

# Pump tuning of an erbium doped-fiber LPG

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## ABSTRACT

Pump power-induced changes in the center wavelength of the attenuation band of the spectrum of long-period fiber gratings (LPG) writing in erbium doped fibers are experimentally checked. The pump tuning of the LPG is demonstrated.

Keywords: Long-period fiber gratings (LPG), erbium doped fiber, optical tuning.

## 1. INTRODUCTION

Long-period fiber gratings (LPG) can be formed by a periodic perturbation of the refractive index of the core of the optical fiber with a period typically in the range 300  $\mu\text{m}$  to 1000  $\mu\text{m}$ . External parameters (temperature, mechanical stress or bend) can modify the period of the LPG and/or the differential refractive index of the core and cladding modes. And hence, it is induced changes of center wavelengths of the attenuation band. The sensitivity to these external parameters should be taken into account in designing fiber-optics components, such as fiber sensor, narrow band loss filters, including tunable filters, modulators of optical radiation, etc. [1].

A complementary alternative of these last procedures to the design of the new fiber-optic components from the LPG can be the use of optical techniques that induce resonance shifts of center wavelengths of the attenuation band.

In erbium doped optical fiber (EDF), the pump power causes changes in the refractive index of the core. This property has long been studied for its application in all-optical switching, signal processing, fiber lasers and amplified lightwave communication systems [2] [3] [4] [5]. Currently, EDF's are usually co-doped with germanium showing sensitivity to UV-light. As consequence, LPG can be written in the mentioned EDF's. Based on the above mentioned properties, the erbium doped fiber LPG response can be optically tuned through the pump power.

In this paper, experimental measurements of the spectral characteristics of an erbium doped optical fiber LPG are presented. Pump power-induced changes in the center wavelength of the attenuation band of spectrum is measured. The paper is structured as follows: in section 2 a brief theoretical introduction is presented, in section 3 experimental results are shown, and finally, some brief conclusions are drawn.

## 2. THEORETICAL INTRODUCTION

In this section, the theoretical base of the pump power tuning of LPG is exposed. The resonant coupling of the fundamental mode and one of the cladding mode is achieved when the equation (1) is satisfied.

$$\Delta n_{\text{eff}} \Lambda_{\text{LPG}} = \lambda_{\text{LPG}} \quad (1)$$

where  $\Delta n_{\text{eff}} = n_{\text{eff}}^{\text{core}} - n_{\text{eff}}^{\text{clad}}$ ,  $n_{\text{eff}}^{\text{core}}$  is the effective refractive index of the propagating core mode,  $n_{\text{eff}}^{\text{clad}}$  is the refractive index of the cladding mode,  $\lambda_{\text{LPG}}$  is the resonance wavelength and  $\Lambda$  is the period of the LPG.

The external parameters sensitivity of a LPG can be defined as follows:

$$\frac{\Delta\lambda_{LPG}}{\lambda_{LPG}} = \frac{\frac{1}{\Delta n_{eff}} \frac{\partial \Delta n_{eff}}{\partial \varphi} + \frac{1}{\Lambda} \frac{\partial \Lambda}{\partial \varphi}}{1 - \Lambda \frac{\partial \Delta n_{eff}}{\partial \lambda}} \quad (2)$$

where  $\lambda_{LPG}$  is the central wavelength of the attenuation band,  $\varphi$  is the external parameter. It is taking into consideration that the effective mode indices are wavelength dependent.

According to equation 2, changes in the period of the LPG and/or the differential refractive index of the core and cladding modes modify the central wavelengths of attenuation bands.

The excitation of the erbium ions in the core of the fiber can be produced through the optical pump power. The latter induces refractive index change which are associated with the  $I_{15/2}-I_{13/2}$  transition. Theoretical studies and experimental techniques about this one have been reported [4], [5]. In these papers, the Kramers-Krönig transform predicts pump-induced changes in the refractive index of the core of the EDF, but analytical expression has been also deduced (equation 3)

$$\Delta n(\lambda) = N \cdot \frac{\Gamma_s \cdot \lambda^3}{16\pi^2 n^2 \tau_2 \alpha_p L} \cdot g_{12}(\gamma - \gamma_0) \cdot \left\{ \alpha_p L - \log \frac{P_{pump} + P_{th} \cdot e^{\alpha_p L}}{P_{pump} + P_{th}} \right\} \quad (3)$$

where  $N$  is the doping concentration,  $\Gamma_s$  is the confinement factor of the signal,  $\lambda$  is the signal wavelength,  $n$  is the refractive index,  $\tau_2$  is the lifetime of the metastable state,  $\alpha_p$  is the pump wavelength attenuation,  $L$  is the length,  $P_{pump}$  is the pump power,  $P_{th}$  is the threshold pump power and  $g_{12}(\gamma - \gamma_0)$  is the lineshape function.

The lineshape function is defined by

$$g_{12}(\gamma - \gamma_0) = \frac{1}{\pi} \cdot \frac{(\gamma - \gamma_0)}{\left(\frac{\Gamma_{12}}{2}\right)^2 + (\gamma - \gamma_0)^2} \quad (4)$$

where  $\Gamma_{12}$  is the full width half maximum of the transition,  $\nu$  is the optical frequency and  $\nu_0$  is the resonance frequency.

According to equation 3, the variation of refractive index of EDF is directly proportional to the  $Er^{+3}$  concentration and increases in the pump power can produce corresponding changes in the refractive index.

In our experimental works, the EDF's used have an absorption peak of 5 dB/m that corresponds to 300 ppm of  $Er^{+3}$  concentration in the core. In order to estimate the change of the refractive index as function of the signal wavelength for a given pump power, the parameters of this fiber are inserted in the equation 3:  $\alpha_p \cdot L = 0.043$ ,  $\Gamma_s = 1$ ,  $n = 1.46$ ,  $\tau_2 = 12.5$  mseg. The obtained results for a pump power of 200 mW are shown in figure 1.



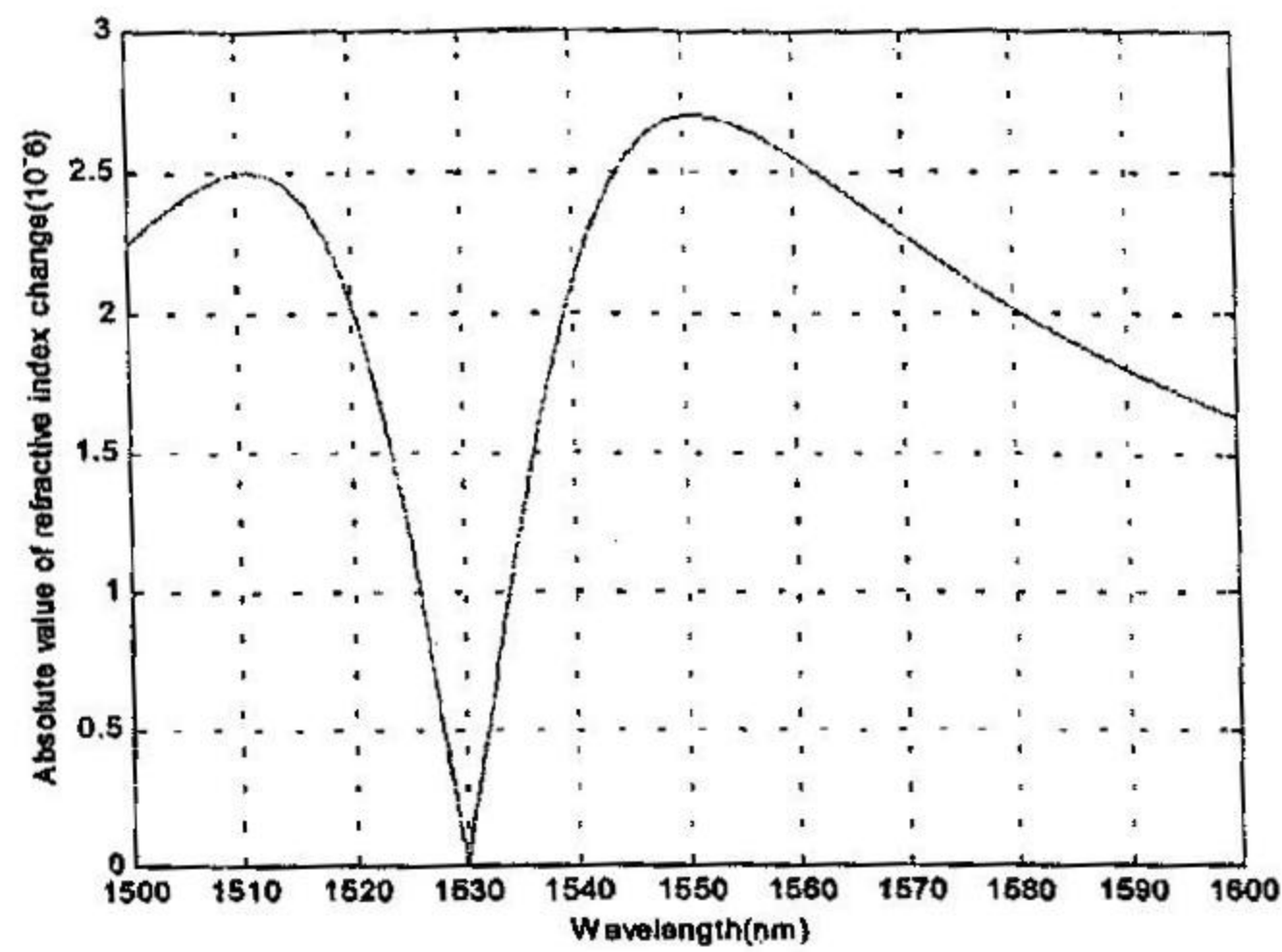


Figure 1. Calculated refractive index change as function of the signal wavelength for a pump power of 200 mW.

As shown in this figure, the change of the refractive index is wavelength dependent with a minimum centered in 1530 nm, which is the wavelength of peak absorption of the erbium. There are also two spectrum ranges at which the change of the refractive index is maximum, these are centered around 1515 nm and 1550 nm.

### 3. EXPERIMENTAL RESULTS

Taking into account the aforementioned results, tunable LPG with the pump power in EDF doted with maximum tunable ranges can be obtained if they are designed around 1515 nm or 1550 nm.

LPG with a period of 346  $\mu\text{m}$  along 4 cm on EDF loaded with hydrogen during a week was written using a 244 nm UV-continuos Ion laser and point-to-point method. In order to tune the maximum attenuation peak in 1570 nm and to obtain special shaped LPG, an UV-postprocesing was used. The LPG area was irradiated with a uniform UV-light. The spectrum of this LPG is shown in figure 2.

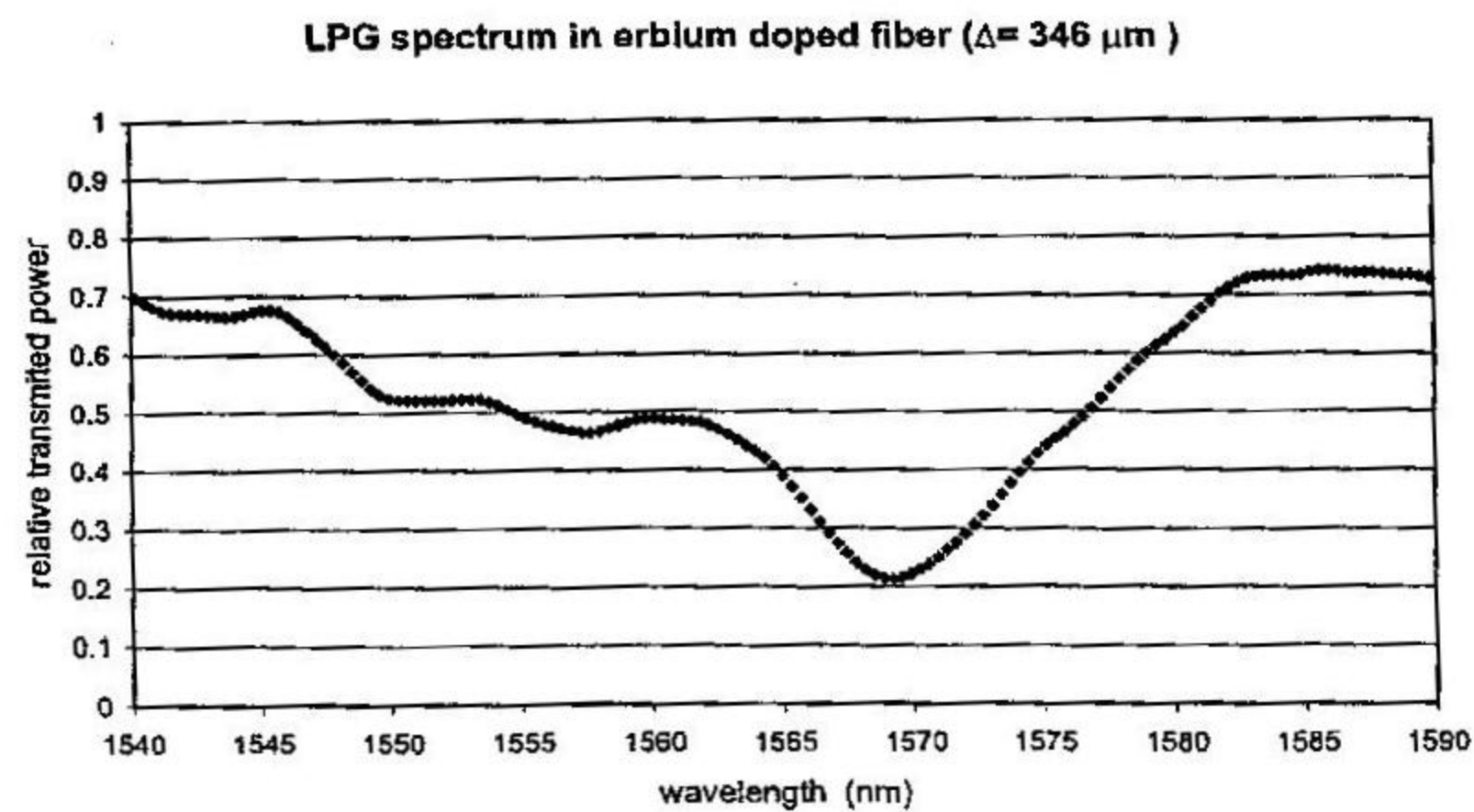


Figure 2. Spectrum of the LPG writes in EDF, with a period of 346  $\mu\text{m}$  and a length of 4 cm.

To check the tunable capacity of the LPG a 1480 nm pump laser diode was used in the experimental works. Results are plotted in figure 4.

Increases of the resonance wavelength of approximately 0.47 nm for a pump power of 180 mW can be observed. The wavelength increase obtained theoretically using the equations (2) and (3) is 0.76 nm. The difference between the theoretical and experimental results can be due errors on the characterization of the EDF.

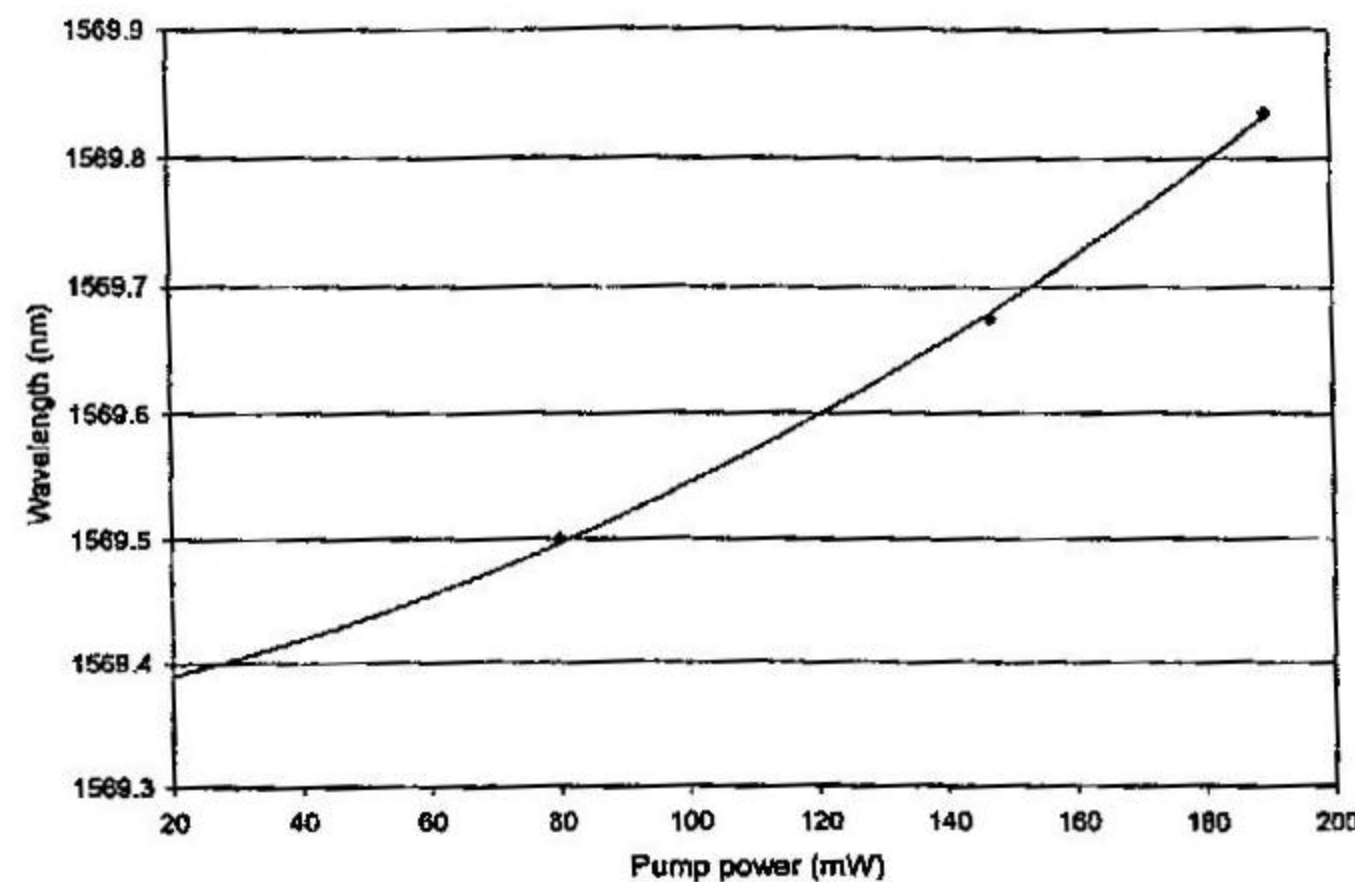


Figure 4. Variation of the resonance wavelength of the LPG as function of the pump power. The solid line is the tendency lines of measured values.

## CONCLUSIONS

Optical tunable LPG's on EDF are demonstrated in this paper. The tuning is based on the refractive index changes induced by the pump power in EDF's. Maximum pump power induced changes were theoretically predicted and experimentally checked using a LPG written on EDF with a 5 dB/m absorption peak. A tuning of 2.6 pm/mW was demonstrated employing a 1480 nm pump laser. As longer tunings are expected using higher concentration EDF, experimental works are in course.

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