

# Controlling two chaotic lasers via OD-DCF

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**Abstract.** We present a novelty optoelectronic delay double-cross-feedback (OD-DCF) scheme to control two chaotic lasers based on coupled lasers. We design out the OD-DCF technical solution to convert two lights from two lasers into two photocurrents by two photo-detectors, and then the delay photocurrents are cross-fed back to each other's lasers respectively to suppress two chaotic oscillations and guide two laser's dynamics behaviours, respectively. By adjusting the feedback levels and delayed time of OD-DCF, two lasers can obtain chaos-control and show all kinds of dynamics behaviours. We find that chaotic oscillation behaviours of two lasers are suppressed into a stable state and different quasi-cycle states, such as a cycle-one, cycle-two, a cycle-three, a cycle-four, and other quasi-cycle states. We find also that two movement behaviours of two lasers can be controlled to lead to two different cycle-double states. The results prove that the control of two chaotic lasers can be effectively realized via OD-DCF. It is very helpful for our studies of control science, nonlinear optics, chaos, and laser.

**Keywords:** Control, Chaos, Laser, Quasi-cycle.

## 1 Introduction

Recent years, a lot of nonlinear optic systems were created to present all kind of irregular oscillations, such as a chaotic oscillation or other random oscillations [1-4]. There is still a great difficulty for people to predict a chaotic movement or chaotic dynamics regular. At present, a lot of chaotic laser systems have been reported in a nonlinear optics. And a chaotic semiconductor laser has the dynamics characteristics of random oscillation and irregular movement [1-4]. In the application of chaotic lasers, the optical feedback and external optical injection semiconductor lasers have become the first used transmitter [1-4]. And in domain of control science, control of a chaotic laser has become another optics hotspot. Since Ott, Grebogi, and York presented the "OGY" chaos-control method [6], studies of chaos-control terms were performed deeply [7-10]. To discover and reveal dynamics characteristics of chaos, people presented all kinds of chaos-control schemes to realize control of a chaotic laser. The optical feedback, small-signal perturbation, and external optical injection methods were performed to obtain control of a single chaotic laser system [7-10]. Therefore, it is of great significance to propose a new chaos-control of laser

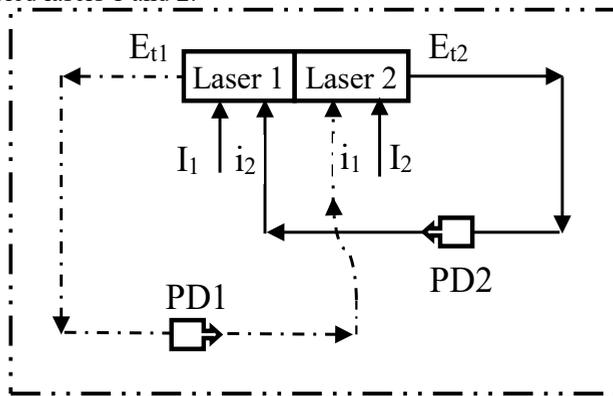
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method for the development of nonlinear optics, laser and control technology. In this paper, we pay main attention to study how to suppress irregular and chaotic oscillations of two coupled lasers using OD-DCF. OD-DCF will be a very significant work for people to study controls of two chaotic lasers. Its result is of great significance to study nonlinear optics, laser and control technology. So this paper will study two chaotic lasers based on coupled lasers to how to obtain chaos-control and stabilize two chaotic oscillations of two lasers by OD-DCF.

The paper is organized as follows: In the first part, we give OD-DCF technical solutions. In the second part, we give our result and discussion. Last, we give a conclusion.

## 2 OD-DCF technical solution and physical model

We kind that the nonlinear coupled interactions of spatially coupled fields of coupled lasers result from the light from two lasers injecting into each other. And the two coupled lasers present nonlinear dynamics states, such as two undamped oscillations, two random oscillations, or two chaotic oscillations. Figure 1 shows an OD-DCF chaos-control block to control two coupled lasers 1 and 2.



**Fig. 1.** OD-DCF chaos-control block.  $I$  is the current.  $i$  is the photocurrent.  $E$  is the light field. PD is the photodetector.

$E_{1,2}$  is the light field from laser 1 or 2. PD is the photodetector.  $i$  is the photocurrent. The OD-DCF technical solution is designed out to convert two lights from the two lasers into two photocurrents by two photodetectors, and then the delay photocurrents are cross fed back to each other's lasers respectively to guide two laser's dynamics behaviors and suppress two chaotic oscillations. And this OD-DCF scheme is named as a double-parameter double-cross-feedback control-chaos method. When OD-DCF is performed on both lasers, OD-DCF controlled dynamics of two coupled lasers is described by [7-10]:

$$\begin{aligned}
 \frac{dE_1}{dt} &= \frac{1}{2}(G_1 - \gamma_p)E_1 + \frac{K}{\tau_L}E_2 \cos(\varphi_2 - \varphi_1) \\
 \frac{d\varphi_1}{dt} &= \frac{1}{2}\beta_c(G_1 - \gamma_p) + \frac{K}{\tau_L} \frac{E_2}{E_1} \sin(\varphi_2 - \varphi_1) - \Delta\omega \\
 \frac{dN_1}{dt} &= \frac{I_1 + i_2}{q} - \gamma_{e1}N_1 - G_1V_pE_1^2
 \end{aligned} \tag{1}$$

$$\begin{aligned}
 \frac{dE_2}{dt} &= \frac{1}{2}(G_2 - \gamma_p)E_2 + \frac{K}{\tau_L}E_1 \cos(\phi_1 - \phi_2) \\
 \frac{d\phi_2}{dt} &= \frac{1}{2}\beta_c(G_2 - \gamma_p) + \frac{K}{\tau_L} \frac{E_1}{E_2} \sin(\phi_1 - \phi_2) + \Delta\omega \\
 \frac{dN_2}{dt} &= \frac{I_2 + i_1}{q} - \gamma_{e2}N_2 - G_2V_pE_2^2
 \end{aligned} \tag{2}$$

where the control terms of OD-DCF are

$$i_1 = \eta_2 I_2 E_1^2 (t - \tau_1) / E_0^2, \quad i_2 = \eta_1 I_1 E_2^2 (t - \tau_2) / E_0^2.$$

**Table 1.** Laser parameters.

Parameter	Symbol	Value
the cavity length	$L$	350 $\mu\text{m}$
the volume of laser cavity	$V$	105 $\mu\text{m}^3$
the mode coefficient	$\Gamma$	0.29
the photon loss	$\alpha_m$	49 $\text{cm}^{-1}$
the carrier density	$n_{th}$	1.2 $\times 10^{18}\text{cm}^{-3}$
the nonradiative recombination rate	$A_{nr}$	1.0 $\times 10^8\text{s}^{-1}$
the radiative recombination coefficient	$B$	1.2 $\times 10^{-10}\text{cm}^3/\text{s}$
the Auger recombination coefficient	$C$	3.5 $\times 10^{-29}\text{cm}^6/\text{s}$
the optical field amplitude at saturation	$E_s$	1.6619 $\times 10^{11}\text{m}^{-3/2}$
the optical linewidth enhancement factor	$\beta_c$	6
the gain constant	$a$	2.3 $\times 10^{-16}\text{cm}^2$
the frequency detuning	$\Delta\omega$	2 GHz
the photon round-trip time	$\tau_L$	8.8667 $\times 10^{-12}\text{s}$
the mode volume	$V_p$	$V/\Gamma$
the referenced amplitude	$E_0$	0.1 $E_s$
the optical coupling factor	$K$	0.05
the current	$I_1, I_2$	24 mA, 26 mA
the unit charge	$q$	1.60219 $\times 10^{-19}\text{C}$

Where the subscripts “1” and “2” represent lasers 1 and 2. The variables  $E$ ,  $\phi$ , and  $N$  are used to describe the amplitude and phase of the optical field, and the carrier number.  $K$  is the coupling factor.  $\Delta\omega$  is the frequency detuning between two lasers. The control parameters  $\eta$  and  $\tau$  are the optoelectronic feedback factor and the delay time, where the two factors may be adjusted to obtain controls of two chaotic lasers. The carrier nonlinear loss rate is:

$$\gamma_e = A_{nr} + B(N/V) + C(N/V)^2$$

And the mode nonlinear gain is:

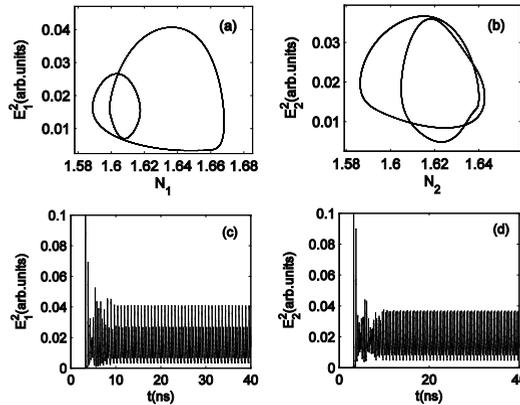
$$G = (v_g a / V_p)(N - N_{th}) / (1 + E^2 / E_s^2)^{1/2}$$

And the other parameters and their instructions are listed in table 1.

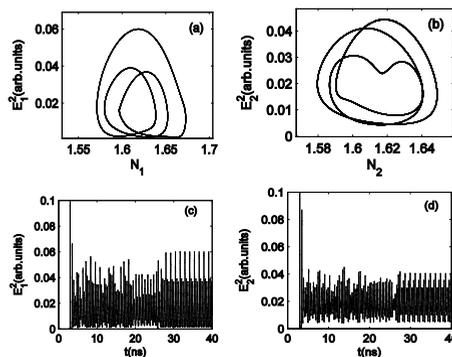
### 3 Results and discussions

Eqs. (1) and (2) are used to simulate controls of two chaotic lasers while the laser parameters are listed in table 1. We can obtain controls of two chaotic lasers to result in two lasers becoming of many quasi-cycle and realizations of stable-state when OD-DCF is performed on both lasers.

When OD-DCF is operated on both lasers and the control parameters are taken as  $\tau_1=\tau_2=1$  ns,  $\eta_1=0.01$  and  $\eta_2=0.002$ , it can be found that movement behaviors of two chaotic lasers are effectively controlled to lead to two different double-cycle states shown in figure 10. Figure 2 (a) shows a double-cycle orbit of laser 1 and figure 2 (b) shows another double-cycle orbit of laser 2. The two results imply realizations of two different cycle-double states when controls of two chaotic lasers are operated via OD-DCF. We find also that two movement behaviors of the two lasers can be controlled to lead to two different cycle-double states when  $\eta_1=0.012$  and  $\eta_2=0.004$ . And there are other chaos-control cases follow as.



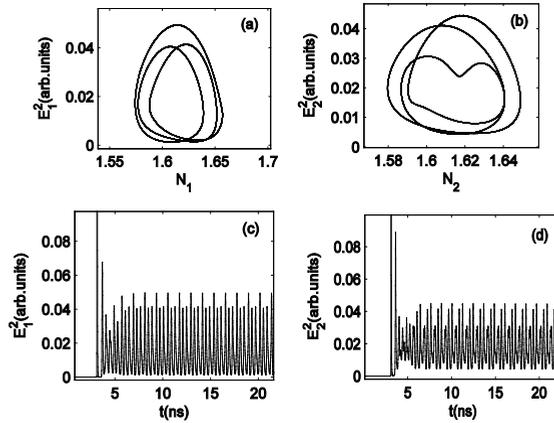
**Fig. 2.** Different double-cycle orbits of two lasers and output. (a) a double-cycle orbit of laser 1. (b) another double-cycle orbit of laser 2.(c) laser 1 output.(d) laser 2 output.



**Fig. 3.** Different quasi-cycle orbits of two lasers and output. (a) a cycle-3 orbit of laser 1. (b) a cycle-5 orbit of laser 2. (c) laser 1out. (d) laser 2 output.

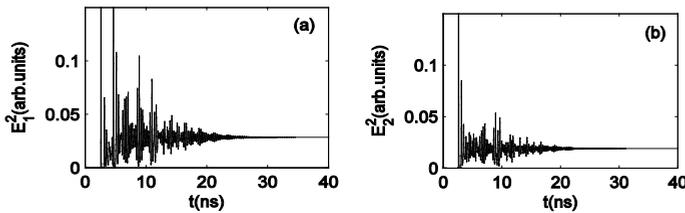
When  $\eta_1=0.007$  and  $\eta_2=0.001$ , two chaotic lasers are controlled to lead to two different double-cycle states in figure 3. Figure 3 (a) shows a cycle-three orbit of laser 1 and figure 3 (b) shows a cycle-five orbit of laser 2. The results imply realizations of two different quasi-

cycle states in processes of controls of two chaotic lasers using OD-DCF. We find also that behaviors of two chaotic lasers can be controlled to a cycle-three state and a cycle-five state when  $\eta_1=0.07$  and  $\eta_2=0.002$ , or  $\eta_1=0.06$  and  $\eta_2=0.0012$ , respectively.



**Fig. 4.** Different quasi-cycle orbits of two lasers and output. (a) a cycle-three orbit of laser 1. (b) a cycle-four orbit of laser 2. (c) laser 1 output. (d) laser 2 output.

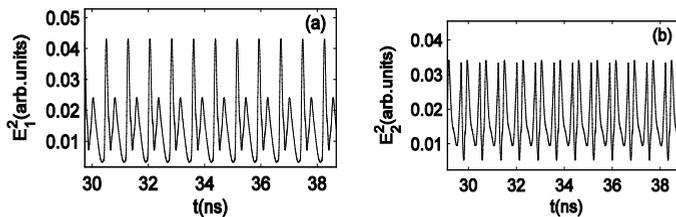
When another OD-DCF performs on both lasers, take  $\tau_1=\tau_2=2$  ns,  $\eta_1=0.18$  and  $\eta_2=0.002$ , two chaotic oscillation behaviors of two lasers are controlled to different quasi-cycle states illustrated by figure 4. Figure 4 (a) shows a cycle-three orbit of laser 1 and figure 4 (b) shows a cycle-four orbit of laser 2. The results imply realizations of quasi-cycle controls of two chaotic lasers via OD-DCF.



**Fig. 5.** Two lasers are becoming of two stable states. (a) laser 1 is controlled to a stable state. (b) laser 2 is controlled into another stable state.

When  $\tau_1=\tau_2=2$  ns,  $\eta_1=0.18$  and  $\eta_2=0.002$ , two chaotic oscillation behaviors of two lasers are suppressed to two stable states after 30 ns in figure 5. Figure 5 shows that two lasers become of two stable states after two damped oscillations of two lasers. The results imply realizations of stable-state controls of two chaotic lasers via OD-DCF.

When  $\tau_1=\tau_2=2$ ns,  $\eta_1=0.13$  and  $\eta_2=0.001$ , two chaotic oscillation behaviors of two lasers are lead to two double-cycle states after 25 ns. Figure 6 shows that two lasers are oscillating at two double-cycle states, respectively.



**Fig. 6.** Different double-cycle oscillations of two lasers. (a) a double-cycle of laser 1. (b) another double-cycle of laser 2.

By our simulation study of controls of two chaotic lasers, it can be found that we can obtain the control of the two lasers to result in two lasers becoming of many quasi-cycle and realize the control of stable-state to result in two lasers becoming of two stable-states when OD-DCF is performed on both lasers. So we can realize the controls of the two chaotic lasers via OD-DCF.

## 4 Conclusion

This paper studied the OD-DCF scheme to how to control two chaotic lasers. By adjusting the feedback levels and delayed time, two lasers can realize chaos-control and show all kinds of dynamics states. We find that two chaotic lasers are oppressed into a stable state, and a cycle-one state. We find that two chaotic lasers can be controlled in different quasi-periodic states, such as a cycle-one, cycle-two, a cycle-three, a cycle-four, and other quasi-cycle states. The result is very helpful to study controlling nonlinear optic systems, a chaotic laser, and laser technology.

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