The Effect of Chaotic Laser beam on near field transducers for Heat assisted magnetic recording

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Abstract

The purpose of this paper is to demonstrate the effects of chaos generated in semiconductor laser with external cavity feedback. Chaotic states of a semiconductor laser with external cavity feedback mirror are generated by varying external feedback strength between 0-3ns^{-1}, which is a function of reflectivity of mirror. To study chaos, Bifurcation, Temporal waveform, and Attractor are used. The results of chaotic states affect near-field. We showed comparisons with stable, periodic, and chaotic states that change the electrical field around 50x50 nm of C-shaped near-field transducer (NFT) by using a semiconductor laser, 830 nm at 50 nanosecond. The effects of chaotic state decrease the electrical field around a near-field transducer. It is very important in the light delivery system designs, which are the components of a heat assisted magnetic recording system

Keywords: Chaotic laser beam, Heat assisted magnetic recording, Near-field transducers

1. Introduction

As the demand for storage data is increased, it makes the storage data development of hard disk drives more important. The current technology, which is perpendicular recording, is approaching its limit at 1TB/in^2 due to unstable thermal, signal to noise ratios and limits of data per bit area. Magnetic data storage can be improved, which is well known as “Heat Assisted Magnetic Recording – HAMR” [1]. HAMR is in the novel recording head, which writes data while temporarily heating the media disk. HAMR consists of a semi-conductor laser and light delivery system (e.g. Optical device and Near-field transducer) [2]. The light delivery system, which is the research focus, adjusts the beam to be smaller than 100 nm. The heat source of HAMR uses a small semiconductor laser (e.g. VCSEL laser). A semiconductor laser can exhibit nonlinear and chaos effects, which was presented by Haken in 1975. In 1979, Ikeda explained the appearance of a chaotic laser by irradiating with a laser through a ring cavity [3]. In 1980 [4], the rising of chaos with external cavity feedback was proposed by Lang and Kobayashi. The released laser reflects back to the laser cavity by an external factor. This decreases the pump current of the laser and increases the laser intensity. However, it leads to instability. It is useful for many applications (e.g. optical communication, secure key distribution, random number generation [3], and optical data storage [5]).

The light delivery system of HAMR consists of a laser and optical waveguide or fiber optic. The connection between them can cause chaos [6].The chaotic effect can be explained by instability of bifurcation diagram, attractor of laser, and temporal waveform [7]. Before the light propagates through a media disk, the transducer has important roles to squeeze the light and to invoke Plasmon resonance [2]. It is the last process, before passing laser light to a media disk. In the future, the media of a hard disk will be developed to contain more data, by utilizing different materials such as L10FePt, FePd, CoPt, and MnAl. These materials have high resistance to the reversion of magnetization because of high anisotropy which affects the Curie temperature (Tc)[1]. For HAMR technology, a promising recording media is Iron-Platinum (FePt) media due to the fact that it allows very small grains down to 4 nm and still maintains a stable magnetization. FePt media requires a temperature at 750K within 1 ns to utilize HAMR [9]. Before transmission of the heat to media and squeezing the laser beam into a nanometer, it is necessary to use a nano transducer, which is a plasma resonance phenomenon. It involves with changing of electrical field, which is related to a near field transducer. Changing the level of the electrical field around a transducer determines the heat transmission to thin film media [10],[11],[12].

This paper presents a chaos state of a semiconductor laser with reflection of the external cavity. Chaos is presented by a bifurcation diagram, temporal waveform, and attractor of laser with variation of factor called the feedback strength or mirror reflection. The result of chaos is studied by fluctuations of the electrical field around the C-shape near field transducer at 50 nanoseconds.

2. Theoretical framework

Lang Kobayashi's equations have been used to study the dynamics of a semiconductor laser with external cavity feedback [4]. Laser dynamics shows many states which are stable states, periodic states, quasi-periodic states, and chaos states. These states depend on several factors (e.g. feedback strength of external mirror, feedback phase, current density, and feedback mirror). The transition state is observed from the temporal waveform, attractor of laser, and bifurcation diagram, as the following equations:

$$\frac{dE}{dt} = (1+ia)NE + \eta E(t-\tau)e^{iC_0} \tag{1.1}$$

$$T\frac{dN}{dt} = P - N - (1-2N)|E|^2 \tag{1.2}$$

Where E is electrical field of semiconductor laser, $|E|^2$ is the intensity of semiconductor laser, N is the carrier density in cavity, α is the linewidth enhancement factor, η is the feedback strength, Cp is the feedback phase, T is the photon lifetime, and P is the current density.

Feedback strength of the Lang Kobayashi equation is written as:

$$\eta = \frac{(1-r_2^2)r_3}{r_3}\frac{1}{\tau_{in}} \tag{1.3}$$

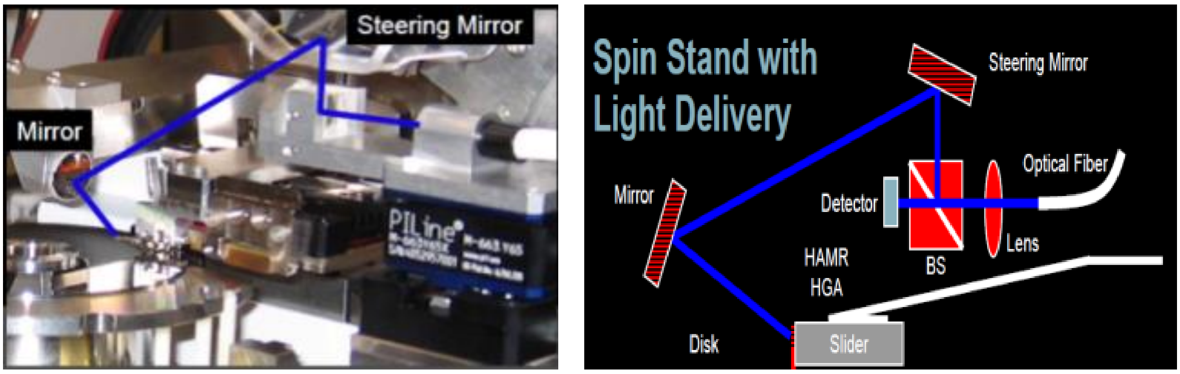
Where τ_{in} is the round-trip time in internal cavity, r_2 is the reflectivity of laser facet, and r_3 is the reflectivity of external mirror.

In the time domain, the laser reflection comes from an external factor, namely, the connection between laser to laser and entering of a laser beam into an optical fiber or waveguide. When the laser reflects back into the cavity, it causes a chaotic state. HAMR also consists of this arrangement, a laser connected to an optical fiber as shown in Figure 1, thus, it causes chaos.

2.1 Temporal waveform and attractor of laser

The study of temporal waveforms and attractors can explain the instability. When feedback strength increases, chaos will happen as shown in Figures 2(a) and 2(b). When chaos happens from graph attractor, it will show a laser intensity which is unstable. The intensity is not repeated as in Figure 2(c). When a periodic state occurs, the intensity laser overlaps as in Figure 2(d). For a stable state, the intensity of the laser is stable. This does not occur for graph attractor.

(a) **(b)**



. **Fig. 1.** (a) Experimental light delivery on HAMR (b) Schematic of light delivery systems.

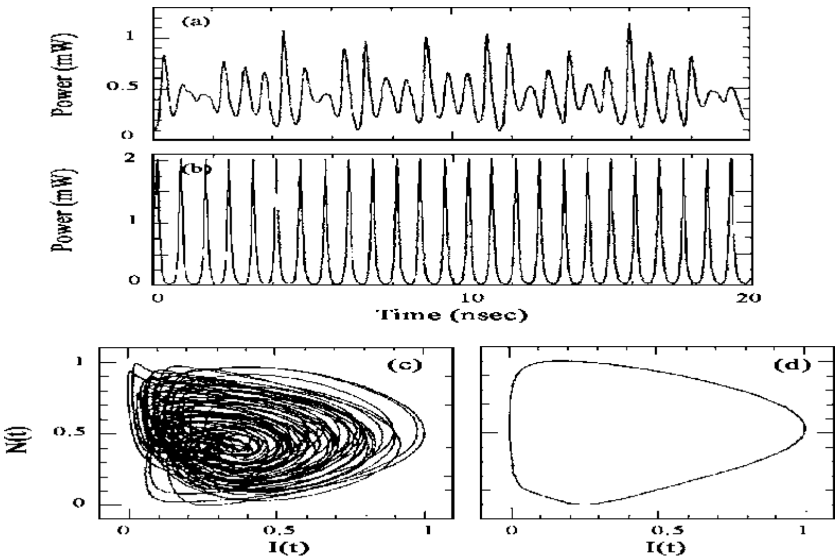


Fig. 2. Temporal waveform showed instability of intensity semiconductor laser (I(t)) in temporal waveform [7].

2.2 Bifurcation diagrams

A bifurcation diagram shows the dynamics of a laser system. As the intensity of the laser changes, the feedback strength also changes showing the chaos state [6]. The intensity of the laser can have various values due to the existence of chaos. A chaos state happens by feedback strength, as shown in Figure 3.

2.3 Near-field on HAMR

Nano transducers made of certain metals, such as Au, Ag, Cu, and Al, exhibit strong form surface resonance at optical near field. These light interactions on transducers exhibit strong field enhancements to a surface metal. This enhancement of field is confirmed in strong light intensity to media by effect of Plasmon resonance, depending on the design of transducers, wavelength, and intensity of the laser beam. In this paper the design of transducers is shown in Figure 4. Table 1 presents the size of frame and transducer dimensions. The method of calculation is FEM (Finite element multiple physics) by changing of light intensity, according to the time to evaluate the electrical field around transducers.

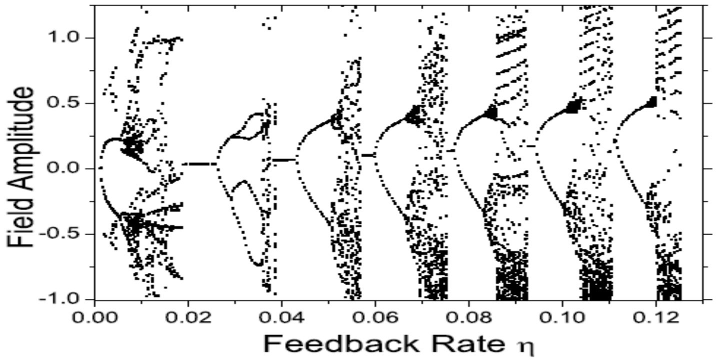


Fig. 3. Bifurcation diagrams of semiconductor laser [6].

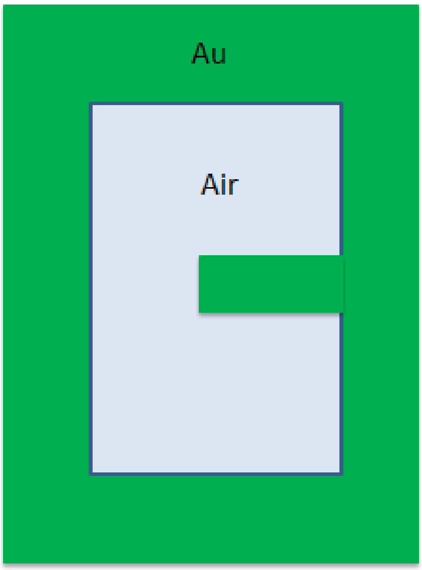


Fig. 4. Design of C-Shape near field transducer.

Table 1. Parameters of near field transducers.

C-Shape transducer	Dimensions
frame W x H	200x300 nm
C-Shape transducers W x H	120x200 nm
ridge gap	5 nm
ridge width	30 nm

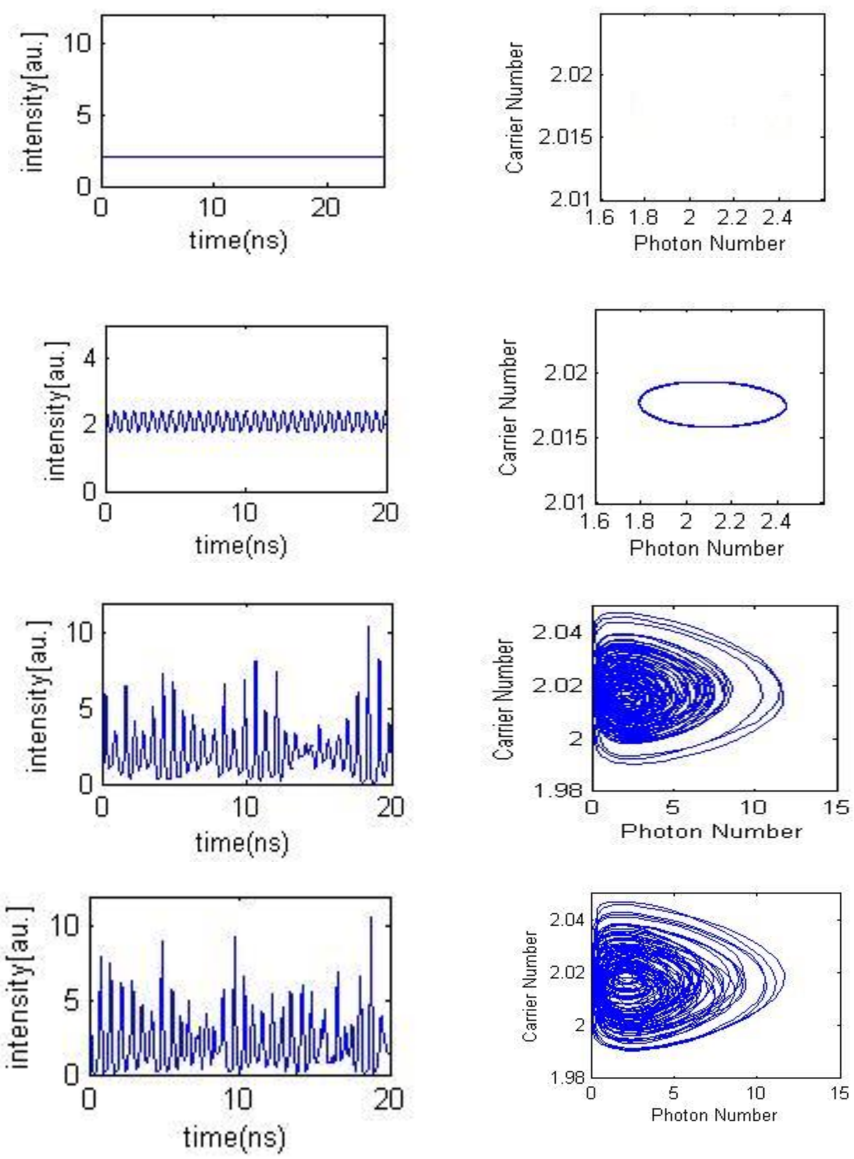


Fig. 5. Shows stable, periodic, and chaos states in time domain and attractors.

3. Results

3.1 Temporal waveform of external cavity feedback

To determine the temporal waveform, the feedback strength was varied from 0 to 3 $ns^{-1}$and the working time of laser (wavelength is 830 nm) was varied from 0 to 50 ns.This duration is enough for the heating process in HAMR. If the reflectivity is varied such that the feedback strength η=0 ns^{-1}, as shown in Figure 4(a), the intensity of the laser is in a stable state. Figure 4(b), η = 0.777 ns^{-1}, shows that it is in a periodic state. For Figure 4(c) and 4(d) η=1.553 $ns^{-1}$and 3ns^{-1}, chaos occurs, which shows the fluctuation of intensity of the laser.

3.2. Transition of Bifurcation

The feedback strength was between 0-3 ns^{-1} as in Figure 6, this shows the transition of state from stable to chaos. A stable state happens between 0-0.777 ns^{-1}. A periodic state happens between 0.777-1.553 ns^{-1}. For feedback strength greater than 1.553 ns^{-1}, a chaos state occurs, which shows the fluctuation of intensity.

3.3 Effect on Near-field on HAMR

For the study of near-field effects on Plasmon resonances, it is necessary to study the electrical field of a C-Shape transducer, which the laser wave length is 830 nanometers, in TM Modes. The stable state of the laser intensity is 2.50 mW. When the state is changed to a periodic state and a chaos state, the light intensity is unstable, as shown in Figure 7. Figure 7 shows the changing of electrical field when states are different. The electrical field is intense in this stable state. The intensity of electrical field of others states will be reduced when the state is changed. Chaos1 shows the lowest electrical field around peg C-Shape transducers. The values of electrical field, which are measured from peg of transducer, for 4 states are 70.02516 V/m at stable state, 67.9213 V/m at periodic state, 65.27268 V/m at chaos1, and 63.829628 V/m at chaos2. Figure 8(a) shows the changing of electrical field around peg rim C-Shape transducer. The rising of a stable state and a chaos state have different values of electrical field.

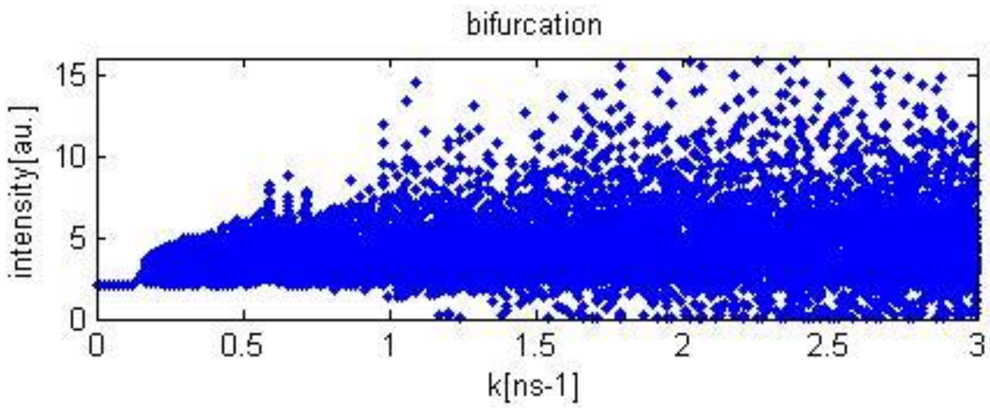
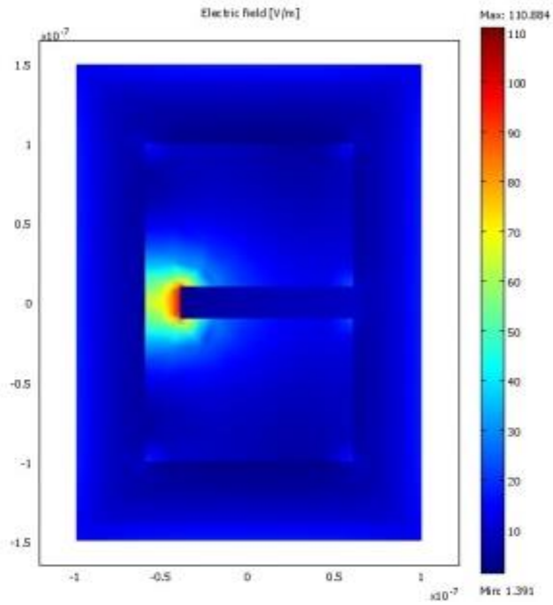
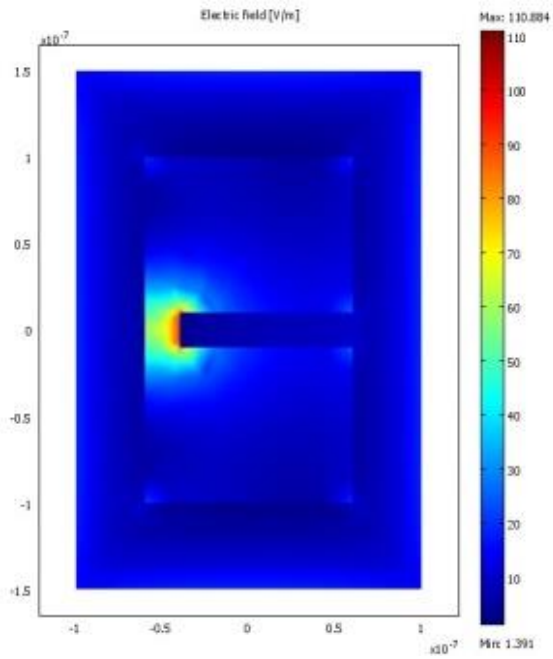


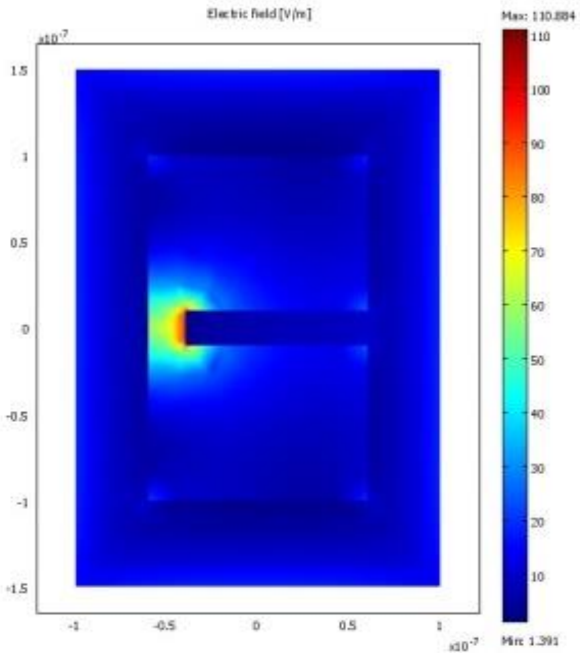
Fig. 6. Bifurcations diagrams transfers from Lang-Kobayashi equation using FFT.


Electric field [V/m]
Max: 110.884
Min: 1.391

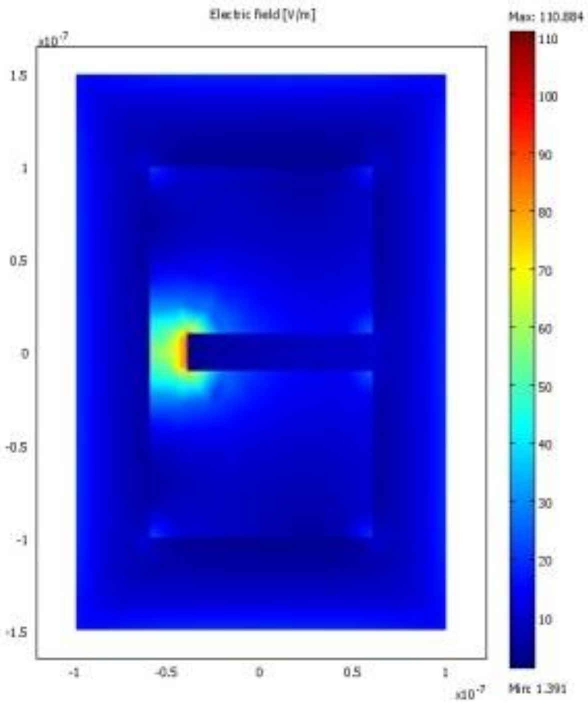
(a)


Electric field [V/m]
Max: 110.884
Min: 1.391

(b)



(c)



(b)

Fig. 7. Near-field transition is shown in picture (a) stable state (b) periodic state and (c) chaos1 (d) chaos2.

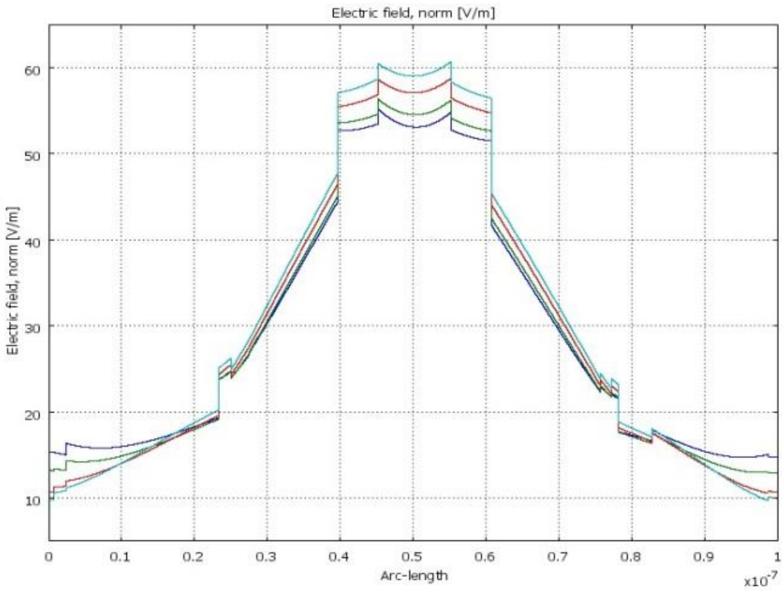


Fig. 8. The picture shows the changing of intensity in 50 ns around a transducers peg.

4. Conclusion

The changing of an external cavity laser presents 4 states of the laser. The stable state has the highest value of the electrical field. It will be reduced continuously according to periodic and chaos states. The rising of chaos affects heat assisted magnetic recording since it uses a heat transition in nanoseconds. In the future, we will propose an experiment of the phenomenon of a chaotic laser beam interacting with transducers.

5. Acknowledgements

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References

[1] Kryder,M.H., Gage, E.C., Mcdaniel, T.W., Challener, W.A., Rottmayer, R.E., Ju, G., Hsia, Y. and FatihErden, M., Heat Assisted Magnetic Recording, Proceedings of the IEEE, Vol.96, No.11, pp. 1810 - 1835, 2008.

[2] Challener,W.A., Peng, C., Itagi, A.V., Karns, D., Peng, W., Peng, Y., Yang, X.M., Zhu, X., Gokemeijer, N.J., Hsia, Y., Ju, G., Rottmayer, R.E., Michael A., Seiglerand E., and Gage, C., Heat-assisted magnetic recording by a near-field transducer with efficient optical energy transfer, Nature Photonics,vol.3, 2009.

[3] Uchida, A., Optical Communication With Chaotic Lasers: Applications of Nonlinear Dynamics and Synchronization, Wiley, 2012.

[4] Lang, R., and Kobayashi K., External optical feedback effects on semiconductor injection laser properties, Quantum Electronics, IEEE., vol.13, pp. 347 – 355, 1980.

[5] Pieroux, D., and Erneux, T., Bridges of Periodic Solution and Tori in Semiconductor Laser Subject to Delay, Phys. Rev. Lett., 87, pp. 193901, 2001.

[6] Heil, T., Fischer, I., and Elsaber, W., Delay dynamics of semiconductor laser with short external cavities: Bifurcation scenarios and mechanisms, Phys. Rev. E, 67, pp. 066214, 2003.

[7] Liu, Y., Controlling dynamical behaviour of semiconductor laser with external optical feedback, Phys. Rev. Lett., 51, no. 4, 1995.

[8] Zana, J.W., Harrell, Y., Inaba, J., Izatt, L., Kang, S., Thomson, G., and Klemmer, T., Modeling Thermal Transients in Pulse Laser Annealing of FePt Thin Films, MINT Center - The University of Alabama, 2007.

[9] Silapunt, R., and Watcharakitchakorn, O., A Study of Near Field Transducer Performance and Deterioration from Local Surface Plasmon Resonance in Heat-Assisted Magnetic Recording System, ICEAA, pp. 582-588, 2012.

[10] Itagi, A.V., Challener, W. A., Peng, C., Karns, D., Peng, Y., Yang, X., Zhu, X., Gokemeijer, N., Hsia, Y., Ju, G., Rottmayer, R., Seigler, M., Rausch, T., and Gage, E., Integrated Near Field Transducer Heat Assisted Magnetic Recording Head: Design and Recording Demonstration, IEEE, no. 4, 2012.

[11] Bakker1, R.M., Boltasseva, A., Liu, Z., Pedersen, R.H., Gresillon, S., Kildishev, A.V., Drachev , V.P., and Shalaev, V.M., Near-Field Excitation of Nanoantenna Resonance, Optics Express, vol. 15, pp. 13682–13688, 2007.