Erbium-doped Fiber Optical Amplifier

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Abstract- Along with fiber optics, optical amplifiers and lasers are a quite relevant technology for optical communication systems. Perhaps the most common example is Erbium-doped Fiber Optical Amplifier (EDFA), which is a conventional silica fiber doped with erbium. In this work a spectroscopic characterization of a commercial erbium-doped fiber amplifier was performed by measuring the dependence of the gain of the signal with the pumping radiation provided by a $980nm$ solid-state laser diode. In addition, by fixating the pumping power, $P_{pump} = 0.3W$, a plot of the output power vs the input power showed a linear behaviour followed by a saturation zone. At last, an erbium-doped fiber laser, made with a cavity built with two tunable Bragg gratings, was implementated and characterizated. One of the gratings can be finely tuned in wavelength through applied stress, effectively changing the cavity feedback. Tuned and detuned cavity configurations were performed. The results show that the current threshold is higher for the detuned configuration ($I_{th} = 65.707mA$), despite the slopes between the two setups were preety close ($\sim 0.03mV$).

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I. Introduction

The Three-level Pumping Scheme

Optical amplifiers perform a critical function in modern optical networks, enabling the transmission of many terabits of data over long distances of up to thousands of kilometers. In the case of erbium-doped fibers (EDF) the optical gain is supplied by the excited Er^{3+} ions. A common requirement with the laser mechanism is the pumping of the medium to achieve population inversion. This assures that the energy stored in the medium is released mainly through stimulated emission, in which the signal must be the stimulant in order to receive the energy and be amplified.

When the erbium is illuminated with light energy at a suitable wavelength ($980nm$) it is excited to a long lifetime intermediate state (see Figure 1), following which it decays back to the ground state by emitting light within the 1525-1565 nm band. If light energy already exist within the 1525-1565nm band, for example due to a signal channel passing through the EDF, then this stimulates the decay process (so called stimulated emission), resulting in additional light energy. The population inversion occurs when the level E2 has more electrons than E1, and from that point the stimulated emission $E2 \rightarrow E1$ occurs at a higher rate than the stimulated absorption $E1 \rightarrow E2$ and therefore the energy is released mainly to amplify the incident light while its absorption is reduced.

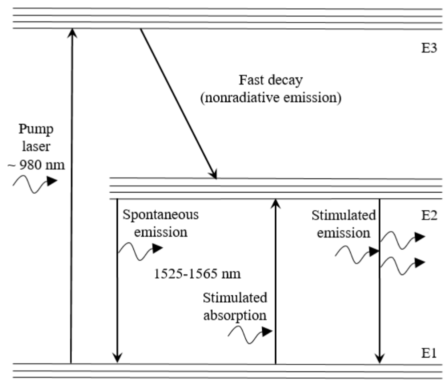

Figure 1. Simplified Energy levels of Er3+ ions in Erbium-doped fiber

Bragg gratings

In this work, the approach to fiber lasers is based on a Fabry-Perot cavity built with two fiber Bragg gratings (FBG) with a small mismatch in the Bragg wavelength. The laser emission is achieved when this mismatch is reduced through longitudinal stress applied to one of the gratings.

A fiber Bragg grating is a periodic perturbation of the effective refractive index in the core of an optical fiber, and is formed by exposing it to an intense ultraviolet periodic light pattern created by the interference of two light beams at the same wavelength. When a broad-spectrum light beam is sent to an FBG, reflections from each segment of alternating refractive index interfere constructively only for a specific wavelength of light, called the Bragg wavelength, λ_B , described in equation 1, where n_{eff} is the effective refractive index of the fiber core, and Λ is the spacing between the gratings, known as the grating period. This effectively causes the FBG to reflect a specific frequency of light while transmitting all others (see Figure 2).

$$\lambda_B = 2n_{eff}\Lambda_B \tag{1}$$

Changes in strain and temperature affect both the effective refractive indexn_{eff} and grating period Λ of an FBG, which results in a shift in the reflected wavelength.

II. Experimental details

First, it was intended to do a spectroscopic characterization of a commercial erbium-doped fiber amplifier (EDFA). The apparatus used consists of a diode-pumped solid-state

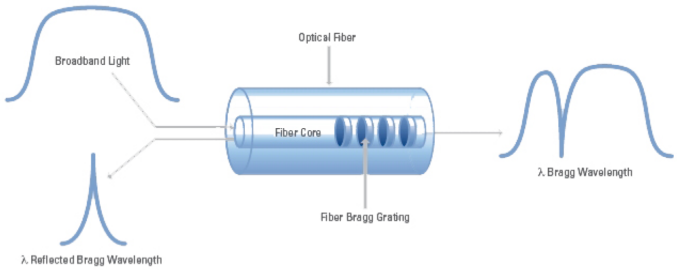

Figure 2. Operation of an FBG Optical Sensor

Figure 3. Schematic of the EDFA experimental setup.

laser coupled to the EDFA, which is connected to an Optical Spectrum Analyzer (OSA) (Figure 3). Here, one can tune the input amplification power or tune the pump power (by fixing the input power).

At last, an erbium-doped fiber laser, made with a cavity built with two tunable Bragg gratings, was implementated and characterizated. Figure 4 ilusstrates the experimental setup used.

The optical pumping is achieved by the use of a laser diode (~ 980nm) including an optical isolator. The optical cavity is assembled between two identical 2x2 wavelength division multiplexer (SMWDM980/1550) to separate the emission from the pump. It is three meter long with 2m of Erbium doped fiber (EDF). Two similar fiber Bragg gratings (FBG's) terminate the output ports of the fiber optic cavity. One of the gratings, serving as output mirror, at the near end of the cavity, feeds either an optical multimeter, or an optic spectrum analyzer (OSA). The other grating, located at the far end of the cavity, is stretched with the aid of a micromechanical translation stage, for cavity detuning. In order to control the pump power, the diode drive current was fixed, $I = 150mA$, and then we just repeatedly decrease it by $10mA$.

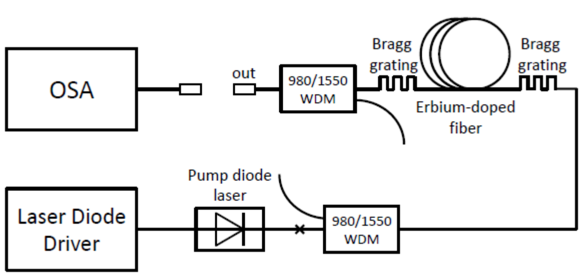

Figure 4. Schematic of the EDF experimental setup.

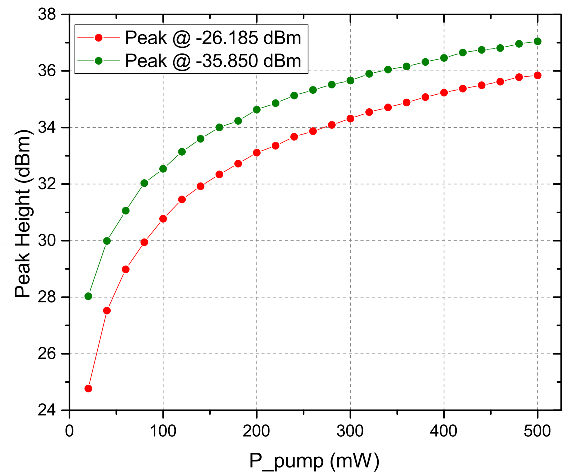

Figure 5. Optical power output of inserted signal as a function of the pump power

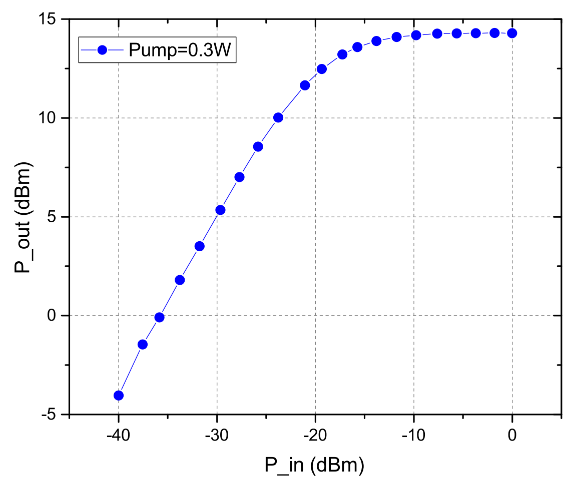

Figure 6. Optical power output evolution

III. Results and Discussion

A. EDFA

First, two optical powers (low and high amplitudes) were injected into the system. For each one, we got the dependence of the gain of the signal with the pumping radiation. We varied the input power from 100 to 300 mW. As sketched in Figure 5 we got that the amplification is stronger for the lower intensity (Peak@-35.85 dBm).

Afterwards, the pump power was fixed, $P_{pump} = 0.3W$. Figure shows the output power gain evolution. We got a linear behaviour followed by a saturation zone.

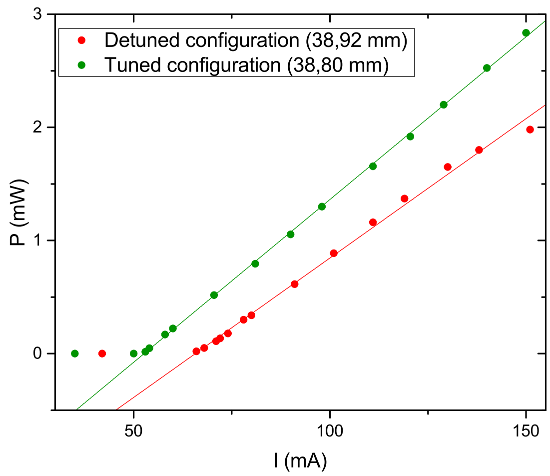

Figure 7. Power output as a function of the drive current of the pump

B. EDF

Since the power of the pump diode laser vary linearly with the drive current, we just measure the output power as a function of the drive current of the pump. The goal is to study how the Fabry Perot cavity change the output power.

One of the gratings can be finely tuned in wavelength through applied stress, effectively changing the cavity feedback. Tuned and detuned cavity configurations were performed ($38.80mm$ and $38.92mm$ in the micromechanical translation stage).

The results are sketched in Figure . Experimental data point out that the slope is about $0.02877mV$ for the tuned configuration and about $0.02464mV$ for the tuned configuration. The threshold currents are $I_{tuned} = 52.657mA$ and $I_{detuned} = 65.707mA$.

The results show that the current threshold is higher for the detuned configuration, despite the slopes between the two setups were preety close.

IV. Conclusions

In this four hours laboratory experiment, an erbium-doped fiber amplifier was built and caracterized. Fiber manipulation and characterization techniques were applied allowing the demostration of the capability of an EDF to work as an optical amplifier, which provide a large dynamic gain.

The dependence of laser output power as a function of pump power, and for different stretching's of FBG's, was also studied. The threshold drive current of the pump diode laser decreases with stretching the Fabry Perot cavity.

References

[1] Carla C. Rosa Paulo V. S. Marques, Manuel B. Marques. Advanced experiments with an erbium doped fiber laser. *In Education and Training in Optics and Photonics (p. EWP12). Optical Society of America*, 2013.

[2] Li Qian. Experiment on erbium-doped fiber amplifiers. *Advanced Labs for Special Topics in Photonics (ECE 1640H) University of Toronto*, 1998.

[3] Orazio Svelto. *Principles of Lasers*. Springer, 5 edition, 2010.