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Design of the Variable Cavity of an Erbium Doped Fiber Laser for the Study of the Threshold

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Abstract:

In this study cavity arrays for a fiber laser are shown in order to compare the performance and pumping power required to reach the threshold in each array, as well as the analysis of the stimulated and spontaneous emission region of the selected model. In the models a Fabry-Perot type structure was used, where the elements that were part of the cavity were: a multiplexer, erbium doped fiber, a Faraday mirror and a Bragg grid, using a laser diode at 980 nm as pumping source. The models studied are rearrangements of the aforementioned elements, placed at different positions of the fiber laser, the model where the Bragg grid was placed at the output of the multiplexer, showed a higher threshold with respect to the other, where the grid was placed before of the erbium doped fiber section, this was due to the change of position of the added grid lost in the cavity, which, in turn, influenced the behavior of the output signal, in addition, the equation of the behavior pattern in the spontaneous emission region was obtained, which on the other hand, did not have the same success for the stimulated emission region due to the limitation of the available data.

Keywords **—Stimultated and spontaneous emission, Threshold, Fiber Laser, Cavity losses**

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I. INTRODUCTION

Recent years the fiber laser has attract attention in the area of communication, metal cutting and lately, in the development of sensors, this one being a topic of interest. This study pretends to perform the experimental characterization of the threshold, spontaneous emission and emission stimulated of different models of fiber laser, with the purpose of comparing, selecting and calculating the behavior of the chosen one, in order to provideinformation and knowledge that helps to later studies of the transient regime in the fiber laser, it has been shown that with the analysis of this characteristic is possible the detection of hydrogen in a closed environment [1].

In a fiber laser with a Fabry-Perot cavity, it starts with the power from a pumping source, usually a laser diode, which is amplified by an erbium fiber doped or another rare earth [2], which is contained inside a resonator formed by 2 mirrors. The power amplification in a fiber laser is achieved in the same way as the generation of the laser is obtained [3], it has the same fundamental elements, an active medium, a pumping system and a resonant cavity, where are carried out 3 physical phenomena [4], absorption, it is when a photon emitted by the pumping source is absorbed by the electron of an atom of the active medium used, which causes a transition of the electron from its level of ground state to a higher or excited state, this occurs as long as the quantum energy of the absorbed photon (hv) is equal to the energy difference (∆ E) between the

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ground state and the excited state, in general terms that is, hν = ∆ E, where ∆ E is the energy difference between the levels involved and h is the Planck constant ($h = 6.626x10^{-34}Js$) and ν is the frequency of the absorbed photon or emitted; the spontaneous emission is when an electron decays to a less energetic level spontaneously releasing energy in form of light, the energy of this light is exactly equal to the difference of the levels involved, the photons are emitted in a random and unrelated direction of phase; and, the stimulated emission, where if an electron is already in an excited state, and a photon with energy equal to the difference between the current level and a lower one, it is incised, the de-excitation of that excited state occurs to one minor or fundamental, producing a second photon with the same energy, direction and phase as the first. When 3 or more energy levels of erbium or other rare earth are used, and the electron population is at an energy level higher than the fundamental level, a condition known as population inversion occurs, this phenomenon sets the stage for multiple emissions of energy, the photons wait for being de-energized, and if you have this active medium inside a pair of mirrors of high reflectivity, known as cavity or resonator, and the photons are bouncing, an amplification of photons with the same frequency and phase occurs, which after a certain time, through the mirror of lower reflectivity, where a coherent spatial and temporal beam of monochromatic and coherent light will be emitted. The point of transition from spontaneous emission to stimulated emission is known as a threshold, so the threshold is the point of inflection where the population inversion between the ground state and the excited state is reached.

The models from which the threshold and characterization were obtained, have as a source of pumping a laser at 980 nm, the beam will be amplified at ~ 1550 nm, which is reached when 5.65 m of fiber doped with Er^3 is used as an active medium, this wavelength is the standard for fiber optic communications, which gives high effectiveness for data transmission; in other hand, feeding the fiber laser with a wavelength at 980 nm presents the highest efficiency in gain, lower cost and a state free of the phenomenon of absorption of excited state (ESA) and the Stokes effect, compared to being fed to other lengths; a multiplexer of 980 nm / 1550 nm is responsible for coupling both signals on the same optical fiber avoiding interferences; and as mirrors of the resonator, a Bragg grid (FBG) with a reflectivity of 95.7% with peak at a wavelength of 1560.2 nm, and a rotator of Faraday (FRM), with a working range of 1520 to 1590 nm were used. The FRM shows the characteristic of eliminating the random polarization fluctuations in the laser output, allowing a stabilization in the amplitude of the laser output pulses [5][6], also a reduction of laser instabilities when the lathe is maintained, and a decrease in noise, [8][9]. The development of the experimental analysis carried out is presented, which results in obtaining the behavior of the models presented and the selection of one of this, with its respective equation of spectrum and umbral behavior.

II. EXPERIMENTAL DEVELOPMENT AND SIMULATION

First, the characterization of the laser diode at 980 nm as pumping source was carried out, where the arrangement used is shown in Fig. 1. The intention was to study the behaviour and power output of the fiber laser while the power of the pumping source or well, pumping power, was controlled at will, the purpose was to relate the value of the supplied power with the output power.

Fig. 1Experimental arrangement for the characterization of the laser diode.

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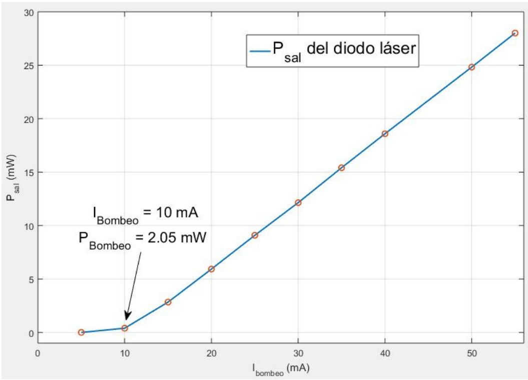

Fig. 2Graph showing the relationship between the power supplied andthe power emitted by the fiber laser.

In the Fig. 2 was observed that if $I_{bombeo} \geq 10\ mA$ there is a linear behavior, this isbecause the state of stimulated emission was reached, producing the laser, therefore, the threshold of the laser diode was 10 mA, where the linear behavior or the behavior of the stimulated emission region was represented by the Eq. (1).

$$y = -4.17998 + 0.62297x \qquad (1)$$

Where:
x represents the current pumping in mA.
y represents the power output in mW.

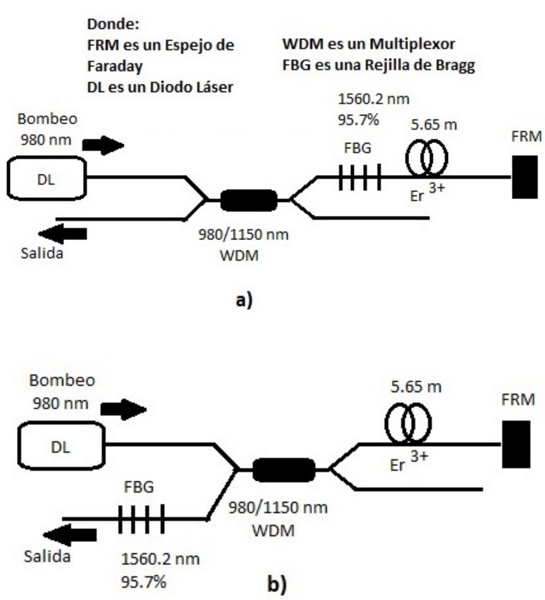

Fig. 3Fiber laser arrangements, a) Experimental arrangement A, b) Experimental arrangement B.

After having characterized the laser diode, the pumping source was coupled to a fiber laser model, which is shown in Fig. 3a, named model A. Then, the supplied $I_{bombeo}$was increased, from 0 to 300 mA with the objective of capturing the values thrown by the power meter, it was placed at the output of the multiplexer, so the potential behavior is shown in Fig. 4, which was obtained with a programming software, where can be observed that the threshold is reached supplying approximately 27.3 mA, in order to demonstrate this result, a spectrum analyzer was placed in the place of the power meter and in the same way was obtained the graph of Fig. 5, which shows that the laser is produced by suppling the model A with a current more than 29 mA, this margin of error is due to the little cooling time that was left between samplings.

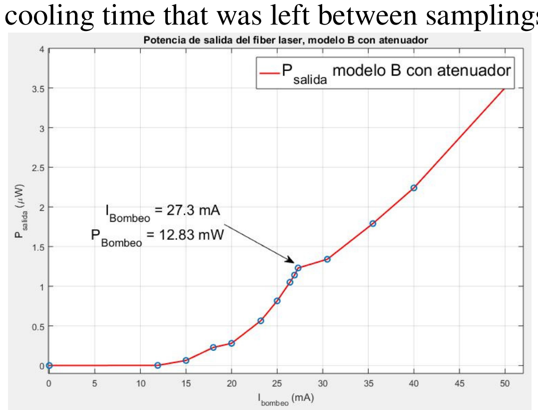

Fig. 4 Potential behavior of the fiber laser model A.

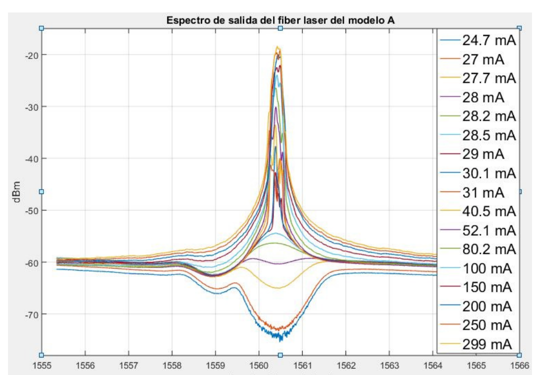

Fig. 5 Spectrum of model A.

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With $I_{bombeo} =$ 27.3 mA, Eq. (1) is used to obtain the required pumping power, where the result was 12.83 mW.

Following the procedure that was used to obtain the power and spectrum graph of model A, in the same way was done to obtain the behavior of model B, shown in Fig. 3b, the results can be observed in Fig. 6 and Fig. 7 respectively, where the value obtained from the threshold was 51.2 mA, and when it is evaluated in Eq. (1), results in a pump power value of 27.72 mW.

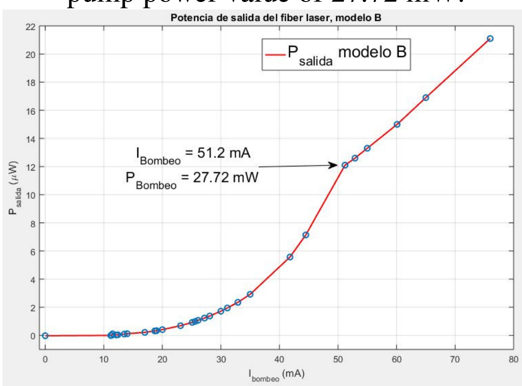

Fig. 6. Potential behavior of the fiber laser model B.

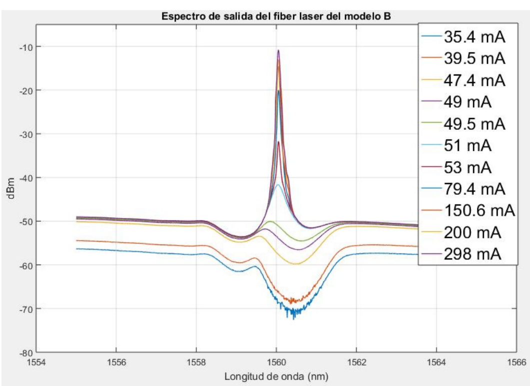

Fig. 7 Spectrum of model A..

During the process of acquiring the previous answers, characteristics led to the selection of model B as the indicated for subsequent studies, one of the reasons for choosing it, was to have a greater range of work in the spontaneous emissionregion, being this from 0 to 27.72 mW compared to the value from 0 to 12.83 mW presented by model A, also, it presented the qualities of having greater reflection, which allowed to make the power measurements without much difficulty, repeatability, showing accuracy in the output power values, just leaving in cooling approx. 1 hour between uses, and major stability, which presented results without irregularities or random values, as it was in model A, which can be seen in the peaks of the spectrum of Fig 5.

Since model B was selected, a programming software was used to deduce the characteristic Eq. (2), which has the expression of a Gaussian function, this describes the behavior of the spectral, and is used to extract information from awhole or from a specific point in the spectrum on this arrangement without having to appeal to using an optical spectrum analyzer again.

$$f(k) = \sum_{i=1}^{n=5} a_i e^{\left[-\left(\frac{k-b_i}{c_i}\right)\right]^2} \quad (2)$$

$Where$:
k is a range of values between 1555 and 1566 with a step of 0.5;
the coefficients a_i, b_i y c_i, where i is from 1 to 5, are:

$$a1 = -0.446 \quad (3)$$

$$a2 = \frac{-1.667x10^{-4}x^3 + 1.172x10^{-1}x^2}{x - 46.91} + \frac{13.3x - 942.6}{x - 46.91} \quad (4)$$

$$a3 = -3.7 \quad (5)$$

$$a4 = 11 \quad (6)$$

$$a5 = -165.2 \quad (7)$$

$$b1 = 1557 \quad (8)$$

$$b2 = -2.68x10^{-6}x^2 + 1.29x10^{-3}x^2 + 1559.98 \quad (9)$$

$$b3 = 1559.1 \quad (10)$$

$$b4 = 1.67x10^{-6}x^2 - 0.0008x + 1560.09 \quad (11)$$

$$b5 = 2085 \quad (12)$$

$$c1 = 1.211 \quad (13)$$

$$c2 = 82.02x^{-1.4736} \quad (14)$$

$$c3 = 0.6 \quad (15)$$

$$c4 = 0.08819 \quad (16)$$

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$$c5 = 480.6 \quad (17)$$

and, x represents the value of the pumping current, expressed in mA.

As last, with the objective of analyzing the behavior of the region of spontaneous emission and stimulated by the addition of losses, an optical attenuator was added to the model which added losses to the cavity of 2, 4, 6 and 8 dB, the arrangement used is shows in Fig. 8.

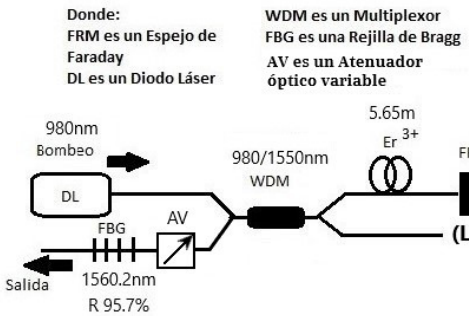

Fig. 8 Arrangement chosen, model B with an optical attenuador added.

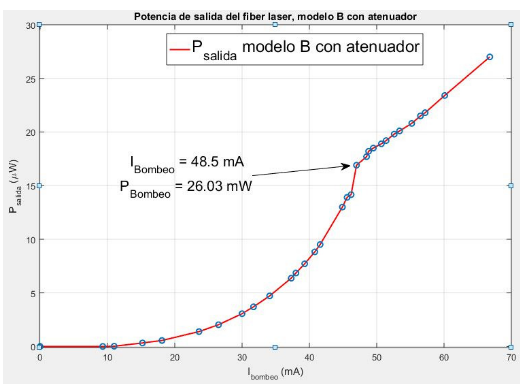

Fig. 9 Potential behavior of the arrangement of Fig. 8.

Fig. 9 shows the potential behavior of the new model with the attenuator set to 0 dB, having a threshold value of 48.5 mA, or 26.03 mW. Once this is obtained, the losses of the attenuator are varied, from which data was taken with the power meter to be processed with a programming software, obtaining the graph of Fig. 10. The Fig. 11 show the data of the figure 10, but plotting only the spontaneous emission region, up to the threshold point, where when joining the end points of each variation (red line), it was observed that it presents an exponential growth pattern for the threshold value, and an increasing value but constant in the separation width of the data at 0, 2, 4, 6 and 8 dB, in order to demonstrate the above, the output power of each loss was normalized with respect to that presented at 4 dB, being the central power, Fig. 12. If the show values are close to 1 and have minimum peaks, we have a constant pattern in that region, which perfectly represents for values with $I_{bombeo} \geq 25\ mA$.

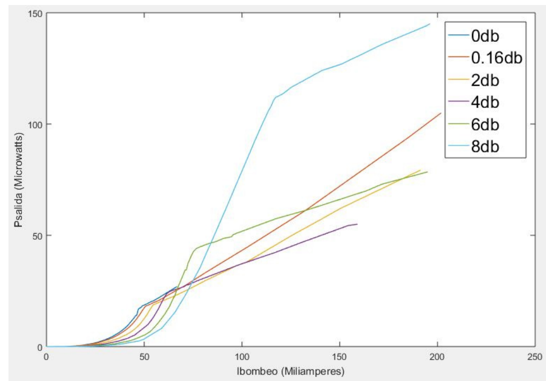

Fig. 10 Potential behavior of the fiber laser at 0, 0.16, 2, 4, 6 y 8 dB.

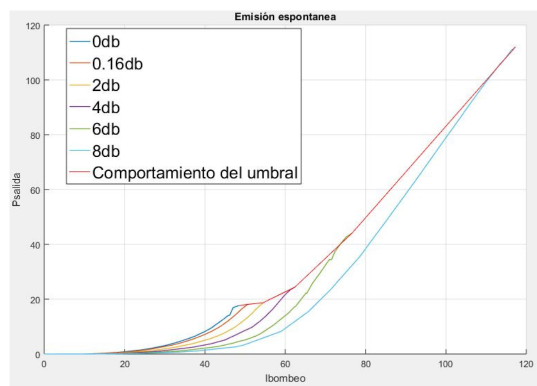

Fig. 11 Behavior of the spontaneous emission region at 0, 0.16, 2, 4, 6 y 8 dB.

In the case for the stimulated emission region, Fig. 13, where a coherent relationship is not observed, itapparently follows a cyclical pattern as the losses increase or decrease, resulting in the decrease or increase of the slope value respectively. For checking this, requires data of values greater than 8 dB, which is a limitation because the

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attenuator used can't provide more than 8 dB. Finally, in Fig. 14 the threshold values were plotted in accordance to the losses added to the cavity, clearly it can be observedthat there's an exponential growth on the threshold which during the calculation of the equation, a better approximation was obtained using a polynomial of degree 4, resulting in Eq.(18), it was obtainedby a programming software.

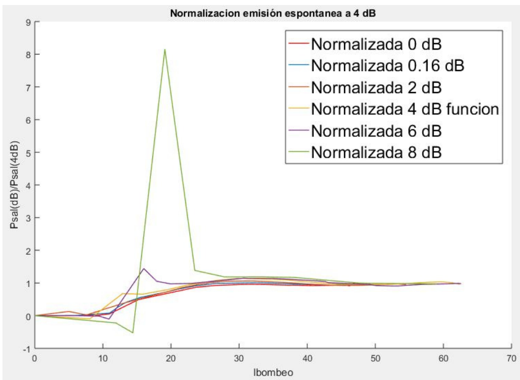

Fig. 12 Normalization of the output power in the stimulated emission region, ${P_{sal}dB}/{P_{sal}\,4dB}$.

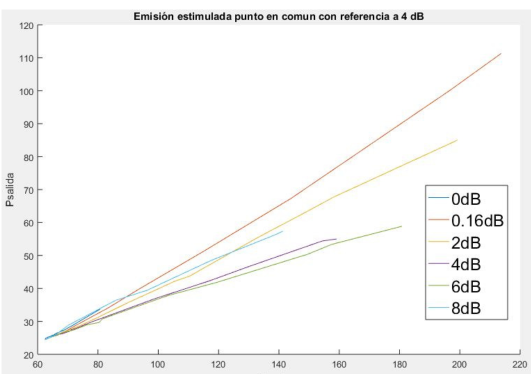

Fig. 13 Behavior of the stimulated emission, with a common point at 4 dB.

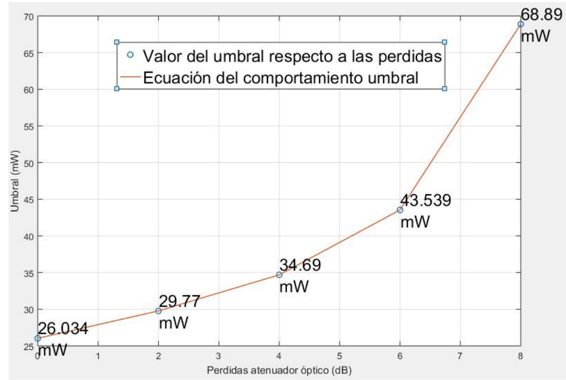

Fig. 14 Behavior of the threshold respect to the cavity losses.

$$y = 0.0255x^4 - 0.249x^3 + 0.931x^2 + 0.801x + 26.034 \quad (18)$$

Where, x represents the dB supplied by the attenuator, and; y represents the threshold value, in other words, the pumping power required for the fiber laser to reach the stimulated emission region.

III. SUMMARY OF RESULTS

For the model A, the power of 12.83 mW was required to reach the threshold, while model B has a threshold higher than this, it is required a power of 27.72 mW to reach the threshold. The part of selection was a pro of the arrangement B, which was chosen because the power required to achieve the threshold is greater being this an important characteristic, which allows to have a wider range of work for the analysis of the spontaneous emission zone, having 14.89 mA more of working range, in addition, that model presented better stability, repeatability and reflection. The Eq. (2), with coefficients (3)--(17), describes the spectral behavior of this arrangement, where it is valid for values 31 < x <298.8, where x is expressed in mA, the 31 mA was because it's when the threshold was reached and the values above it, are in the stimulated emission. Finally, it was discovereda pattern in the region of spontaneous emission when losses were added to the cavity, it presented a constant increase of the threshold and in the area of spontaneous emission, the Eq. (18) represents the value of the threshold respect to the losses provided by the optical attenuator, in the other hand, there was no a pattern deduced in the stimulated emission region, it was due to a limit data, but it is thought that the value of the slope (as the stimulated region presents a linear behavior, it is possible to calculate its slope) is cyclical, from increasing to decreasing values.

IV. CONCLUSIONS

The difference between the threshold of both arrays was due to the fact that the multiplexer added greater losses inside the cavity when it's placed between the Bragg grating and the Faraday mirror, it was possible to discard the losses that could be made by the splicing process and taking measurements, because the process was made paying attention and care for the correct assembly. The advantages of the arrangement of Fig. 3b over the Fig. 3a, were evident, it presented greater stability and greater range of work, above and below the threshold, the stability can be seen by comparing the spectrum of both models, the greater range of work shown by the second arrangement, provides more space to be studied and analyzed in later studies, for example, for studying the transient regime of this fiber laser with lower values of power than the threshold, where is known that modifying the characteristics of the cavity (reflection, power, losses) and external (power, devices and others), lead to an alteration in the output signal of the fiber laser.

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