfying the requirements for energy efficiency and reduction of power per circuit\function. Optical fiber sensor technology offers conclusive solutions to monitoring and evaluation of extreme parameters associated with safety and security applications. Novel and innovative structures and materials, as well as security application requirements offer a number of advantages in using fiber sensor: increased sensitivity over existing techniques, geometric versatility due to arbitrary shape configuration, sensing various physical perturbation, stressing environment operation and compatibility with optical fiber telemetry technology (Giallorezi, 1982).

This paper describes a power-amplitude sensor, designed to operate as a bending positioning transducer with accuracy of the order of microns. The sensor can be designed with a sensitivity that can be set at a specific value according to the requirements of the measurement condition. Displacement and position sensing by means of fiber optic technology is achieved by means of obtaining a variation in near-total internal reflection of light accepted at the input along the length of the fiber. Connected with multiplexed sensing processing schemes, the distributed sensor array may find an application in the real-time monitoring and damage detection of large and critical engineering structures.

The system designed has been guided to obtain a low-cost sensor based on LMA fiber. The simulation taking in account the macrobending effect shows that for a short length of the active fiber, depending direct proportionally with the dopant concentration, the 1µm difference in fiber bending radius is quite well discerned. The distortion can be applied to fibers with core diameters in the range of 1.7 µm up to 100 µm. In the first range (1.7 µm…2 µm) takes into account traditional step-index single mode EDFA operation. Larger core fibers are essentially multimode, with a competition of all modes as the fiber is amplifying. It was studied the multimode fiber with core greater than 20 µm using parabolic index and doping profile and different double-clad index profile for diameters greater than 40 µm up to 100 µm, used to help with higher-order modes attenuation. The effective area (MFD) values are studied under the bending effect.

2. Sensor Modeling

The sensor principle of operation relies on the schematics shown in Fig. 1.

It was chosen an Erbium Doped fiber with

$$\lambda_{\text{signal}} = 1{,}550\ \text{nm},\ P_{\text{signal}} = 1\ \text{mW and } \lambda_{\text{pump}} = 980\ \text{nm},\ P_{\text{pump}} = 100\ \text{mW}. \qquad (1)$$

These parameters are typical for telecommunication links.

The power distribution among the fundamental mode for different bending radius is depicted in Fig. 2 and shows that for a 1μm difference in the fiber bending radius a variation in excess of 10 μW (–20 dB.m) has been obtained.

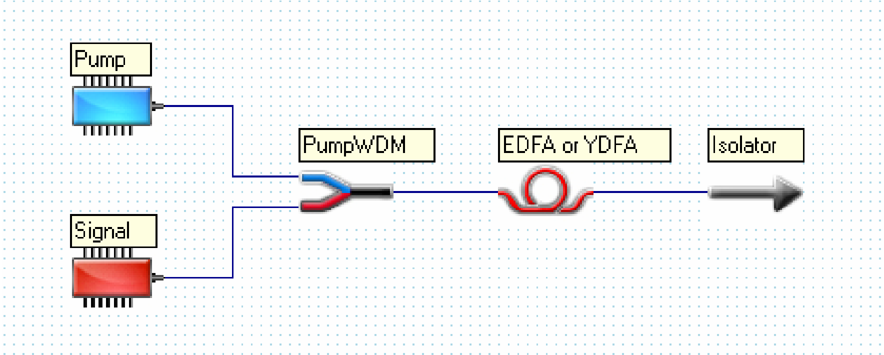

Fig. 1 – Standard Fiber Amplifier Setup for Bending Measurement (LAD 4.0 license).

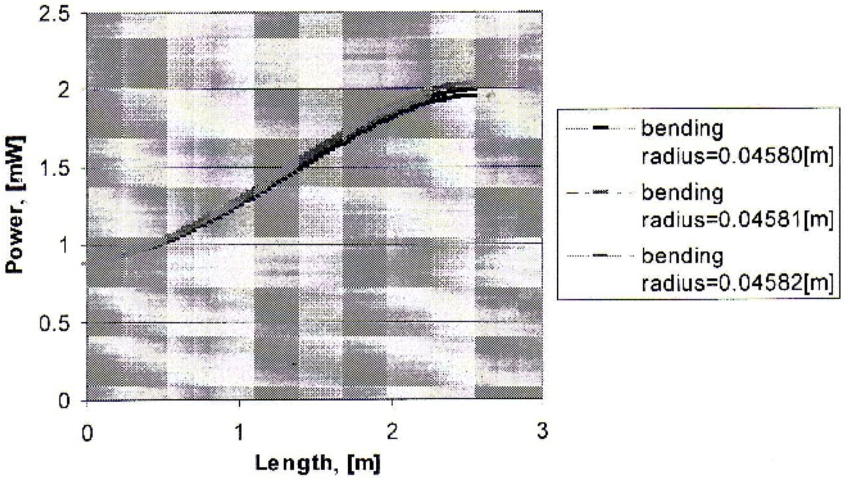

Fig. 2 – EDFA bending effect simulation, for a doped fiber, single step, with radius=1.7um and doping density=1.22^25/m^3 .

In the same setup, using a multiplexed system with a different core radius step index EDFA, a different power-on based bending radius transducer was obtained (Fig 3). But the operations are range limited by real-values core and multimode operations. To obtain a wide range of the bending radius transducer, the optical fiber radius was increased, but a multimode operation is always more likely to happen. As a result, the multimode coupling effect can modify the operating principle introducing power amplification in the fundamental mode, as a stressing effect. A solution for reducing this phenomenon is to obtain a LMA fiber with the main power distribution among the fundamental mode (Voiculescu, 2008), to linearize the transducer working region. Fig. 1 depicts the depressed-cladding EDFA index profile and used dopant concentration for a 100 μm LMA, to study the fiber bending influence.

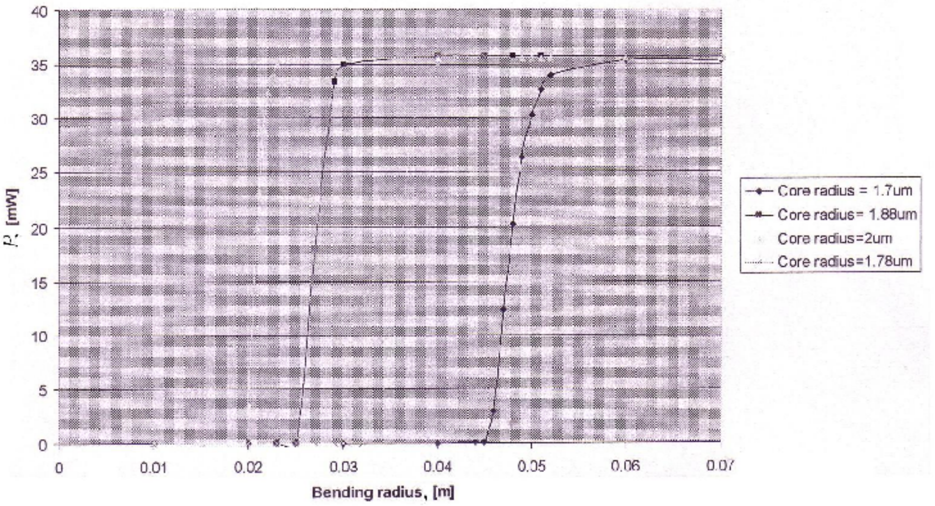

Fig. 3 – Comparative results for different values of the step index, EDFA's core radius.

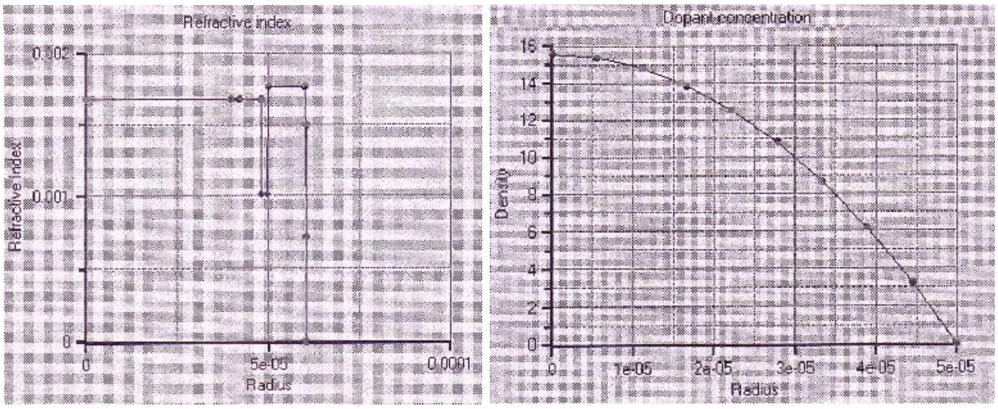

Fig. 4 – Depressed clad shape index profile, and dopant concentration for EDFA
(Liekki, LAD 4.0 (Hotoleanu *et al.*, 2007)).

A seven modes operating system is obtained, with a MFD = 54 μm for a 100 μm wide core. Interactive modifying the index profile, concurrently with doping profile, a substantial attenuation of the higher order modes was obtained.

A larger operating window is obtained for the same LMA fiber. For the 1 μm difference a power variation of the fundamental mode increases, comparative with the step index fiber, in excess of 48μW.

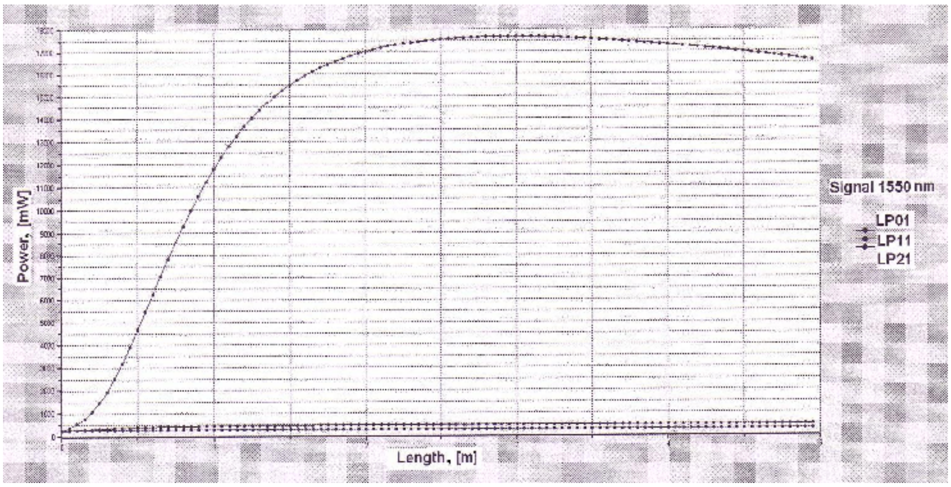

Fig. 5 – Power distribution among modes for depressed clad shape index profile EDFA (Voiculescu, 2009; Sakai & Kimura, 1998).

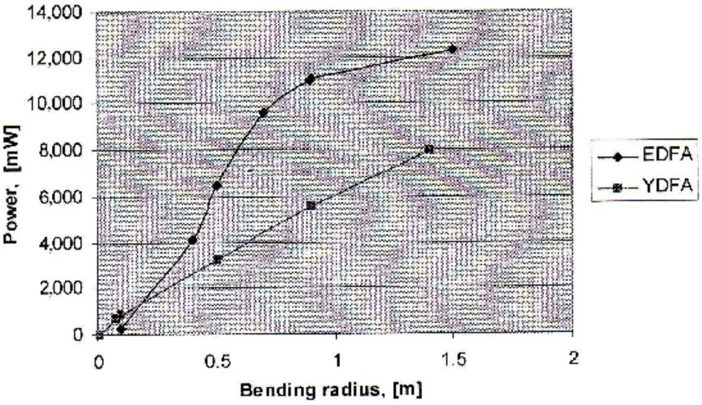

Fig. 6 – Comparative results, with YDFA (Voiculescu, 2009), using the same parameters of interest

4. Conclusions

This paper reports the simulation results obtained using active monomode and LMA, EDFA fiber, acting as an optical bending sensor. The results point out that such a kind of high resolution sensor may be very useful in applications related to safety, automatic control, where the precision of 1 μm bending radius difference need to be quite well discerned. Different bending operation windows are obtained by playing with the index profile, dopant concentration, core radius (Large Mode Area fiber), in application that offers compatibility with telecom operating window, at 1,550 nm. EDFA shows better results than YDFA sensor. The main advantage of designed bending sensor is represented by the fact that it has a wide range of uses especially in distributed sensor applications.

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SENZOR CU FIBRĂ OPTICĂ PENTRU MĂSURAREA ÎNCOVOIERII (TRADUCTOR DE POZIŢIE)

(Rezumat)

Se prezintă un sistem simplu, bazat pe fibre optice de tip LMA (Large Mode Area) (Hotoleanu *et al*., 2007), caracterizate de un diametru util de până la 80 um (în practică), chiar 200 um (aflate în studiu) (Voiculescu, 2009), care poate fi utilizat cu success în proiectarea unor traductori de poziţie având o acurateţe de ordinul micronilor. Rezulatatele simulărilor arată că pentru o fibră activă, dopată cu Er+, de lungimi cuprinse între 1 şi 3 m, în funcţie de concentraţia dopantului, se obţine un sensor care, pentru o diferenţă de 1 μm a razei de îndoire a fibrei, produce la fotodetector o variaţie de minimum 10 μW (–20 dB.m), uşor detectabilă cu un wattmetru obişnuit. Sistemul propus funcţionează în banda de comunicaţii optice la 1550 nm (tipic), lungimea de undă de pompaj utilizată fiind de 980 nm. Optimizarea performanţei senzorului s-a realizat variind indicele de profil al fibrei active, concentraţia dopantului Er+ şi diametrul miezului fibrei LMA.