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Implementation of a dynamically flexible optoelectronics logic gate using a fiber laser, numerical study

Implementación optoelectrónica de una compuerta lógica dinámicamente flexible usando un láser de fibra

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ABSTRACT

We implement an algorithm to reproduce the behavior of a dynamic logic gate which consists of three elements: a fiber laser in chaotic regime, a threshold controller and the output of the logic gate. The output signal of the fiber laser is sent to the logic gate input as to the threshold controller; threshold controller output signal is sent at the entrance of the logic gate and also fed back to the fiber laser which changes their dynamic behavior. The output of the logic gate consists of a difference amplifier; this compares the signals sent by the threshold controller and the fiber laser, resulting logic output that depend on an accessible parameter in threshold controller. We present the numerical results of the implementation of a dynamic logic gate using fiber laser, which demonstrates the ability to change the type of logic gate by modifying a parameter of threshold control.

RESUMEN

Nosotros implementamos un algoritmo para reproducir el comportamiento de una compuerta lógica dinámica que consiste en tres elementos: un láser de fibra, un controlador umbral y la salida de la compuerta lógica (amplificador de diferencias). La señal de salida del láser de fibra es enviada a la entrada de la compuerta lógica como al controlador umbral, la señal de salida del controlador umbral se envía a la entrada de la compuerta lógica y además retroalimenta al láser de fibra la cual cambia su comportamiento dinámico. La salida de la compuerta lógica consiste en un amplificador de diferencias, éste compara las señales enviadas por el controlador umbral y el láser de fibra, dando como resultado una salida lógica, que dependerá de un parámetro accesible en el controlador de umbral. Se presentan los resultados numéricos de la implementación de una compuerta lógica dinámica utilizando el láser de fibra, en los cuales se muestra la capacidad de cambiar el tipo de compuerta lógica modificando un parámetro de control de umbral.

INTRODUCTION

Recently, there has been a new theoretical direction in harnessing the richness of nonlinear dynamics, namely the exploitation of chaos to do flexible computations (Ditto, Murali & Sinha, 2008; Pisarchik, Kir'yanov, Barmenkov & Jaimes-Reátegui, 2005). The aim is to use a single chaotic element to emulate different logic gates and perform different arithmetic tasks, and further have the ability to switch easily between the different operational roles. Such a computing unit may then allow a more dynamic computer architecture and serve as ingredients of a general purpose device more flexible than statically wired hardware. A system is capable of universal general purpose computing if it can emulate all logic gates.

In the present work, we are interested in an optical system that is capable of universal general purpose computing if it can emulate all logic gates such as the logical gate AND, OR, NOT and XOR (exclusive OR), from which

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we can directly obtain basic operations such as bit-by-bit addition and memory. This Letter is organized as follows: In section 2 we introduced to the model of fiber laser. In sections 3 we give the theoretical scheme for flexible implementation of fundamental logical NAND and NOR operations using a fiber laser in the chaotic regimen. In the section 4 we discussion the results and finally in the section 5 we give the mail conclusion.

Theoretical model

The fiber laser is described by the balance equations for the laser intensity *P* and the average population *N* in the active medium to the upper level (Pisarchik *et al.*, 2005).

$$\frac{dP}{dt} = \frac{2L}{T_r} P\{r_\omega \alpha_0 [N(\xi_1 - \eta) - 1] - \alpha_{th}\} + P_{sp}, \quad (1)$$

$$\frac{dN}{dt} = -\frac{\sigma_{12} r_w P}{\pi r_0^2}(N\xi_1 - 1) - \frac{N}{\tau} + P_{pump}, \quad (2)$$

$$P_{sp} = N\frac{10^{-3}}{\tau T_r}\left(\frac{\lambda_g}{w_0}\right)^2 \frac{r_0^2 \alpha_0 L}{4\pi^2 \sigma_{12}}, \quad (3)$$

$$P_{pump} = P_p \frac{1 - \exp[-\alpha_p L(1-N)]}{N_0 \pi r_0^2 L}, \quad (4)$$

$$P_p = P_p^0 [1 + m\sin(2\pi F_d t) + E]. \quad (5)$$

Where N is the population of the upper laser level, n_0 is the refractive index of a "cold" Erbium Doped Fiber Laser (EDF) core, and L is the active fiber length, σ_{12} level "1" level"2". $\sigma_{12} = \sigma_{21}$ that yields $\xi = (\sigma_{12} + \sigma_{21})/(\sigma_{12}) = 2$, $\eta = (\sigma_{23})/(\sigma_{12}) = 0.4$ at the laser wavelength. $T_r = ((2n_0)/c)(L + l_0)$, ($l_0$ being the intra-cavity tails of the fiber Bragg grating (FBG) couplers), $\alpha_0 = N_0\sigma_{12}$ is the small-signal absorption of the erbium fiber at the laser wavelength, $N_0 = N_1 + N_2$ being the total concentration of erbium ions in the active fiber), $\alpha_{th} = \gamma_0 + (1/2L)ln(1/R)$ is the intra-cavity losses on the threshold (γ_0 being the non-resonant fiber loss and R is the total reflection coefficient of the FBG couplers), τ- level "2", r_0 is the fiber core radius, w_0 is the radius of the fundamental fiber mode, $r_w = 1 - exp[-2(r_0)/(w_0)^2]$, is the factor addressing a match between the laser fundamental mode and erbium-doped core volumes inside the active fiber. In the equation (3) P_{sp} is the spontaneous emission into the fundamental laser mode. We assume here that the laser spectrum width is 10-3 of the erbium luminescence spectral bandwidth (λ_g is the laser wavelength). In the equation (4) P_{pump} is the pump power, where P_p is the pump power at the fiber entrance and $\beta = \alpha_p / \alpha_0$ is the dimensionless coefficient that accounts for the ratio of absorption coefficients of the erbium fiber at pump wavelength λ_p to that at laser wavelength λ_g. To account for the pump modulation, one needs to write the pump power at the active fiber P_p as in equation (5), where a sinusoidal character of modulation is supposed, with modulation frequency F_m and modulation depth *m*.

Implementation of a optoelectronic logic gate

The implementation of dynamic logic gate consists of:

- A laser fiber doped with erbium, which is represented by the balance equations for *P* laser intensity and the average population *N* in the medium active (Pisarchik *et al.*, 2005).

- The threshold controller *E* that depended on an the logic inputs $I_{1,2} = V_{in}$, and a dynamic control signal V_c, with a change in V_c we can change the type of gate

$$E = V_c + I_1 + I_2. \quad (6)$$

We chose a variable as threshold, in this case the laser intensity *P* is used, if any value of *P* that exceeds the threshold *E* is resets to *E*, and otherwise it is *P*.

$$VT = \begin{cases} E \text{ if } P > E \\ P \text{ if } P < e \end{cases}. \quad (7)$$

- An output V_0 given by an amplifier of differences which subtracts the threshold signal *VT* from the fiber laser *P*, see figure 1 (Pisarchik *et al.*, 2005):

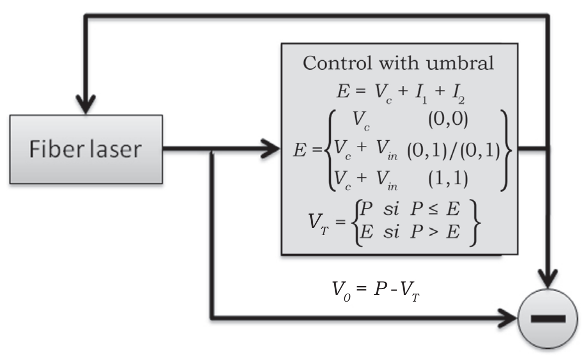

Figure 1. Scheme for the implementation of the dynamic logic gate.
Source: Authors own elaboration.

RESULTS

In the figure 2 we show the voltage timing sequence, $V_{in} = 15$. The NOR gate is realized around $V_C = -3$. At this value of control signal, we have the following: for input (0, 0) the threshold level $E = -3$, which yields $V_0 \approx 3$ for inputs (1, 0) or (0, 1) the threshold level $E = 12$, which yields $V_0 \approx 0$ and for input (1, 1) the threshold level $E = 27$, which yields that $V_0 \approx 0$ as the threshold is beyond the bounds of the chaotic attractor (see figure 2 for timing sequences). The NAND gate is realized around $V_C = -20$. The control signal yields the following: for input (0, 0) the threshold level $E = -20$, which yields $V_0 \approx 20$; for inputs (1, 0) or (0, 1) the threshold level $E = -5$, which yields $V_0 \approx 5$; and for input (1, 1) the threshold level $E = 10$, which yields $V0 \approx 0$ see figure 2 for timing sequences).

CONCLUSIONS

We numerically demonstrated the ability to build the NOR and NAND logic gates taking advantage of the dynamic richness of chaotic fiber laser. With the implementation of a threshold controller, we can emulate two logic gates that depend on an accessible parameter in the threshold controller. This way we propose an optoelectronics logic gate dynamic, which is based on an erbium doped fiber laser and an electronic control. Numerically, we demonstrate the functionality of this implementation in the configuration of pump modulation of fiber laser.

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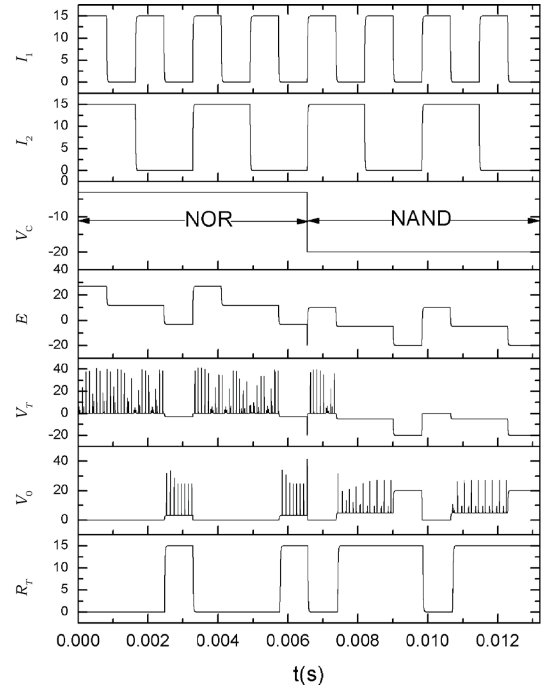

Figure 2. Results of optoelectronic flexible logical gate. $I_{1,2}$ are entrance of logical gate, V_c is the dynamic voltege, E is the voltege threshold. V_0 is the output of logical gate and RT is the logical signal recovered from V_0.
Source: Authors own elaboration.

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