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Spin- polarized VCSE lasers dynamics

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Abstract:

We report the results of a detailed numerical study of the vertical-cavity surface emitting VCSE lasers using a theoretical model that included the spin-flip of electrons based on the original work by San Miguel et.al (1995). Various types of dynamics appeared to happen together with types of attractors.

Key words: Vertical Cavity Surface Emitting Lasers, Spin-polarized electrons, Attractors.

1. Introduction:

A real breakthrough in the semiconductor laser technology turned out to be the implantation of double hetrostructures, where the term hetrostructures refers to an artificial built of two semiconductor materials with different values of the energy bandgap, refractive index, effective mass, mobility of charge carriers etc.[1]. In the most common approach a narrow energy bandgap material is sandwiched between materials with larger energy bandgap, which results in the formation of potential barriers at the junctions. Such barriers can be effectively used to confine charge carriers, because they always attempt to lower their energy. If the thickness of the middle layer is comparable with the deBroglie wavelength of the charged carriers, then this particular band alignment is called a quantum well (QW). Vertical-cavity surface-emitting lasers (VCSELs) have advantages compared to conventional edge-emitting lasers [2]. They show an improved beam quality, they exhibit low threshold currents and high efficiency, and their parallel growths allows for on wafer testing. Optoelectronic devices with spin-polarized carriers offer the possibility of output polarization control through the injection of spin-polarized electrons are already of interest as a source for optical computing and cryptography, in chemistry and biology for studying molecules exhibiting optical activity, and in a growing list of other areas. The operation principle relies on the coupling of spin-up (down) electrons to the left (right)-circularly polarized optical field in a quantized system [3].

The challenge in such devices is the injection of spin-polarized carriers with an enhanced spin lifetime at room temperature. We seek in this article to show the dynamical instabilities of VCSELs under the effect of a number of control parameters that appear in the theoretical model of such lasers.

Theoretical model

The semiclassical four-level spin-flip model (SFM) of VCSELs was developed by San Miguel, Feng and Moloney [4]. This model describes very well the dynamics of these semiconductor lasers and is widely used for understanding of the phenomena polarization switching, as an example. The spin-flip model takes into account the spin sublevels of the total angular momentum of the heavy holes in the valence band and of the electrons in the The four sublevels interact with conduction band [4-6].

two circularly polarized electromagnetic waves in the laser resonator, and it is this interaction that is responsible for the complicated polarization dynamics demonstrated by this type of laser. The following six equations SFM model are written in terms of normalized carriers $N=\frac{n_+ + n_-}{2}$ and $m=\frac{n_+ - n_-}{2}$, right (E_+) and left (E_-) circularly polarized complex field and two populations corresponds to them i.e., n_+ *and* n_- respectively [5].

$$\frac{dE_{\pm,R}}{dt}=\kappa(N\pm m-1)(E_{\pm,R}-\alpha E_{\pm,I})-\gamma_a E_{\pm,R}+\gamma_p E_{\mp,I} \quad (1)$$

$$\frac{dE_{\pm,I}}{dt}=\kappa(N\pm m-1)(E_{\pm,I}+\alpha E_{\pm,R})-\gamma_a E_{\pm,I}-\gamma_p E_{\mp,R} \quad (2)$$

$$\frac{dN}{dt}=\gamma\left[\eta_+ +\eta_- -\left(1+|\overline{E}_+|^2+|\overline{E}_-|^2\right)N-\left(|\overline{E}_+|^2-|\overline{E}_-|^2\right)m\right] \quad (3)$$

$$\frac{dm}{dt}=\gamma(\eta_+ -\eta_-)-\left[\gamma_s+\gamma\left(|\overline{E}_+|^2+|\overline{E}_-|^2\right)\right]m-\gamma\left(|\overline{E}_+|^2-|\overline{E}_-|^2\right) \quad (4)$$

R and *l* denotes right and left polarizations respectively.

$2k=\tau_p^{-1}$ is the photon lifetime

α is the linewidth enhancement factor

γ_a is the Gain anisotropy or dichroism rate

γ_p is the Birefringence rates

$\gamma=\tau_n^{-1}$ is the electron lifetime

η_+ is the Right polarized pump component

η_- is the left polarized pump component

is the Electron spin polarization relaxation rate γ_s

$E_\pm = E_{\pm R} + i\ E_{\pm I}$

Results and discussion:

The set of equations (1-4) was solved numerically by the fourth order Runge-kutta method and using MATLAB code and initial conditions with the help of the parameters values given in table (1) [5].

Table(1):Parameters values for the VCSELs [5]

Symbol	Description	value	unit
γ	Electron rate	1×10^{9}	Hz
k	Losses rate	125×10^{9}	Hz
α	Linewidth enhancement factor	1	——
η_{+}	Right polarized normalized pump component	5	——
η_{-}	Left polarized normalized pump component	5	——
γ_{s}	Electron spin polarization relaxation rate	10×10^{9}	Hz
γ_{a}	Gain anisotropy rate	10	Hz
γ_{p}	Birefringence rate	20×10^{9}	Hz

Figure(1) shows the relations between (a) right circularly polarized (RCP) intensity and the normalized carrier variable (N), (b) left circularly polarized (LCP) intensity and the normalized carrier variable (m), (c) imaginary right circularly polarized field (IRCPF) and real right circularly polarized field (RRCPF), (d) imaginary left circularly polarized field (ILCPF) and real left circularly polarized field (RLCPF), (e) total light intensity vs. time, (f) right circularly polarized (RCP) intensity vs. time, (g) left circularly polarized (LCP) intensity vs. time, (h) (N) vs. time and (i) (m) and vs. time for the parameters values given in table (1) [5].

The effect of lifetime ($\tau_n\ (=\frac{1}{\gamma})$):

Decreasing the electron lifetime, τ_n , from 10^{-4} sec to 10^{-12} sec drastically reduces the total laser light intensity from 100(normalized value) to less than 10^{-10} sec. It started with the usual output produced from semiconductor lasers i.e a transient region of 0.35×10^{-8} sec (3500 P sec) and frequency of $5\times10^{9}\,Hz$ (5 GHz) followed a steady output. Through the same range of τ_n ,attractors are generated of the relations RCP intensity against N and LCP intensity against m while the relations amongs IRCPF and RRCPF and ILCPF and RLCPF are increasing and decreasing linear straight lines respectively. The temporal variations of RCP intensity, LCP intensity, N, and m followed that of the total intensity i.e. transient regions followed by straight constant values, as can be seen in fig (1) f ,g, h, i.

The effect of photon lifetime, $\tau_p\ (=\frac{1}{2k})$:

The variation of τ_p from 10^{-6} sec to 10^{-13} sec produced new relations amongs the difference quantities shown in fig(1) a, b, c, d, f, g, h, i, as can be seen in figs(2) and (3) for high values of τ_p .

The effect of the linewidth enhancement factor α :

The increase of linewidth enhancement factor enhances the variation of both refractive index and the medium gain with the variation population inversion i.e. it enhances types of nonlinearities in the laser field and medium. For $\alpha \leq 1.05$ the laser power is very low together with different types of attractors seen to occur.

The effect of circularly polarized pump component, η_+ , η_- .

Keeping η_- constant at (5) increasing η_+ from 5 to 5.2enhances new types of dynamics while increasing η_- from 4 to5.2 and keeping η_+ =5 enhances different types of dynamics as can be seen in figs (4,5).

The effect of relaxation between spin up and spin down electrons, γ_s :

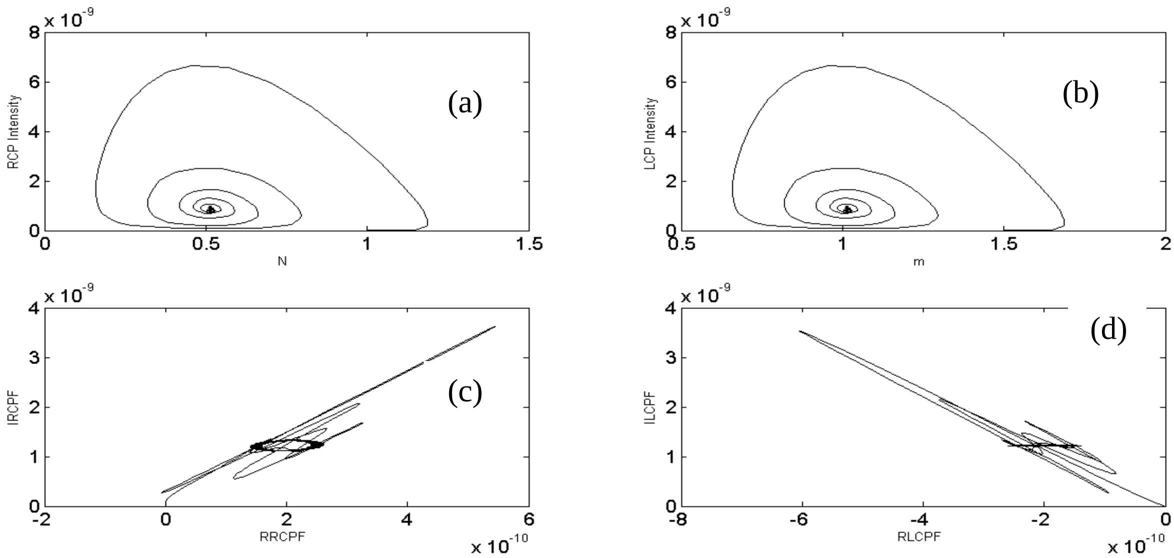
No clear effects of γ_s on all the variables mentioned above even the total laser light intensity.

The effect of gain anisotropy rate, γ_a :

Once again no clear effects of γ_a on all semiconductor laser dynamics discussed above.

The effect of birefringence rate, γ_p :

For low values of $\gamma_p \leq 10^7 \sec^{-1}$, all dynamics are the usual ones except for the variation of (RCP) intensity which shows abnormalities while for $\gamma_p \geq 10^8 \sec^{-1}$new dynamics appeared on the attractors RCP intensity vs. N, LCP intensity vs. m, IRCPF vs. RRCPF,ILCPF, total intensity, RCP and LCP intensities with time and N and m with too as shown in figs(6-8).



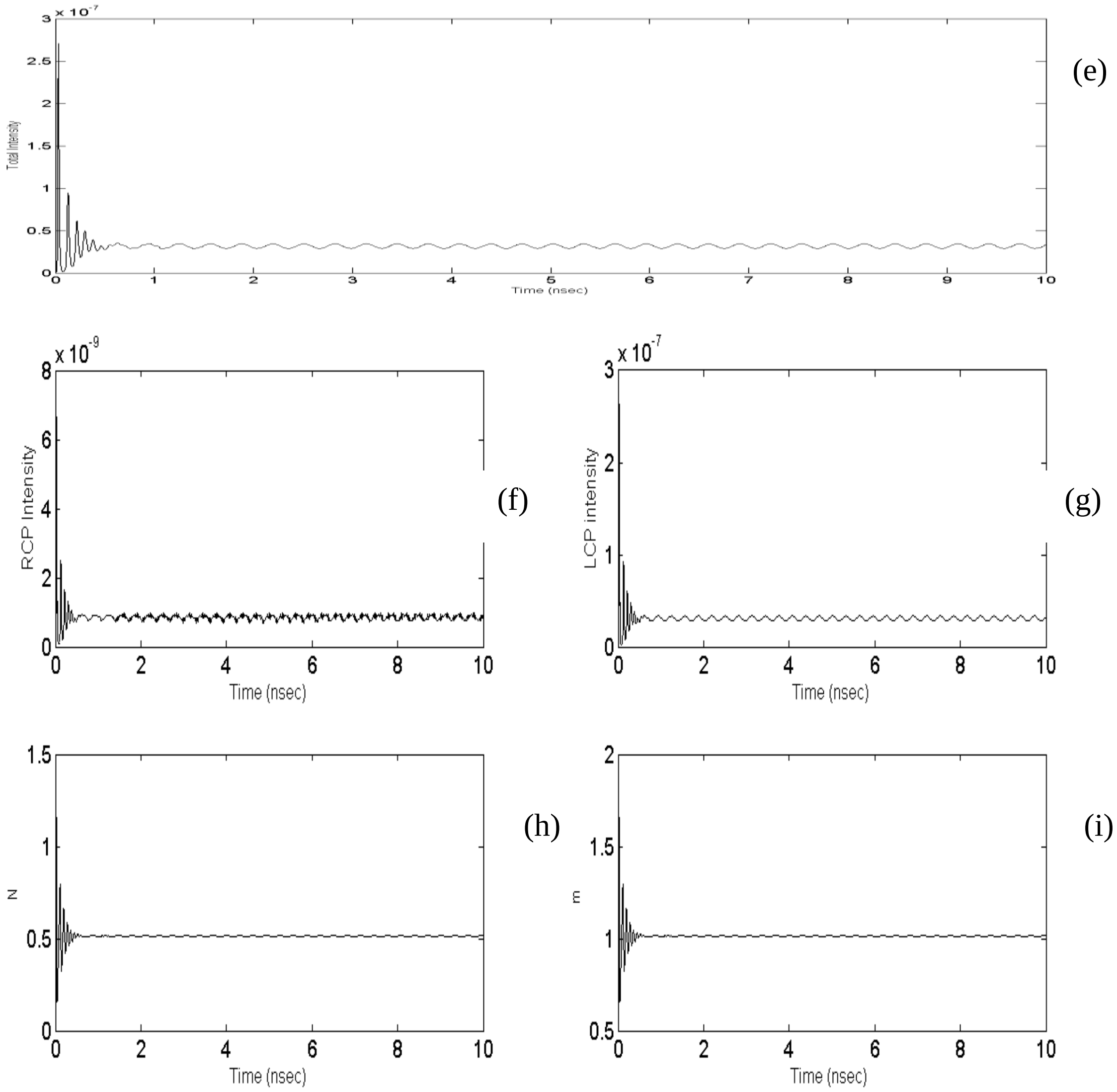


Fig (1) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time; (y- axis is in arb. unit).

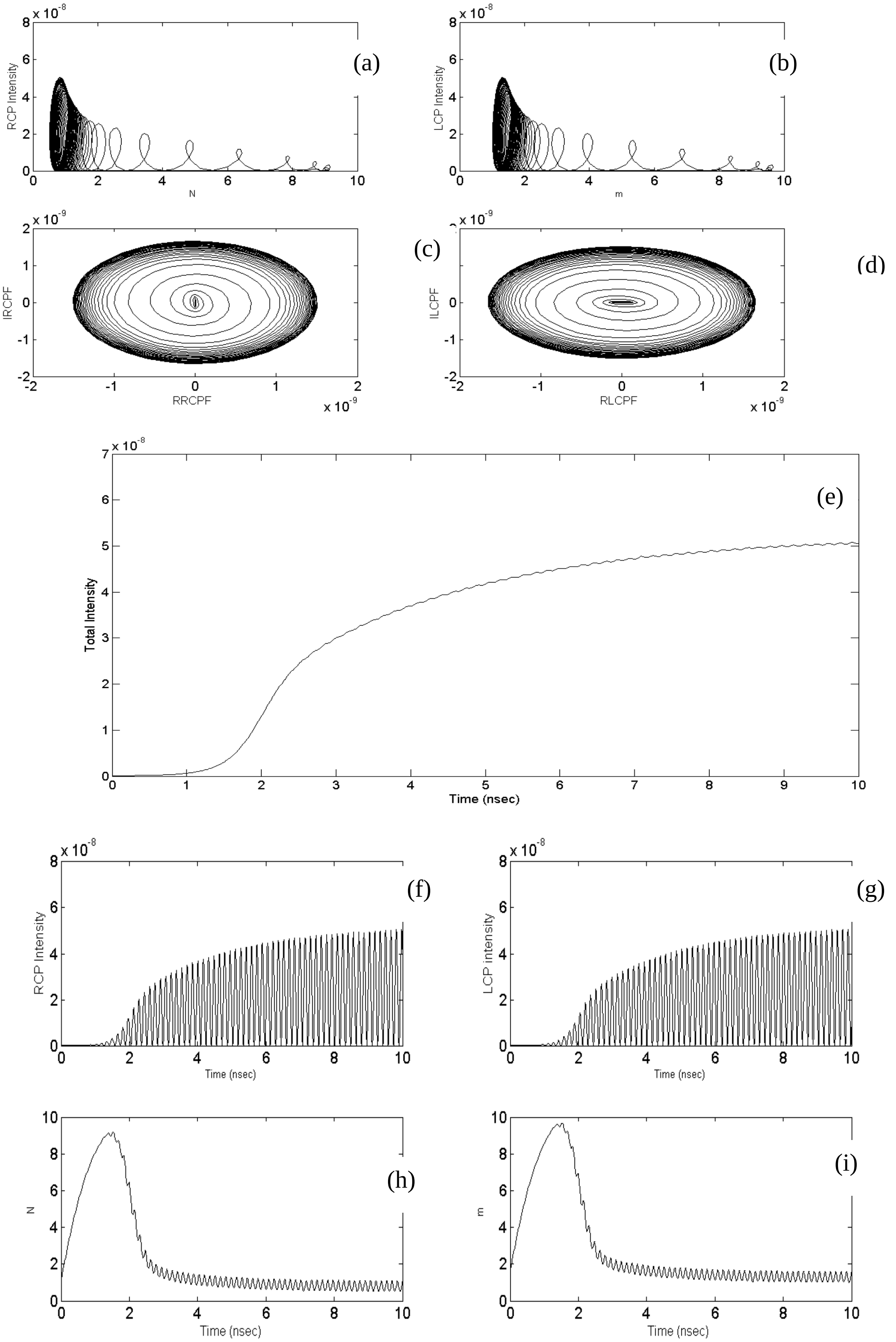


Fig (2) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\tau_p = 10^{-8}$ sec ; (y- axis is in arb. unit).

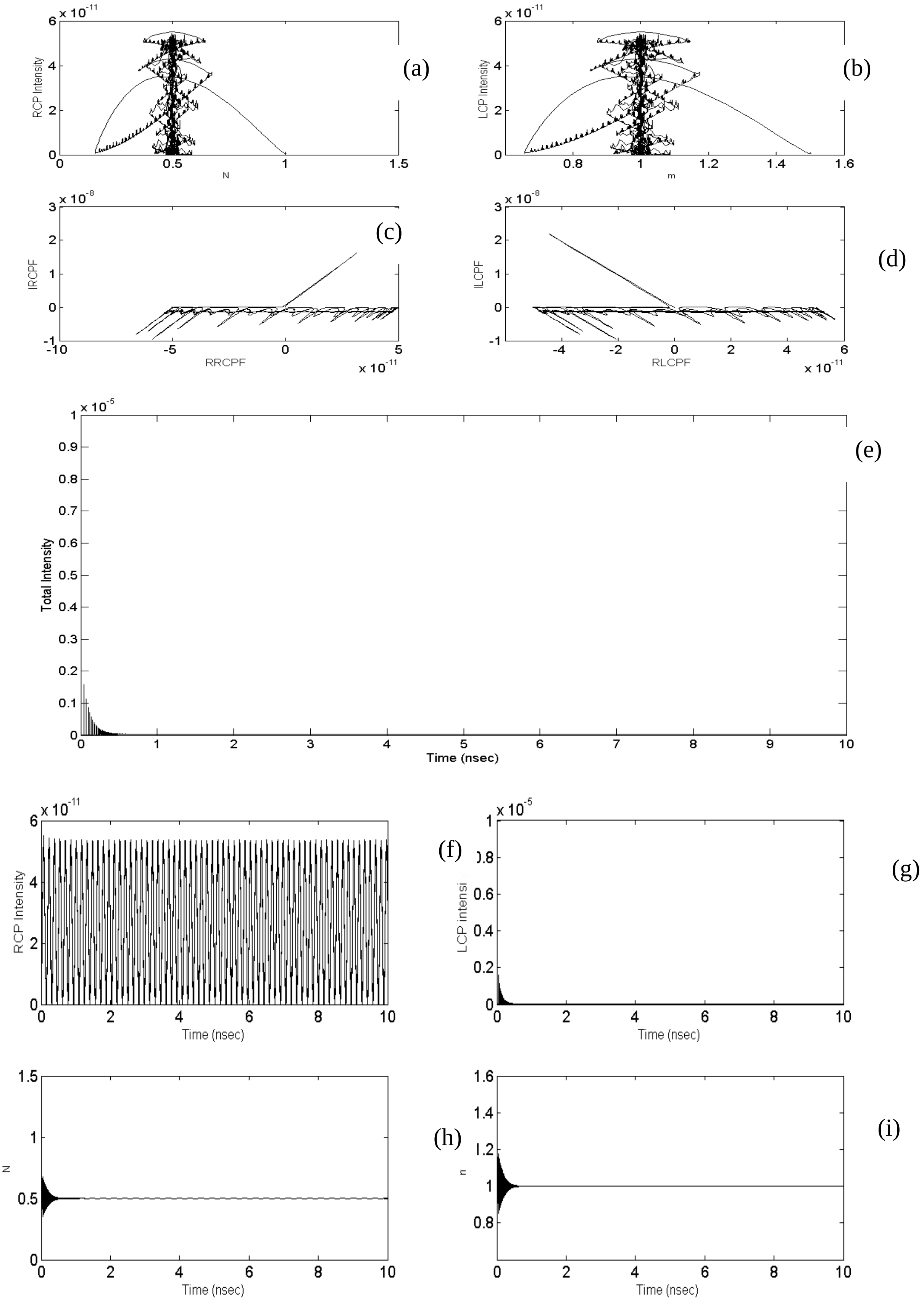


Fig (3) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\tau_p = 10^{-13}$ sec ; (y- axis is in arb. unit).

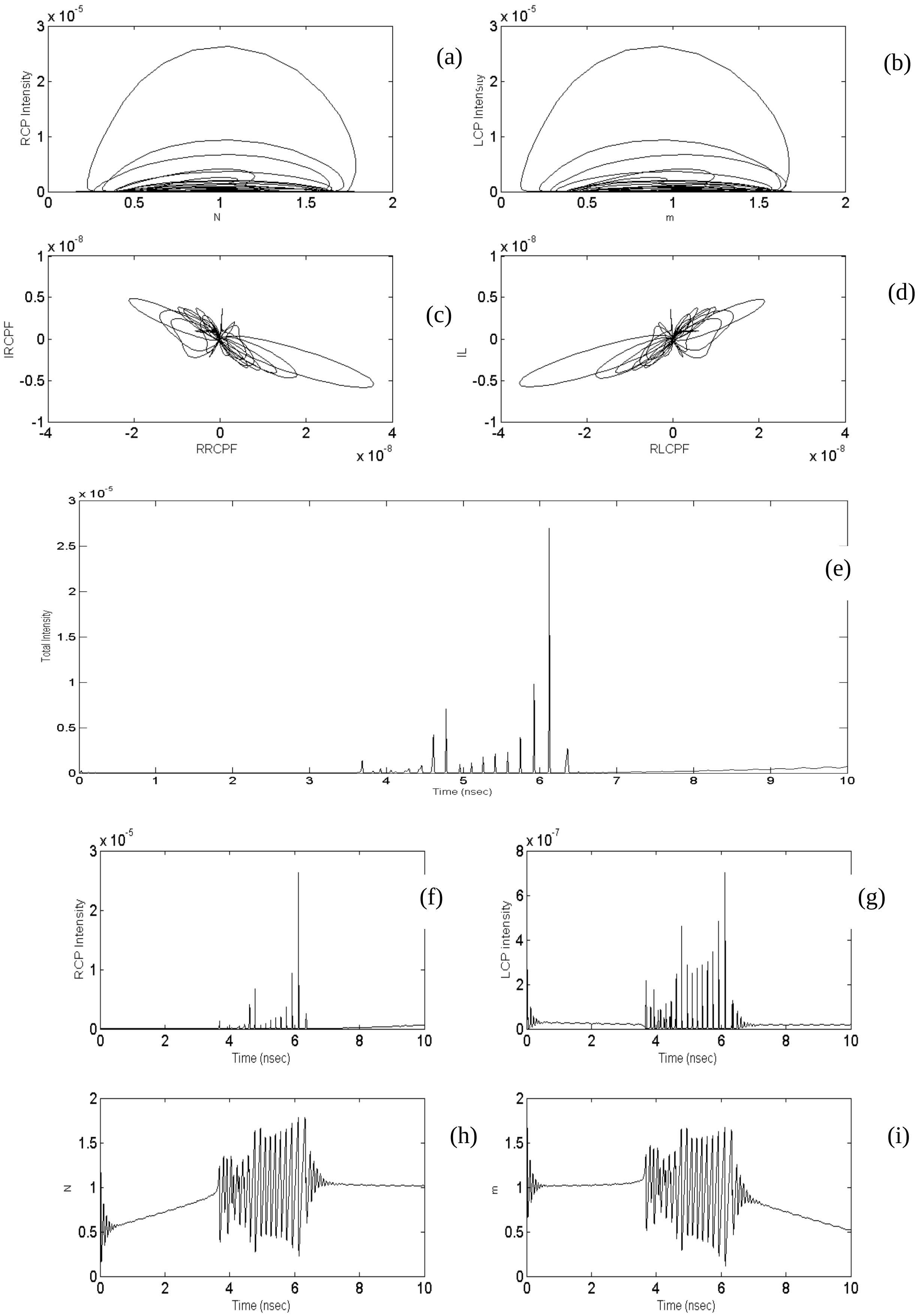


Fig (4) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\eta_p = 5.05\, and\ \eta_n = 5$; (y- axis is in arb. unit).

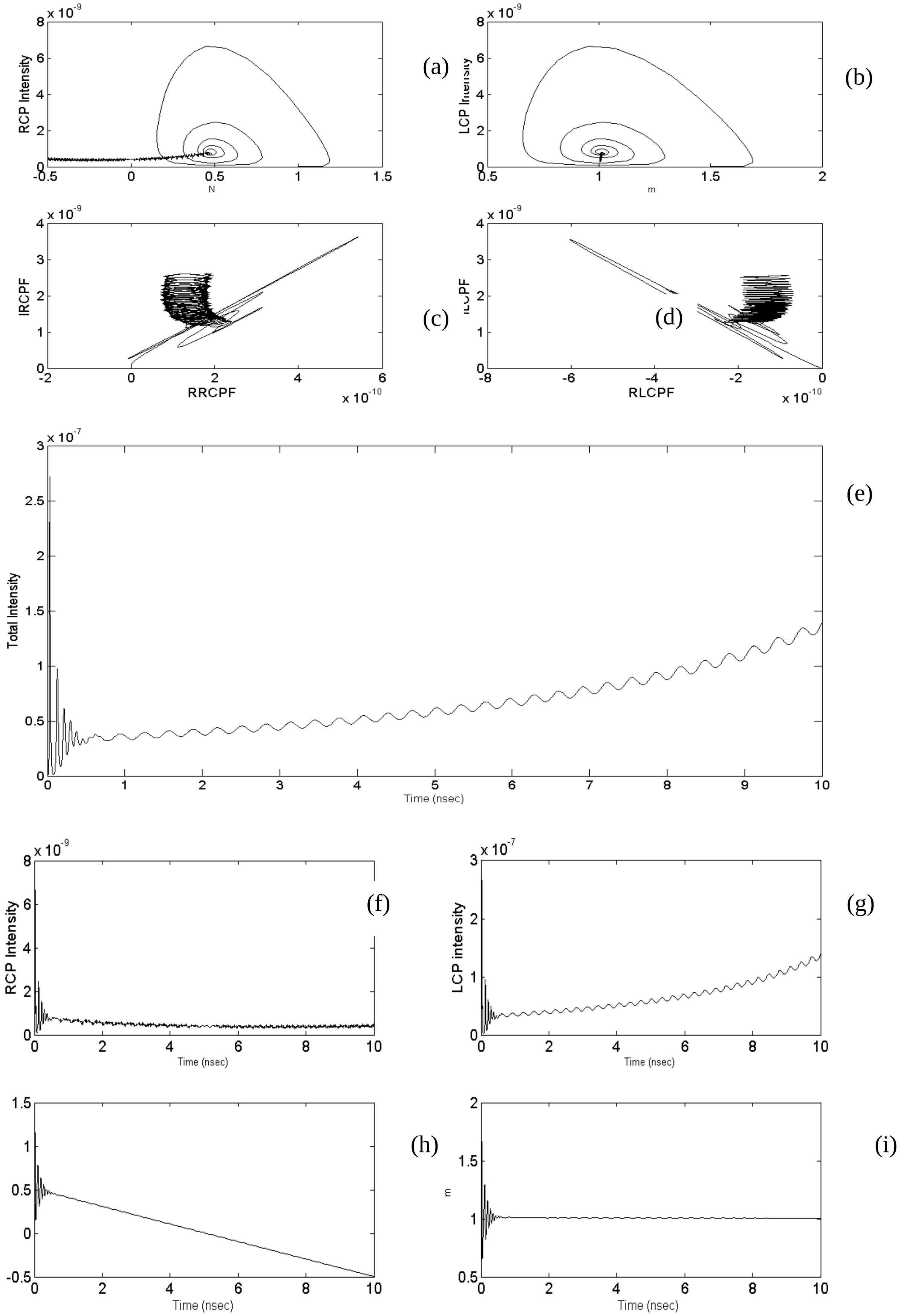


Fig (5) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\eta_n = 5.05 \, and \, \eta_p = 5$; (y- axis is in arb. unit).

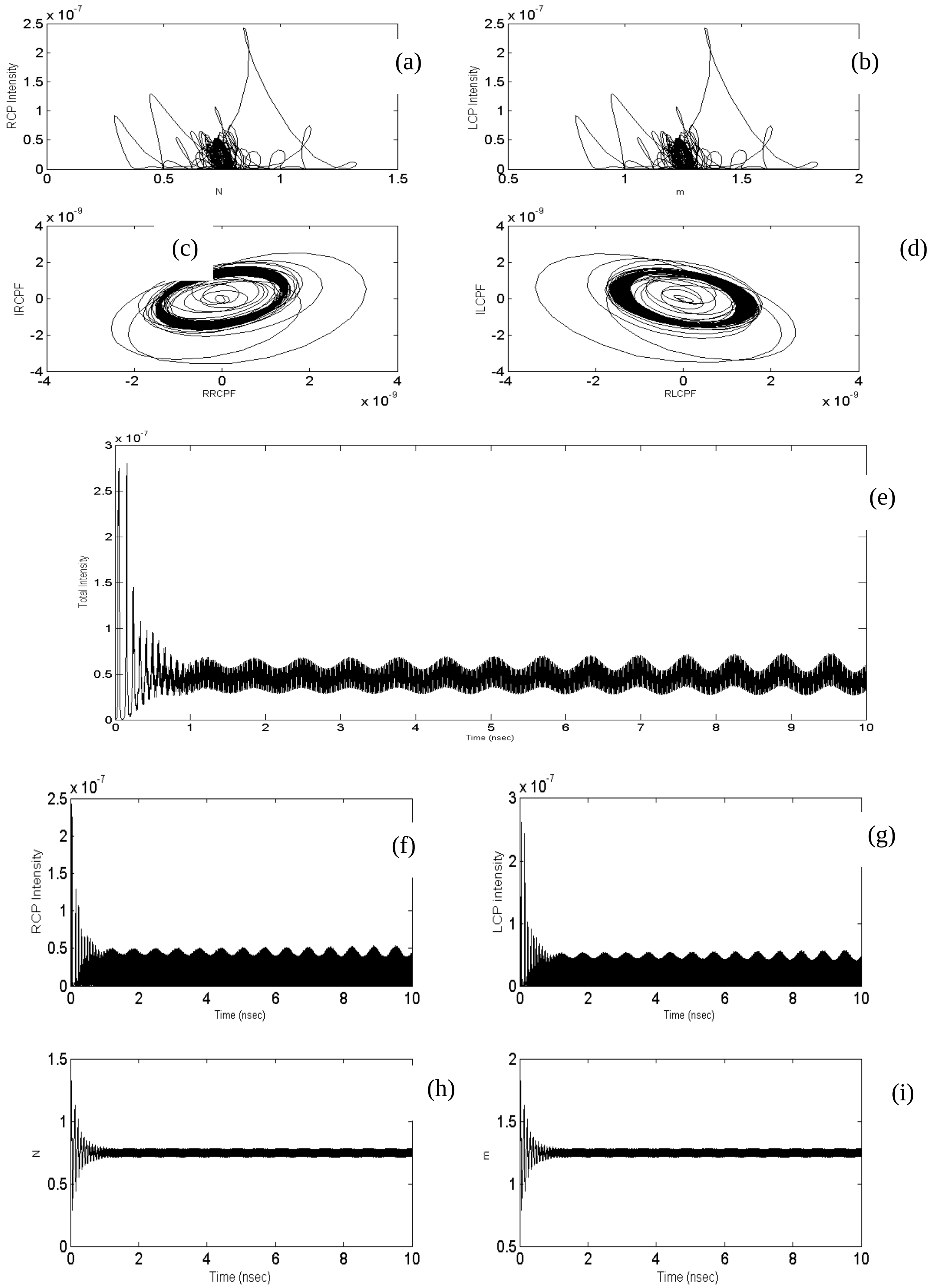


Fig (6) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\gamma_p = 20\times10^{10}$; (y- axis is in arb. unit).

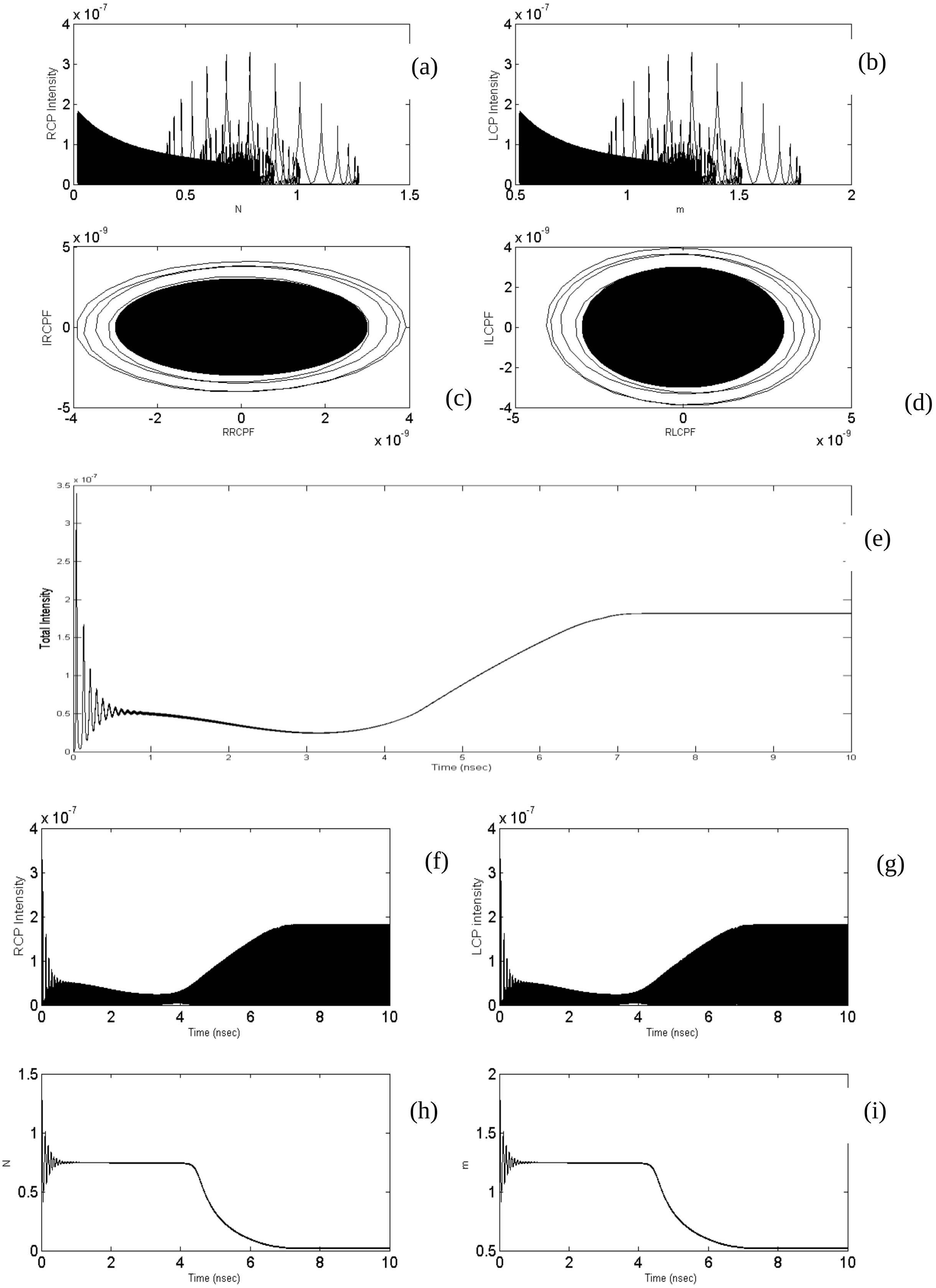


Fig (7) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\gamma_p = 20\times10^{11}$; (y-axis is in arb. unit).

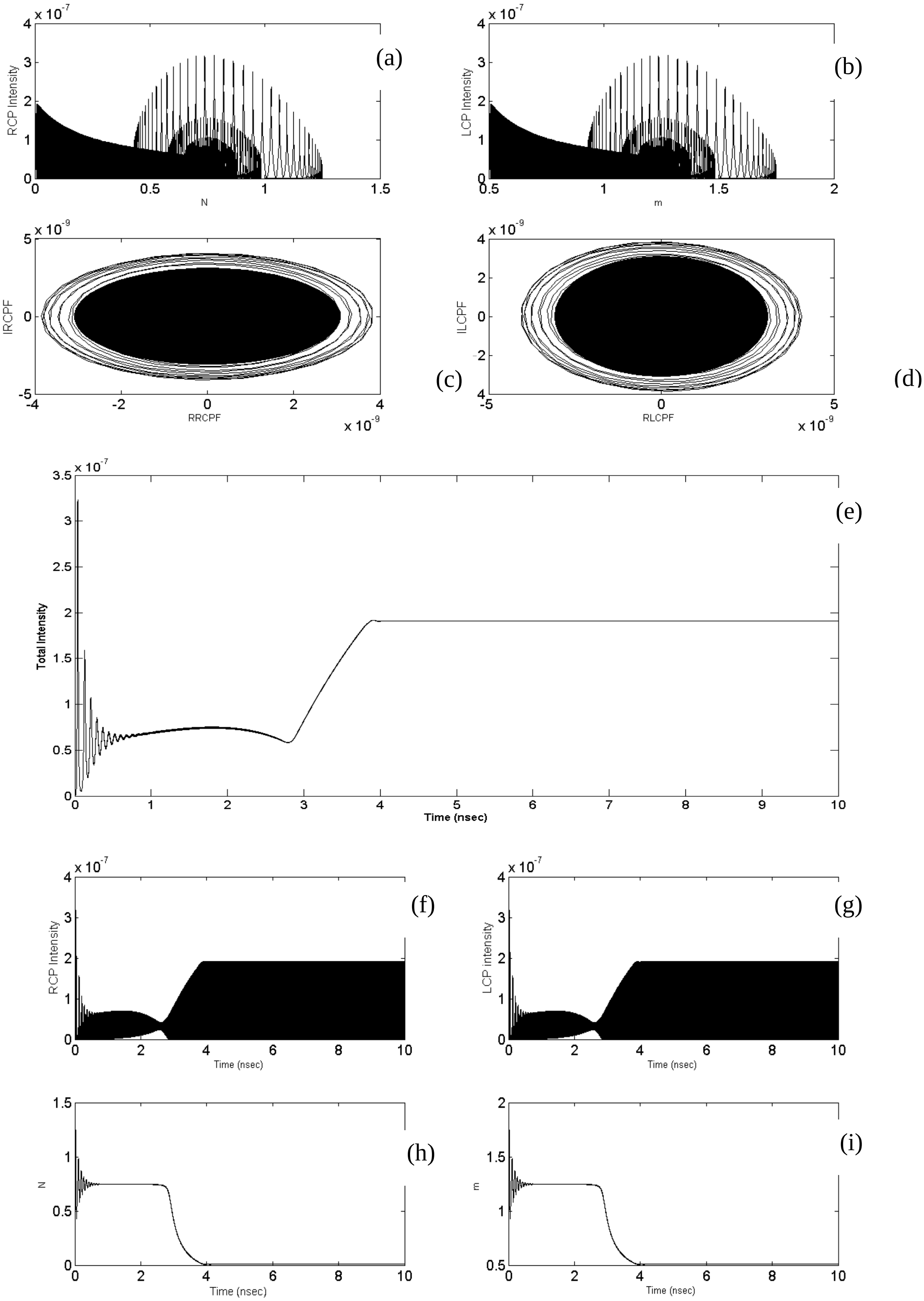


Fig (8) Relations of (a) RCP intensity vs. N; (b) LCP intensity vs. m; (c) IRCPF vs. RRCPE; (d) ILCPF vs. RLCPE ; (e) total light intensity vs. time; (f) RCP intensity vs. time; (g) LCP intensity vs. time; (h) N vs. time; (i) m vs. time for $\gamma_p = 50\times10^{11}$; (y- axis is in arb. unit).

Conclusions:

In this article, we present a numerical study of the spin-VCSE laser dynamics following the work of Al-Seyab et.al [5]. The six equations model used is solved using the fourth –order Runge-kutta numerical method using MATLAB code. Most of the parameters appeared in the model affect the spin-VCSE dynamics. The spin relaxtion rate, γ_s , and the gain anisotropy rate, γ_a , have very little effects on the laser dynamics. New types of attractors are generated between the different quantities of lasers such as imaginary right polarized (RCP) intensity against the normalized carrier variable (N) and LCP intensity against (m).

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حركيات ليزرات ذات التجويف الشاقولي والباعثة للضوء سطحيا وذات البرم المستقطب

مشتاق عبيد عليوي
قسم الفيزياء / كلية التربية للعلوم الصرفة / جامعة ذي قار /ذي قار
العراق

الخلاصة :

نقدم في هذا البحث نتائج دراسة عددية مفصلة لليزر ذات تجويف شاقولي باعثة للضوء سطحيا باستعمال انموذج نظري يشتمل على تنطيط البرم للالكترونات مستندا الى اعمال San Miguel (1995) . ظهر ان العديد من الحركيات تحدث مع انواع مختلفة من الجاذبات.