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خفض العتبة في ليزر شبه الموصل باستخدام تقنية التغذية العكسية الضوئية

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الخلاصة:

في هذا البحث العملي تمت دراسة ديناميكية الانبعاث المرافق لعمل الليزر من نوع "ليزر شبه الموصل ذي التغذية العكسية الموزعه". شملت الدراسة سلوك الانبعاث الليزري في حالة العمل بشكل معزول "بدون مؤثر التغذيه العكسية" وكذلك بوجود هذا المؤثر. تبين من خلال هذه الدراسة بأن تسليط تغذيه عكسية شديدة على الليزر من نفس انبعاثه يقود الى تولد انبعاث ليزري غير مستقر، بحيث ان نمط الانبعاث الليزري الوحيد الذي يمتلكه الليزر المستخدم ينغمر بين عدد لانهائي من الانماط الجديدة في ظل تولد ظاهره "الفوضى المسيطر عليها" حيث يدخل الليزر في وضع يسمى بانهيار التشاكه.

Threshold Reduction for a Diode Laser by using the Technique of Optical Feedback

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Abstract:

In this experimental work, the dynamics of a distributed feedback semiconductor laser was studied. Dynamics in free running for a solitary laser was satisfied experimentally, and then dynamics in the present of optical feedback, via a free space as a waveguide, was studied experimentally. Results showed that the insertion of strong level of optical feedback led the laser emission to be instable due to a bifurcation.

The higher feedback level make the laser operating in the so called coherence collapse, which means that the dominant operating mode, and any modulated modes within this range could be translated securely inside a controlled chaos.

Abbreviations: SL: Semiconductor Laser, EC: External Cavity, ECMs: External Cavity Modes. RO: Relaxation Oscillation, FR: Free Running, OFB: Optical Feedback, LD: Laser Diode, LFF: Low Frequency Fluctuations, LK: Lang-Kobayashi, TR: Threshold Reduction, NB: Non Polarized, DSO: Digital Storage Oscilloscope, DFB: Distributed feedback, SEED: Self Electrooptic Effect Devices, CW: Continues Wave, EOSA: electrical optical spectrum analyser, RFSA: Radio Frequency Spectrum Analyser

1: Introduction

The so-called laser threshold current is an important merit for device applications as it governs the minimum power consumption that is necessary for lasing operation [1]. Adding a mirror at the output of the laser emitted beam is an essential way for threshold reduction and instabilities insertion in (SL), i.e. an optical time delayed feedback will re-injected towards the laser output again. This mechanism is classified into three length scales for each scale there are a few conjugated effects. The first is the extremely short (EC), which was in sub-centimetre of range; this implies control with a special technique [2], while the second scale, is the one that deals with few centimetre ranges. Finally, the long cavity regime, in which the length of the external cavity ranges from 10 cm up to several meters [3,4]. In all cases, the comparison between the external cavity modes and relaxation oscillation for solitary laser is the judgment [5]. This work is dealing with the 3^{ed} type.

2. Theory:

In many applications, such as fiber coupling, a non-negligible amount of feedback is produced nearly inevitably. Hence, the understanding of (SL) under the influence of (OFB) is of great importance from a point of view of applications. Depending on the (OFB) strength, i.e., on the amount of light that is reflected back into the laser cavity, different types of behaviour are known to occur. Below certain feedback strength, the emission of the (SL) can be stabilized and the linewidth can be narrowed. If the strength of the feedback exceeds a certain level, the semiconductor can be destabilized and a variety of interesting dynamical behaviours can be observed. The output mirror of the laser and the external source of reflection, which is in the simplest case a mirror, constitute the so called (EC). Modes that are resonant in this cavity are called (ECMs). The equidistant frequency spacing of these modes is called external cavity frequency.

There is a general discrimination between different (EC) lengths, i.e., between long and short (EC) lengths. Short (ECs) are characterized by a mode spacing of the external cavity modes that is larger than the (RO) frequencies of the (FR) laser. The most investigations so far have been restricted to the case of a long cavity. It is a typical issue of this regime that the occurring dynamics are qualitatively independent of small variations of the feedback phase, i.e., the phase with which the reflected light enters back into the laser cavity.

The effects of (OFB) on the operating characteristics of a (LD) are depending on several parameters. These include the level of the (FB) in comparison to the (LD) output power, the relative phase of this (FB), the length of the (EC), and the injection current of the (FR) (LD).

One of the most intensely studied phenomena in the case of a long cavity is the (LFF), which was observed first by Risch *et al.*, manifest themselves as sudden dropouts followed by continuous, slow recoveries in the output power of a (SL) with feedback at constant current [6]. The (LFF) have often been modeled using the (LK) equations, which is valid only with low-feedback regimes of operation [4, 7,8,9]:

$$\frac{d}{dt}\varepsilon(t) = \frac{1}{2}(1+i\alpha)[g(\gamma)]\varepsilon + \kappa e^{-i\Omega_o\tau_{ec}}\varepsilon(t-\tau_{ec})$$

$$\frac{d}{dt}N(t) = \frac{I}{q} - \gamma_e N - g|\varepsilon|^2$$

where:

ε: complex electric field, N: number of excited carriers in the active medium, γ: Photon decay rate, γ_e: Carrier decay rate, τ_{ec}: Round-trip time in the external cavity, α: Alpha factor, I: pump current, κ: feedback rate, Ω_o: Solitary laser frequency, q: lectron charge.

Closely related to the (LFF) is the phenomenon of (CC). This phrase describes the circumstance that the linewidth of a (SL) with (FB) can reach extraordinary large values of several tens of Gigahertz or more i.e., the coherence length of the output light shrinks drastically. The temporal dynamics in this regime are characterized by irregular pulsations.

(LDs) operated with (FB) have found applications in a number of areas due to the improvement that the (FB) can lead to in many of the operating characteristics of the (FR) (LD). A source for coherent optical communication systems (particularly for heterodyne detection and wavelength division multiplexing) and spectroscopic applications is required to be single frequency, narrow linewidth, and continuously tuneable over a wide range of wavelengths, chaotic output may be used to provide secure optical communications [10].

The (OFB) properties of (LDs) have been sometimes classified into III regimes, this is according to the so called “feedback parameter (C)",

While it is almost classified into I – IV regimes of behaviour, which are pointed out experimentally by Chung [11], fig. 1.

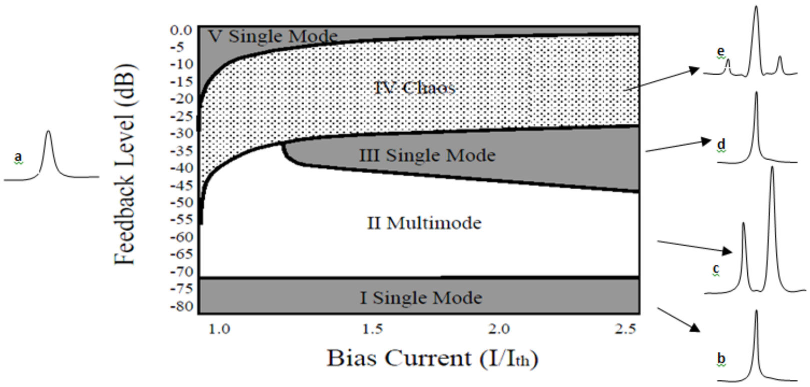

Fig. 1: Optical spectra for: a. laser without feedback.
b. Regime I, c. II, d: III, and e. regime IV, according to feedback strength [9].

There has been a great deal of interesting into the properties of (LDs) in regimes I – IV. These regimes encompass the low-feedback properties of (LDs) and the (CC) state of operation. Few studies have been performed on the properties of (LDs) with strong (OFB), which is considered to occur when the external feedback reflectivity is comparable with, or greater, than the (LD) facet reflectivity.

For the behavior of (SLs) subject to arbitrary levels of (OFB), an iterative travelling wave model based on the original research of Sporleder was developed. An iterative travelling-wave model of a (LD) subject to strong (OFB) is represented in fig. ٢.

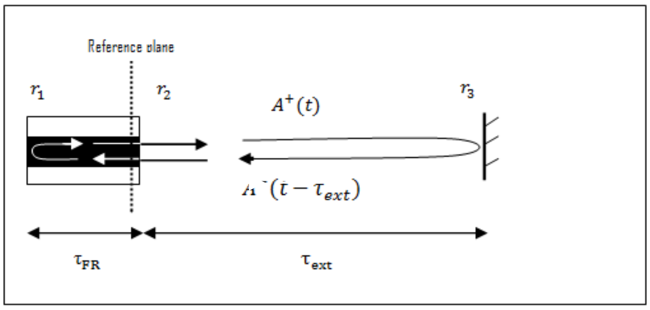

Fig. 2:
Representation of Sporleder model [12].

3. The Experimental Setup:

In the present experimental study, five setting has been studied, fig.3 shows there diagrams. In order to collimate the laser beam propagating from the laser lens to the reflecting mirror plane, and again to laser lens, laser D.C. emission sensitivity were observed. This system represents an *unstable* resonator, fig.3-A.

For this observation, laser bias current was set to be near below its solitary threshold level, slightly matching between outgoing and incoming beams, led to a significant jump in the D.C. level in the oscilloscope. Now, in order to determine the TR ratio, the free (solitary) laser running threshold is measured separately by blocking the feedback beam arm temporally.

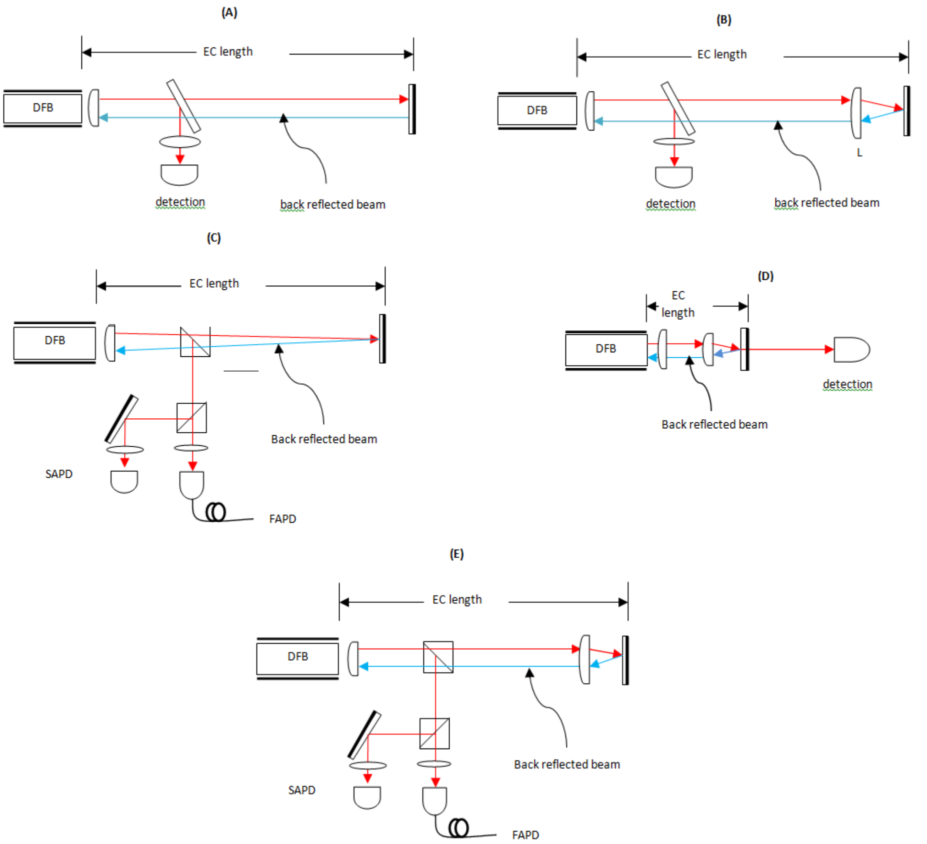

Fig. 3:
Possibilities for maximize the TR: A: Unstable EC resonator, B: Stable EC by using a lens, C: Stable EC by using a laser lens itself, D: Detection position and E: Beam splitter instead of beam sampler.

The procedure is repeated with a beam focusing, as a stable resonator regime, by inserting a lens near the feedback mirror as shown in fig. 3-B, such that it locates in a distance equals to its focal length. This is achieved by using a movable (slide) lens mounting.

The procedure is repeated with a direct beam focusing, fig.3-C, by changing the collimating laser lens to be focusing, by tuning lens Z direction till achieving a minimum spot area, which was optimized to be minimum by using a beam profiler.

Detection position is tried, which is equivalence to delay time variation, in low reflectivity mirrors, fig.3-D, and beam splitter versus beam sampler is tested, fig. 3-E, finally, the same figure, EC length is also tested in large cavities regime.

The laser source for all these experiments is, quantum well, DFB laser, with standard specifications, $ML725B11F$/ThorLabs Co. Laser active medium is an InGaAsP, emitting peak wavelength around $1310nm$, with (CW) operation and peck power $P_o = 10\ mW$. This type is well suited for light source in long-distance digital transmission systems. It has a wide temperature range operation$(-40\ to\ 85^oC)$, low threshold current (typical $6mA$), high speed response (typical $0.1nsec$), and flat window cap.

A GPIB network cable is connected to the laboratory desktop computer, this is in order to both remote controlling these equipment scales and saving the optimal experimental data by "*Labveiw*" program. GaAs photo-detectors are ideal for applications that require high speed, high sensitivity, and clean responses. A (DSO) was used for laser D.C. emission level determination, line shape (calibration with the FP Interferometer. ThorLabs Photo-detector amplifier (PDA255)" detector, which is a high speed amplified, InGaAs detector designed for detection of light signals from DC to 50 MHz.

"Anritsu" MS2665C, 21.2GHz, (RFSA) was used for studying RF frequency dynamics and "*Agilent"* HP 86140, (EOSA), was also used for lower resolution optical frequencies analysing.

In order to laser temperature stabilization, a *Peltier cell* with its heat sinking, for temperature was used, with a penalty of $\mp 0.2^oC$ temperature fluctuation. To optimize thermal contact with the Peltier cell, a *thermal paste* has been used. A *thermometer* is used for laser temperature screening during the running.

4. Results and Discussion:

The part E in fig.3 was used to study the real laser characteristics in solitary case, this is by blocking the beam reflected from the eternal. The measured splitting ratio for operating wavelength is:

$50.50\% : 43.84\%$ for $I_1 : I_2$, respectively, with 9.4% as a loss. While Laser operating temperature was chosen to be: 14.5C^o, this is to avoid any water vapour which might be condensed on laser device due to central air conditioner system turn off inside the laboratory during the night, which could causes a laser device damage. At this operating temperature, measured laser threshold current was $4.03mA$, and its maximum output optical power was 10.28mW at 30mA, as calculated from fig. 4 below. This is after including the reduction of power due to absorption inside the NB and mirror.

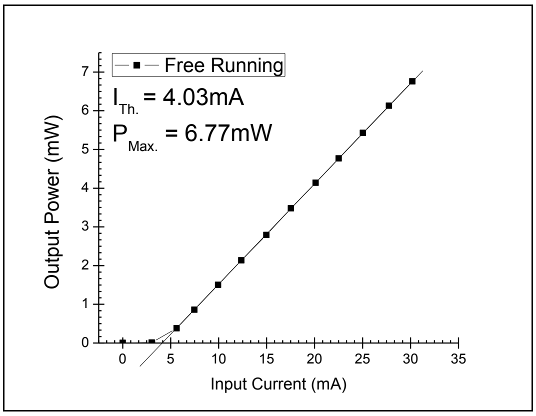

Fig.4: Solitary laser (L/I) curve at 14.5C^o.

The observed laser optical spectra, according to pumping current levels, are shown in fig.5.

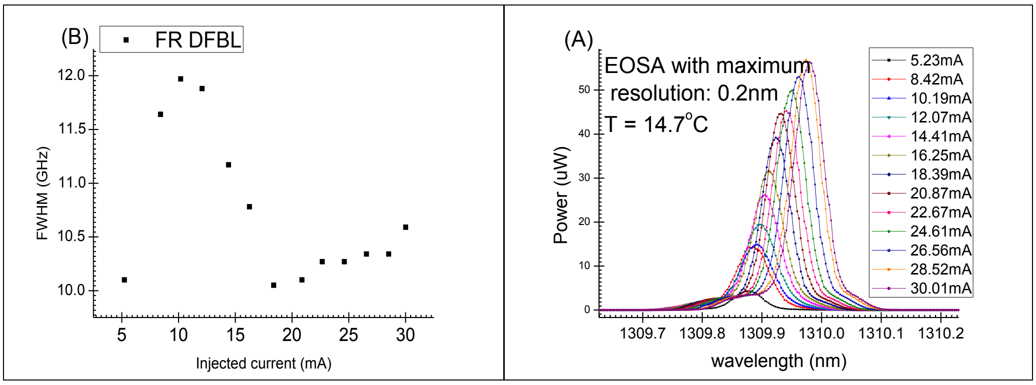

Fig. 5: Free running laser optical spectra
A: lineshape modifications with injection current, B: coresponding FWHM value variation.

Results showed that there is a variation in peck wavelength from $1309.87 - 1309.98nm$ with respect to laser injection current level, which means a shift of wavelength to current: $(3.6 \times 10^{-3}\mathrm{nm/mA})$. The other observation is pulse line width which fast increasing values in low driving current levels, but it goes to be lower in intermediate, to higher currents, around $10.25GHz$.

Present analysis was based on observations for (DFBL) in the (FR) case by using: direct time domain observation by using (DSO), then their (FFT) both power and (RF) spectra, finally; optical spectra. This is to indicate the exact laser dynamics developments with laser injection current level.

Fig.6 gives its (FFTs) power spectra map for specific operating currents. These results shows that except in low (5mA multimode operation) levels for laser current, their is a highely amplitude, single longitudenal lasing mode.

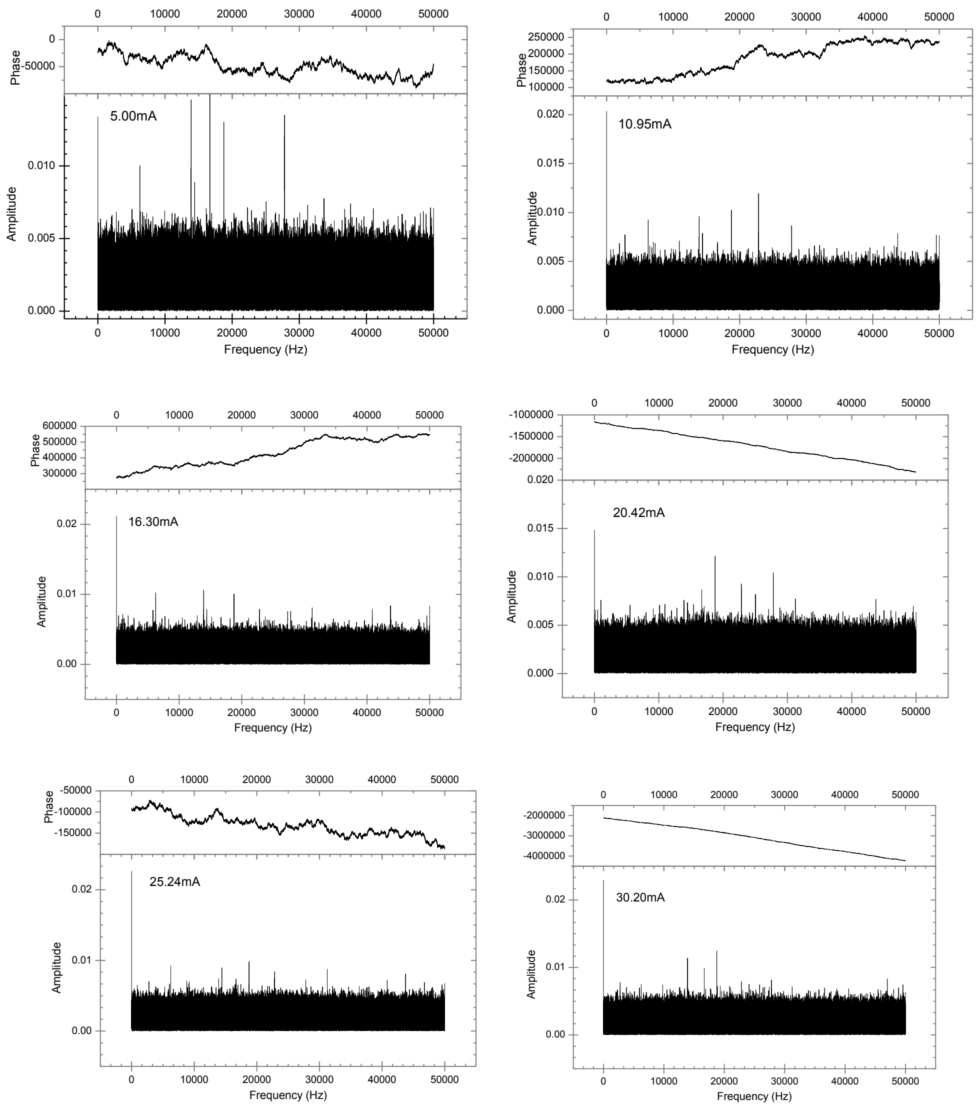

Fig. 6: Free running (FFTs) power spectra map for (DFB) Laser

Fig.7 gives time scale map for specific operating currents in nanoSecond and its associated (FFTs) power spectra. In this figure, the dominant feature is the blue shift, where, power spectra gave a blue shift in lasing frequency with increasing pumping current.

Highly amplitude lasing frequency was observed at operating just near above threshold. Running in intermediate current level (15.5mA) gave steady oscillation dynamics lead to periodic, sharp peaks. This is due to pumping away than spontaneous-emission noise level.

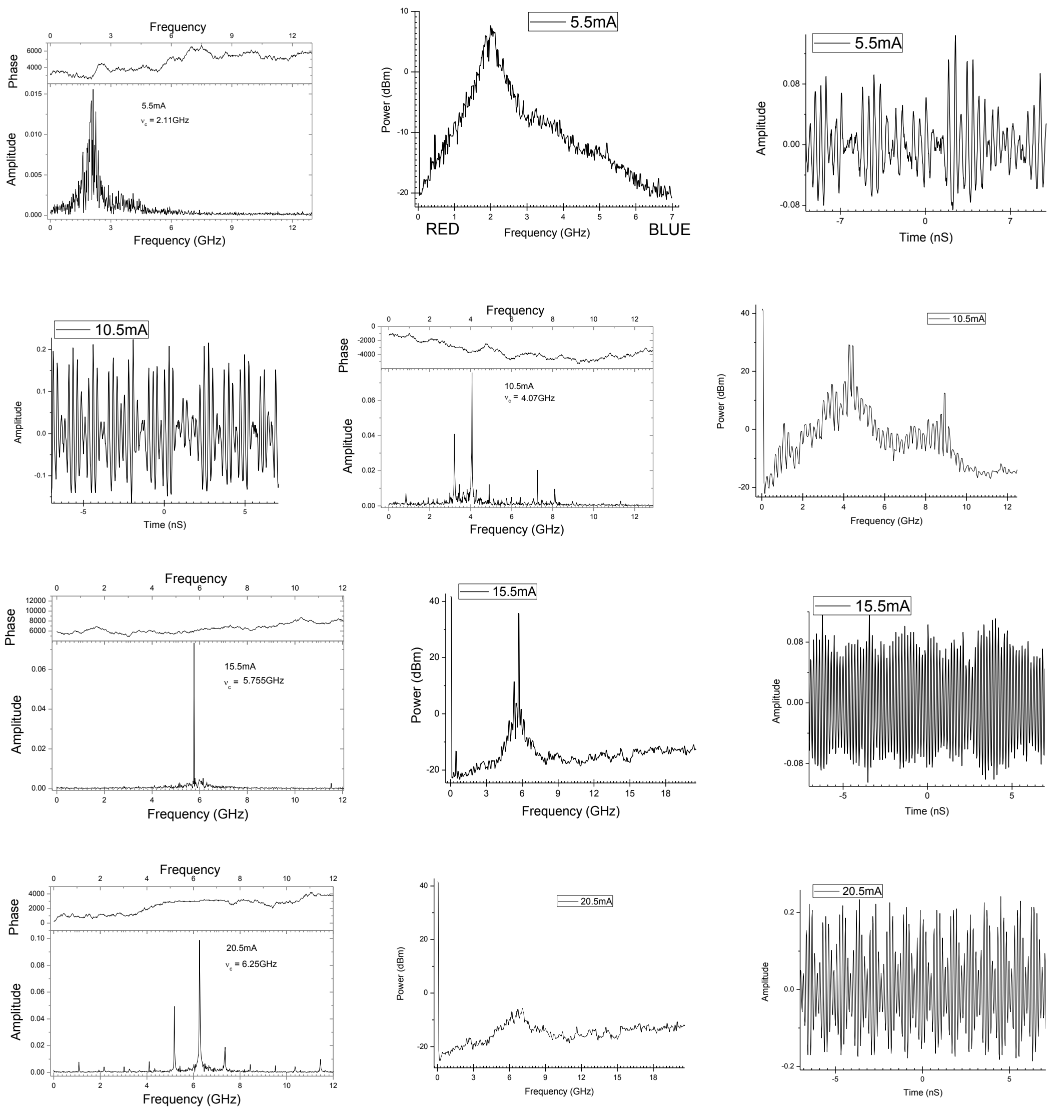

Fig. 7: Laser dynamics with free running at 16.3 ^{o}C.

It can be noticed that the mode-suppression-ratio was constant from low to highly pumping currents. Growing of new low amplitudes frequencies in high laser pumping current level is interpreted as an increase of Joule heating effect.

Chung and Lee, [13], showed that the sensitivity of a (SL) to external (OFB) depends on the stored energy in the cavity and the coupling of the laser mode to the external field. Thus, to compare the feedback sensitivities of edge emitted lasers, such as (DFBs), an (OFB) parameter k is important.

In the following fig. 8, results for experimental free running and running with feedback. In part A, a beam splitter and beam sampler two measurements with 20 cm cavity, in which the beam splitter gave maximum threshold reduction. In part B, four ECs length experimented, the maximum (TR) indicated with 90 cm. In part C, unstable cavity was experimented with three (ECs) lengths, 30, 60 and 85cm, in which the maximum (TR) was indicated with 60cm. Finally, in part D, six external cavity mirror reflectivity were experimented, the maximum (TR) indicated with the maximum reflectivity. The experimented techniques for these figs. were those given in fig.3 A, B, C, and D, respectively.

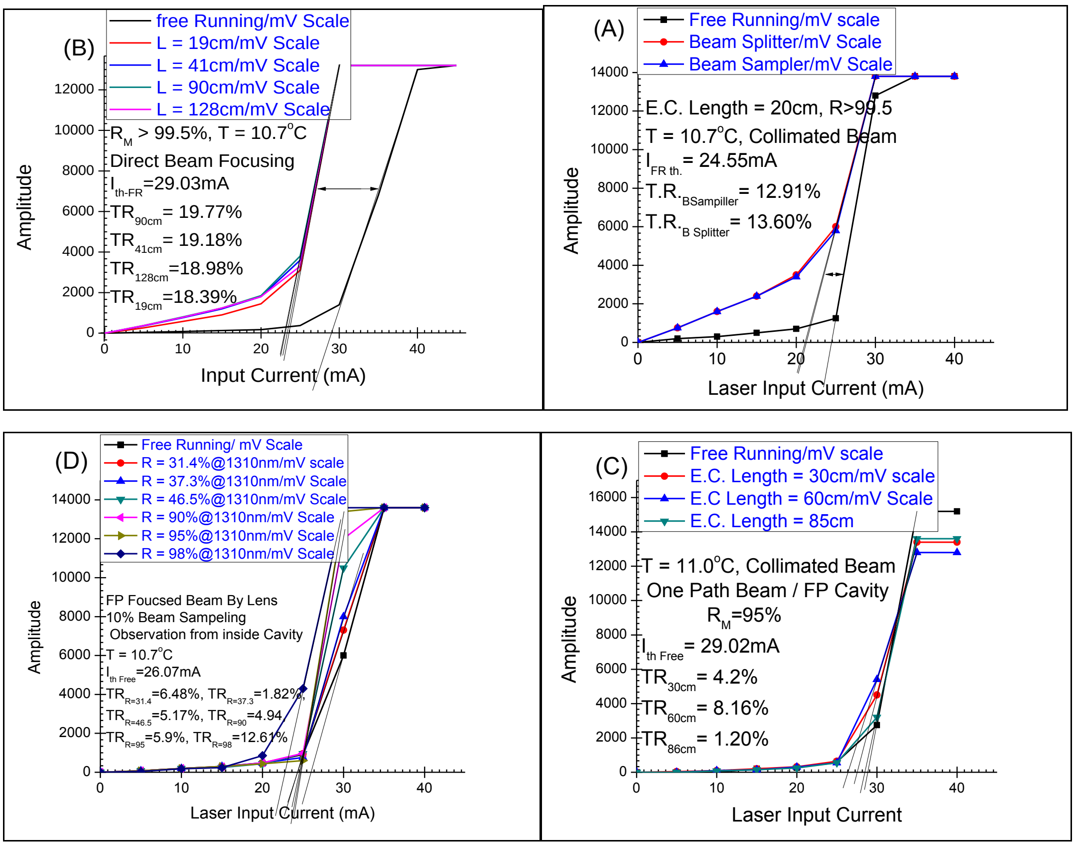

Fig.8: Threshold reduction possibilities: A: (NBS) and beam sampiler, B: direct foucsed beam, C: collimated beam, and D: foucsed beam by a lens.

In the coming fig. 9, another type of measurments was carreid out for two techniques, the 1st (part A) considerd the stable (EC) (given in fig. 3C) according to the possibility of foucsing the outgoing and incoming – back reflected from the mirror- beamsassociated with several (EC) lengths. Results indicated maximum (TR) with 90cm length. In fig. 9, part B, teqnique of foucsing the beam by using a plano convex lens was experemented. Results indecated a meximum (TR) with 60cm (EC) length.

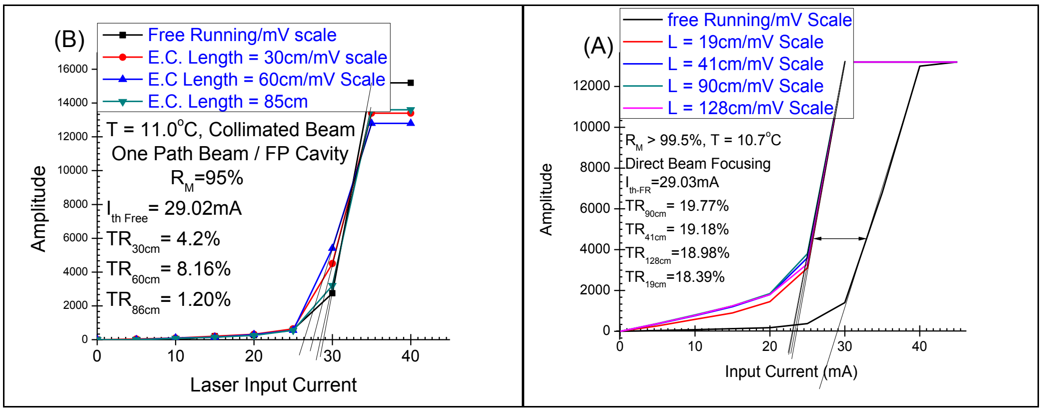

Fig.9: Threshold reduction for different (EC) lengths, A: foucsed and B: collimated beam geometry.

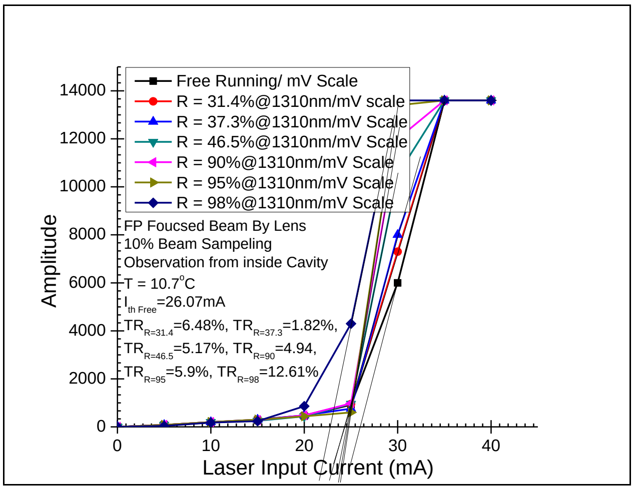

Fig.10: Mirror reflectivities effect on laser TR.

Results shown in fig.10 show slightly dependence of (TR) on (EC) length in foucsed regime, while it was highely dependent when operating in collimated regime.

The attractive observation indicated with the threshold reduction by optical feedback phenomenon is that the possibility of lasing in stimulated-emission pumping region. This could be interpreted according to bi-stability effect. In which, the re-injected optical beam might be considered as a secondary pump source, which was in this case an optical pump. This type of bi-stable could be considered as a mutual type of the (SEED), in multi-quantum well materials, as it had explained theoretically by B. Al-Hilli, [14].

Dynamics observed with this value of (TR) gave the phenomenon of (CC), as shown in fig.11.

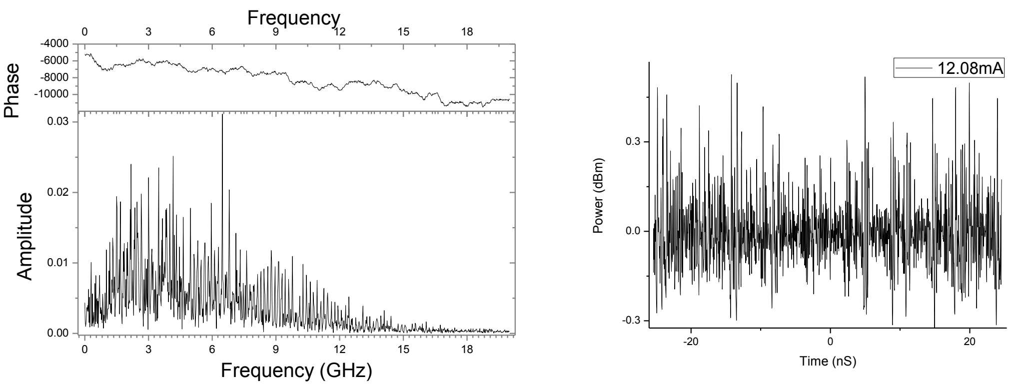

Fig. 11: Laser dynamics, time sereis and its power spectrum with 85cm single EC.

5. Conclusions:

Applying very strong optical power, as a feedback source, to a (DFB) simiconductor laser caused internal cavity excited laser instability. Threshold reduction is one of those instabilities, which maks the laser as a (SEED)

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