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Communication in Quantum Dot Light Emitting Diode with Optoelectronic Feedback Technique

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Abstract- A communication scheme based on the synchronization of two chaotic quantum dot light emitting diodes is theoretically examined. The Chaos in the quantum dot light emitting is generated by means of a positive optoelectronic feedback technique. Synchronization of the chaos is achieved by varying coupling strength between the transmitter and the receiver as unidirectional coupling. We then test a proposed chaos shift keying communication scheme by successfully transmitting messages.

Keywords- **QD-LED, positive OEFB, CSK communication, synchronization.**

I. Introduction

QD-LED is considered as a next technology after organic light emitting diodes (OLED). Nowadays, it has been studied as a short distances light emitting source, which could provide an alternative for applications such as communication. Because QD-LEDs, have several advantages such as tunable emission wavelength with changing particle size and narrow emission spectrum (characterized by its full width at half the maximum value) (Hyunki *et al.*, 2011). Progress in the understanding of mechanisms and techniques for the controlled generation of chaos in QD-LEDs has led to efforts to apply their benefits in communication systems (Al Naimee *et al.*, 2014).

Chaotic synchronization is widely investigated topic of research in the past few decades, due to its application in physical, chemical, biological as well as technological fields (Pecora and Carroll, 1991; Fujino and Ohtsubo, 2000). Synchronization of chaotic dynamics of systems has attracted much attention in the recent years because of its potential application in secure communication (Tang *et al.*, 2001; Sanchez-Diaz *et al.*, 1999).

Communications using chaotic waveforms as "carriers" of information promise possible advantages over traditional communications strategies in the achievement of power efficiency output and better use of broadband capability. Optical communication utilizing synchronized chaotic systems with optoelectronic feedback has been demonstrated for quite slow data rates by using chaotic wavelength fluctuations (Goedgebuer *et al.*, 1998). The first high speed optical chaotic communication has been achieved using fiber ring lasers with a rare earth doped fiber segment as active element (Wiggeren and Roy, 1998). For practical applications, where bit rates of gigabits per second are desirable, one has to consider different active elements in the laser cavity, which give rise to fast chaos. In the following, firstly we present a rate-equation analysis which incorporates the essential aspects of electronic transitions. We apply the analysis to propose a rate equations model of three levels states in dimensionless form that exhibits extremely complicated behavior and modulation rate of QD-LEDs, taking into account both the photon reabsorption and non-radiative recombination processes. And secondly, we investigate QD-LED with OEFB. This is one way to generate high-frequency chaos and has in comparison to optical feedback the advantage of being phase insensitive, thus, significantly improving the performance of the communication system. Synchronization of the chaos is achieved by varying coupling strength between the transmitter and the receiver as unidirectional coupling. We then test a proposed chaos shift keying communication scheme by successfully transmitting messages.

II. Mathematical model

To describe the mathematical model currently used for QD-LED study, where it takes into consideration pumping the electrons into the WL before they are diffusion in the QD layer. The system equations describe the number of carriers variation in the QD ground state, n_{QD} , the number of carriers in the WL, n_{wl} , and the number of photons in the optical mode, S , are as follows.(Al Naimee *et al.*, 2014)

$$\dot{S} = W n_{QD}^2 - W n_{QD} S - \gamma_s S$$

$$\dot{n}_{QD} = \gamma_c n_{wl}\left(1 - \frac{n_{QD}}{2N_d}\right) - \gamma_{r_{QD}} n_{QD} - \left(W n_{QD}^2 - W n_{QD} S\right) \quad (1)$$

$$\dot{n}_{wl} = \frac{I}{q} - \gamma_{r_{wl}} n_{wl} - \gamma_c n_{wl}\left(1 - \frac{n_{QD}}{2N_d}\right)$$

the caused processes of spontaneous emission and reabsorption in the QDs are modeled by the first and second terms of the first equation of the system (1). The Einstein coefficient W is given by $W = \left[\left(|\mu|^2 \sqrt{\varepsilon_{bg}}\right) / \left(3\pi\varepsilon_o \hbar\right)\right] / (w/c)^3$ where ε_{bg} ,is the static relative permittivity of the background medium , ε_o is the vacuum permittivity, c is the speed of light in vacuum and μ is the dipole moment of the QDs. $\gamma_{r_{QD}}$ and $\gamma_{r_{wl}}$ are the nonradiative decay rates of the number of carriers in the QD and WL respectively; N_d is the total number of QDs; and I is the current, q is elementary charge, γ_c is the take rate from WL into the dot, γ_s is the output coupling rate of photons in the optical mode. The energy diagram of the QD-LED under study is shown in Fig. (1).

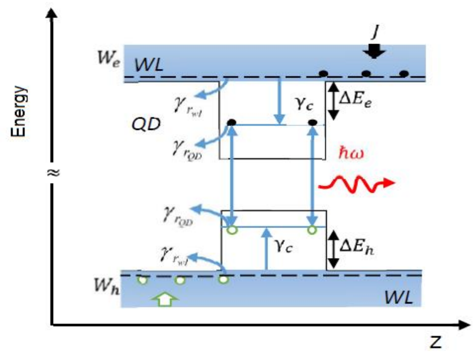


Fig.1: Energy diagram the recombination mechanisms considered in this work of conduction band of the active layer QD-LED.

In such a case, the spontaneous emission coefficient and absorption coefficient have the correct possess relation. For realistic QD material system both the QD and WL states can be inhomogenously broadened. Population distributions in both WL and QD are taken into account clearly and definitely in order to decide figure out the correct relation between and unplanned emission spectra.

On this model, we do some conversions to get unit-free equations after applying the OEFB term to the QDL-EDS equations system, we re-select the system into a set of equations without dimensions. Identify new variables and parameters without dimensions through the following.(Al Naimee *et al.*, 2014)

$$\gamma = \frac{\gamma_s}{\gamma_{r_{wl}}},\ \gamma_1 = \frac{W}{\gamma_s},\ \gamma_2 = \frac{W}{\gamma_{r_{wl}}},$$

$$x = S,\ y = \frac{W}{\gamma_s} n_{QD},\ z = \frac{n_{wl}\gamma_c}{W},$$

$$\gamma_3 = \frac{\gamma_{r_{QD}}}{\gamma_{r_{wl}}},\ \gamma_4 = \frac{\gamma_c}{\gamma_{r_{wl}}},\ N_d \equiv a,\ \delta_o = \frac{I}{Wq},$$

After using the previous conversions, the system equations and the time scale became.

$$\gamma_1 \dot{x} = \gamma\left(y^2 - \gamma_1 x (y+1)\right)$$

$$\dot{y} = \gamma_2 z(\gamma_1 - y/2a) - y(\gamma_3 + \gamma y) + \gamma_2 xy \quad (2)$$

$$\dot{z} = \gamma_4(\delta_o - z + yz/2\gamma_1 a) - z$$

here, the upper subscript "dot" $(\dot{})$ refers to differentiation with respect to (t). The bias current is represented by (δ_0) The QD-LED rate equations system is working with the positive OEFB effect represented by a term added to the pumping current of modified system equations، as follows,

$$\dot{n}_{wl} = \frac{I}{q}\left(1 + \frac{k\,S(t-\tau)}{S_o}\right) - \gamma_{r_{wl}} n_{wl} - \gamma_c n_{wl}\left(1 - \frac{n_{QD}}{2N_d}\right) \quad (3)$$

In this case, the photon number, $S(t-\tau)$, fed from the external OEFB circuit to the QD-LED and it is mixed with pumping current. Where k is strength of feedback. The system is in positive feedback for a positive value of k and vice versa. S_o is the steady state value of the photon number. τ is the delay time taken by the feedback signal after applying the OEFB term to a system of QDL-EDS equations, as shown in Fig. (2).

Eqs. (3) can be rewritten in the following form

$$\dot{z} = \gamma_4\left(\delta_o\left(1 + \frac{k\,x_\tau}{x_o}\right) - z + yz/2\gamma_1 a\right) - z \quad (4)$$

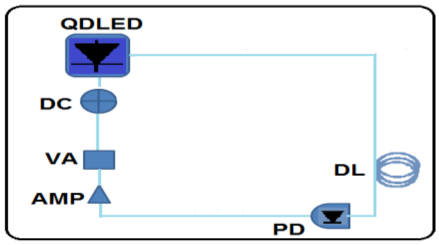


Fig. 2. Scientific diagram of OEFB in a QD-LED; PD: Photodiode; AMP: amplifier; VA: variable attenuator; DL; Optical delay line.

III. Synchronization in QD-LED

Synchronization in chaotic systems has increasing attention with several studies on the theoretical analysis basis of and even realization in laboratory having demonstrated the pivotal role of this phenomenon in communications coding (Hyunki *et al.*, 2011). Making two or more systems look same of behiver at the same time of coupled chaotic systems has been a subject of great interest and importance, in different fields of application, such as secure communication and the science of nerves and the brain.

Synchronization is mainly studied in periodic (regular) and complex (chaotic or irregular) states. In QD-LED system with self-feedback, varies behaviors of unidirectional (going in one direction) will be presented in the following sections.

A. Synchronization of Unidirectional Coupling

In this part of work, a one-way system with positive OEFB was investigated to study the chaotic synchronization as unidirectional coupling. In QD-LED systems with positive OEFB, the rate equations for the photon and carrier number are adequate describing the systems.
Equations for the photon and carrier number are written in QD and WL in the T transmitter and the R receiver of OEFB by.(Mirasso *et al.*, 1996)

$$\gamma_1 \dot{x}_{T,R} = \gamma(y_{T,R}^2 - \gamma_1 x_{T,R}(y_{T,R}+1))$$

$$\dot{y}_{T,R} = \gamma_2 z_{T,R}(\gamma_1 - y_{T,R}/2a) - y_{T,R}(\gamma_3 + \gamma y_{T,R}) + \gamma_2 x_{T,R} y_{T,R}$$

$$\dot{z}_{T,R} = \gamma_4(\delta_o(1 + k_{T,R}\, x_{\tau_{T,R}} + \sigma k_c\, x_{\tau_T} + \sigma k_c\, x_{\tau_R}) - z_{T,R} + y_{T,R} z_{T,R}/2\gamma_1 a) - z_{T,R}$$

Where $k_{T,R}$ is the coefficient of the OEFB strength in the T and R respectively.
σ = 0 in T rate equations and σ = 1 in R rate equations system. The schematic setup of the synchronization is shown in Fig. (3). In this model on the coupling of QD-LEDs, the factor k_c, ranging from 0 to 1 as maximum, which represents the percentage of participation in the feedback is included . The transmission time by τ_c; the time connected with the spread of the signal to the R system is represented . A state of complete is successfully-reached in case of identical T and R systems, where the dynamical of both are equal. So, the case of identical systems was discussed in this work and positive feedback was selected which not study in previous works.

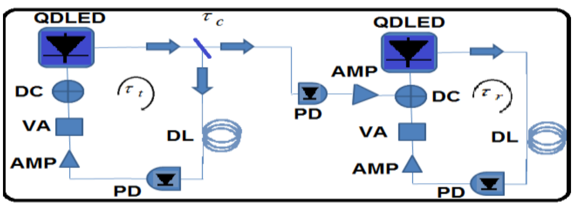


Fig. 3:Schematic diagrams of scheme for the synchronization of two chaotic systems with delayed optoelectronic feedback. QD-LED: quantum dot light emitted diode; τ: feedback delay time; τ_c: transmission time.

IV. RESULTS OF SYNCHRONIZATION

First, we discuss dynamics evolution in positive OEFB system. The rate equations system (2) with modify in Eq. (4) are solved numerically using the fourth-order Runge-Kutta method by using Berkeley Madonna program. The parameters used in the simulation are listed in Table (1). The initial values are obtained by solving the system (2) at steady state.

Fig. (4) Shows the QD-LED intensity output as function of the time series in first column at different time delays, fast Fourier transformation (FFT) of the output spectrum, and their attractors are shown in the mid and the left columns, respectively. These figures are plotted at δ_o=0.006 for bias current, k_1=-3× 10^{-3}, k_2=-3× 10^{-3} for feedback strength and k_c=-3× 10^{-3} for coupling strength. The attractor was obtained in a delay-embedding space of photon versus carrier numbers using the theoretical time series.

A number of different frequency dynamics were obtained, respectively; Fig. 4 (a) represents the state of the periodic frequency at delay time τ =1902, Fig. 4(b) represents the state of the tow- frequency at τ =1820, Fig. 4 (c) represents the three-frequency state at τ

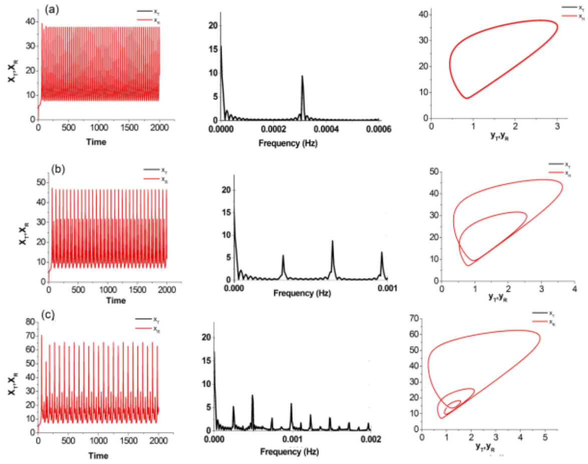
=1736 and Fig. 4(d) represents the state of chaos at the τ =1474.

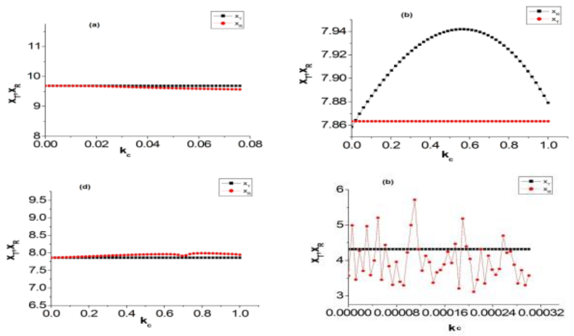
In the mid and right columns and in panels (a)-(c). The FFT in Fig. 4(a) has only one fundamental pulsing frequency, which is about 0.0003 Hz. The attractor in Fig. 4 (a) shows only one circle, it is corresponding with the state of the system which is found in a regular
Table. 1. Numerical parameters used in the simulation if not declared otherwise.

pulsing state with a constant interval and pulsing intensity. When decreased the delay time of coupling, one can observe how the system enters in a two-frequency periodic pulsing state as shown in FFT of Fig. 4(b). There, the attractor clearly shows the circles corresponding to the peaks intensity in the power spectrum. While continuing to reduce the delay value, more peaks appear with a faster and more variable time interval as in Fig. 4(.c). In Fig. 4 (d), when the delay time of coupling is further decreased, the QDLED with positive OEFB transform to a chaotic pulsing state as shown in FFT plot, both the peaks intensity and the peaks interval are vary chaotically. The numerical and experimental results for bulk LED (Abdalah *et al.* 2013) shows a good agreement with chaotic case, Therefore, the QDLED with positive OEFB is shown to move into a chaotic pulsing state out of a periodic trajectory as it was appeared in most QD lasers(Ghalib *et al.*, 2012). The case of high dynamics for short delays is also shown in QD laser with OEFB circuit and relates to fast interdot dynamics (Scholl and Schuster, 2008).

Figs. 5 (a)-(c) were taken for the period, two- period, three-period and chaos states, respectively. Bifurcation scenario in Figs. 5(a)-(c) show a clear synchronization regions under coupling strength effect. Fig. 5(a) shows that synchronization regions reach up to 0.02 of the coupling strength. While in Fig. 5. (b) we see only one synchronization case at less than 0.02. While we have more than a sync point of up to 0.08 of the coupling strength as in Fig.5 (c). Finally in Fig. 5(d) we have two regions for synchronization are in 0.00012 and 0.00022, respectively. Fig. 6 shows the synchronization systems at 0.00012 of coupling strength which it is one case for two cases of completely synchronization in Fig. 5 (d).

Parameters	value	Parameters	value
x_{oT}	0.066	γ	0.173
y_{oT}	0.99	γ_1	0.0144
z_{oT}	0.0049	γ_2	0.003
x_{oR}	0.066	γ_3	0.07
y_{oR}	0.99	γ_4	0.087
z_{oR}	0.0049	a	1.00





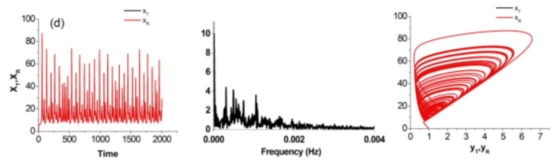


Fig 4: Time series, FFT and attractor sections at different delay times. From top to bottom: (a) periodic oscillations, at τ=1902; (b) two-frequency, at τ= 1820; (c) three-frequency, at τ= 1736; (d) chaos, at τ =1474. The parameters measured are δ_0=0.2884, k_T=1e-4, k_T=1e-4, and k_c=1e-4.

Fig. 5: bifurcation scenario of two chaotic systems as a function of coupling strength. The unidirectional coupling synchronization systems are done with two different cases of feedback signal strength in the R and T. The parameters are used in Table 1.

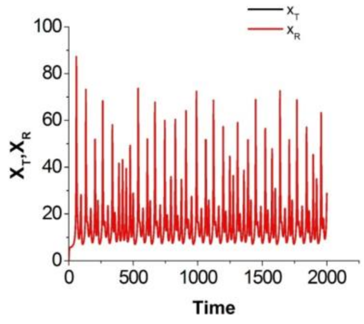


Fig. 6: Synchronization of two unidirectional coupling chaotic systems. The synchronization systems are done at 0.00012 of coupling strength which it is one case for two cases of completely synchronization in Fig. 5 (d).

V. QD-LED MODEL OF CHAOS COMMUNICATION

The schematic architecture for chaos-based secure communication using QD-LED is illustrated in Fig. 7. Here communication scheme have been proposed for encoding the message, realizations of the third equation of system (3) can be modelled by,

$$\dot{z}_T = \gamma_4(\delta_o(1+k_T x_{\tau_T} + k_c x_{\tau_T} + \eta_{CSK} m_{CSK}) - z_T + y_T z_T / 2\gamma_1 a) - z_T \qquad (6)$$

Here the components mCSK correspond to the modulation signals used in the CSK systems, and ηCSK are the modulation coefficients for system. The procedure for recovering messages involves tuning for optimal synchronization and then extracting the message by comparing the received signal and the output of the receiver QD-LED.

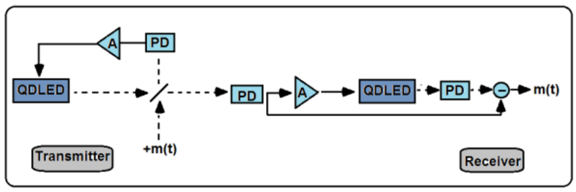
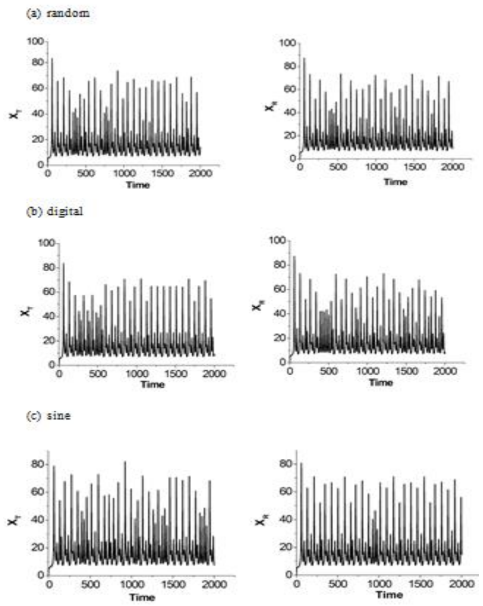


Fig. 7: Schematic diagrams of scheme for chaos synchronization and communications using QD-LEDs with OPEFB. Chaos shift keying (CSK) system.

The performance of synchronization of two chaotic QD-LEDs with positive OEFB allows us to utilize communication schemes in which the message is put into the transmitter dynamics via a reversible operation. The transmitted signal is then a combination of the message and the chaotic output of the transmitter. Since on the receiver side we know the expected chaotic output of the transmitter, due to the identical synchronization, we can use the expected output to extract the message from the received signal.

The schematic diagrams of scheme is shown in Fig. 7, where we use the unidirectional configuration at k_c=0.00012. It is important to note that the message signal m(t) enters the dynamics of the transmitter via the feedback loop. Therefore the combined signal of output plus message enters symmetrically both the transmitter and receiver, which ensures that synchronization is maintained when we transmit information.

In Fig.8, we consider an examine of data transmission based on CSK. Fig.8 (a)-(c) shows results the time series of the random, digital and analog signals encoding in transmitter and receiver respectively. The left column is the transmitter signal with the message encoded and the right column is the local receiver output, which is due to the synchronization equal to the transmitter output before the addition of the message. Fig.9 (a)-(c) left column represents decoding and recovering cases for a variety of different messages. The message is therefore decoded by subtracting the receiver output from the received signal, and then recovered after filtering. The recovered message shows good quality of decoding as indicated by the recovered train, which is to be compared with the original 'message', right column of Fig. 8 (a)-(c).



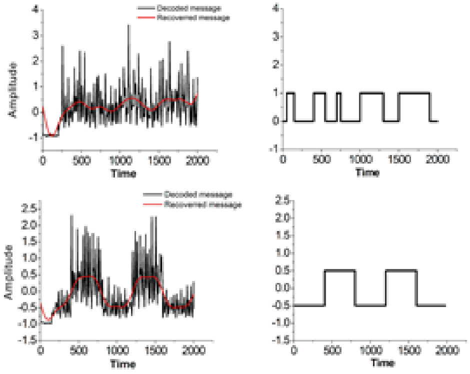


Fig. 8: Chaotic communication based on CSK. Transmitter signals in the left column and receiver signals in the right column. (a) Chaotic oscillation in the transmitter and receiver with a random message. (b)

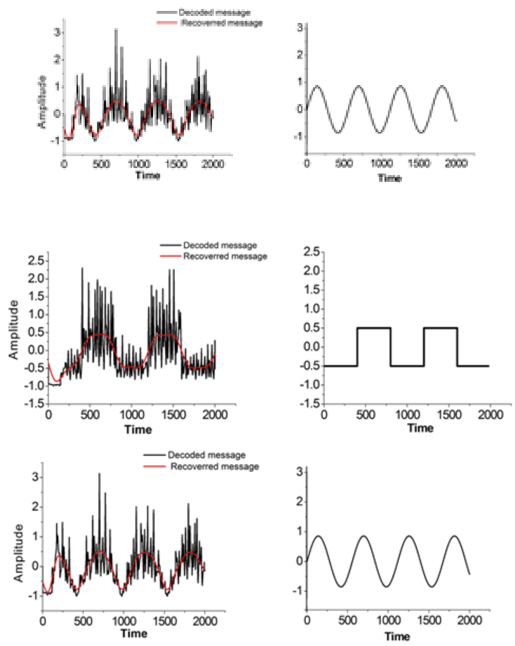


Fig. 9: Right column is the original messages of amplitude 1, 1 and 0.855, respectively. Left column is the decoding and recovering of (a) random message, (b) digital message and (c) analog message using unidirectional coupling scheme with CSK: decoded message (black line) and recovered message after filtering (red line).

VI. CONCLUSION

In conclusion, we demonstrated that positive OEFB in QDLEDs exhibit frequency chaotic via a periodic route. We achieved chaos synchronization of two such systems. We furthermore demonstrated that a high speed frequency messages can be successfully encoded and decoded. Since the transmitter and receiver remain synchronized when a message is transmitted the encoded messages can be possibly as the repetition rate of the chaotic frequency.

VII. References

Abdalah, S.F.; Al-Naimee, K.; Marino, F.; Ciszak, M.; Meucci, R.; and F.T. Arecchi, F.T. (2013). "chaos and mixed mode oscillations in optoelectronic networks. ", IREPHY. 7: 3.

Al Naimee, K.; Al Husseini, H.; Abdalah, S.F.; Al Khursan, A.; Khedir , A.H.; Meucci , R., and Arecchi, F.T . (2014). “Mixed mode oscillations and chaotic spiking in Quantum Dot Light Emitting Diodes” Complexity in Engineering (COMPENG), IEEE Conference Publications.

Fischer, I .; Liu , Y. and Davis, P. (2000). “Synchronization of chaotic semiconductor laser dynamics on sub-ns timescales and its potential for chaos communication,” Phys. Rev. A, vol. 62 011 801(R).

Fujino, H . and Ohtsubo, J . (2000). “Experimental synchronization of chaotic oscillation in external cavity semiconductor lasers,”Opt. Lett., vol. 25: 2000

Ghalib, B.A.; Al-Obaidi, S.J. and Al-Khursan , A.H . (2012). "Quantum dot semiconductor laser with optoelectronic feedback. ", Superlattices and Microstructures, 52(5): 977-986.

Goedgebuer, J.P ; Larger, L . and Porte, H . (1998).” Electro-optic phase chaos systems with an internal variable and a digital key,” Phys. Rev . Lett., 80: 2249-2252.

Goedgebuer, J.P.; Larger, L., and Porte, H. (1998). “Optical cryptosystem based on synchronization of hyperchaos generated by a delayed feedback tunable laser diode,”Phys. Rev. Lett., vol. 80: 2249–2252.

Hyunki, K.; Ji Yeon Han, A.; Dong Seok Kang; Sung, W.; Dong, S.; Minwon, S.; Artavazd, K., and Duk, Y. (2011). “Characteristics of CuInS2/ZnS quantum dots and its application on LED,” Journal of Crystal Growth, 326: 90–93.

Locquet, A.; Rogister, A.; Sciamanna, F .M .; Mégret, P. and Blondel, M .(2001). “Two types of synchronization in unidirectionally coupled chaotic external-cavity semiconductor lasers,” Phys. Rev. E, vol. 64(4):045203-1—045203-4.

Mirasso, C.R .; Colet, P. and García-Fernández, P. (1996). “Synchronization of chaotic semiconductor lasers: Application to encoded communications,” IEEE Photon. Technol. Lett., vol. 8: 299–301.

Pecora, L.M ., and Carroll , T.L . (1991). “Driving systems with chaotic signals,” Phys. Rev. A, vol., 44: 2374–2383.

Revuelta, J.; Mirasso, C.R.; Colet, P. and Pesquera, L.F. (2002). “Criteria for synchronization of coupled chaotic external-cavity semiconductor lasers,” IEEE Photon. Technol. Lett., vol. 14(2): 140–142.

Rogister, F.; Locquet, A.; Pieroux, D.; Sciamanna , M .; Deparis, .; Még r, P. (2001). “Secure communication scheme using chaotic laser diodes subject to incoherent optical feedback and incoherent optical injection,” Opt. Lett., vol., 26(19): 1486–1488.

Sanchez-Diaz, A.; Mirasso, C.R.; Colet, P. and Garcia-Fernandez, P. (1999). “Encoded Gbit/s digital communications with synchronized chaotic semiconductor lasers,” IEEE J. Quantum Electron., vol., 35(3):292–297.

Scholl, E. and Schuster, H.G. (2008). "Handbook of Chaos Control, 2nd Ed", wiley VCH Verlag GmbH & Co. KGaA, Weinheim ISBN.

Spencer, P.; Mirasso, C.R.; Colet, P., and Shore, A .(1998). “Modeling of optical synchronization of chaotic external-cavity VCSELs,”IEEE J. Quantum Electron., vol.,34: 1673–1679.

Tang, S., Chen, H. and Liu, J. (2001). “Stable route-tracking synchronization between two chaotically pulsing semiconductor lasers,” Opt. Lett., vol., 26, (19): 1489–1491.

Wagering, V., and Roy, R. (1998) .” Communication with chaotic lasers,” Phys. Rev. Lett., 81: 3547-3550.

Xiang, S.; Pan, W.; Luo, B.; Yan, L., and Zhu, H.(2012). “Wideband unpredictability-enhanced chaotic semiconductor lasers with dualchaotic optical injections,” IEEE J. Quantum Electron., vol., 48(8): 1069–1076.