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External Switching Dynamics of Optical Bistability System Simulation

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Abstract

In this work, the external switching dynamics of a Fabry-Perot etalon are studied via optical bistability system simulation. The simulated set-up of this investigation consists of two laser beams; the first beam is continuous (CW) which is considered as a biasing beam and capable of holding the bistable system for a certain range, which we are interested in, from a point that is very close self-switching to a point where the switching is unachievable. The second beam is modulated by passing the first beam through an acousto-optic modulator (AOM) to produce pulses with a minimum rise time and is used as an external source (coherent switching). In this work, we obtained the optical bistable loops by applying absorption coefficient (α) = $20 cm^{-1}$, e sample etalon thickness (D) = 110μm, forward mirror reflectivity (R_f) = 0.6, and backward mirror reflectivity (R_b) = 0.95. The steady state characteristic of an initial detuning of the cavity (φ_0) = 0.8 was studied at the conditions of no external input pulse intensity ($M_{(t)}$ = 0) and switching that takes place at $I_{s(ON)}$= 0.57mW and $I_{s(OFF)}$ = 0.4mW.
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Keywords: Bistability dynamic response, response time, switching dynamics.

ديناميكية التحويل الخارجي لمحاكاة نظام بصري ثنائي الاستقرارية

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الخلاصة

في هذا العمل ، تم دراسة ديناميكيات التحويل الخارجي من مرنان فابري – بيروت اللاخطي لمحاكاة نظام ثنائي الاستقرارية البصرية. الطريقة المستخدمة لإكمال حل المعادلات التفاضلية للوسط غير الخطي ولنظام المحاكاة ثنائي اللاستقرارية ولهذا التحقيق يتم استخدام حزمتين ليزريتين ، واحدة منهما مستمرة (CW) والتي تعتبر بمثابة حزمة متحيزة وقادرة على تثبيت النظام ثنائي وضع الاستقرار لمدى معين والذي نحن بصدد دراسته من خلال نقطة قريبة للتبديل الذاتي إلى نقطة حيث التبديل غير قابل للتحقيق. أما الحزمة الأخرى فيتم تشكيلها بتمرير الحزمة الأولى من خلال مشكِّل صوتي ضوئي (AOM) لإنتاج نبضات ذات ادنى زمن ارتفاع وتُستخدم كمصدر خارجي (تبديل متماسك). في هذا البحث تم استخدام قيم $\alpha = 20\, cm^{-1}$, $D = 110 \mu m$, $R_f = 0.6$, $R_b = 0.95$ للحصول على حلقات ثنائية الاستقرارية البصرية. ان خصائص الحالة المستقرة درست عند $\varphi_o = 1.8$ هو بعدم وجود نبضة خارجية اي ان $M_{(t)}=0$ لذلك التحويل يحدث عند $I_{s(ON)} = 0.57$, $I_{s(OFF)} = 0.4$.

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Introduction

The phenomenon of optical bistability (OB) is interesting both in the physical systems involved and in light of potentially exciting applications. Optical hysteresis in cavities containing gain media are not considered within the current discussions even though some of them were proposed and observed earlier. The analysis of a Fabry-Perot (FP) containing a nonlinear gain medium is similar to that for a nonlinear absorptive and dispersive medium, but the physical consequences and practical implications are quite different. A major factor and incentive for the rapid developments in this area has been the possibility of using light beams for parallel processing and the expectation of achieving a significant increase in computing speed as compared with conventional electronic computers [1,2].

In conventional transistors, the term "electronic" means that the input signals regulate the output by means of electrons in the switching elements. This is also the case for photonic switches, which, also in this connection, can be regarded as an extension of electronic elements to optical frequencies [3].

It has been established that the switch-ON and OFF in optically bistable devices will occur by superimposing an external pulse on a continuous wave holding the system close to one of the critical points of the bistability curve. The role of the external pulse in this process is to generate more carriers in order to change the refractive index and thereby change the optical path length of the beam. However, if the difference between the critical power and the holding power is small compared with the power change involved by the switching pulse, the switching is ruled by a pulse energy scaling law [4]. This characteristic was pointed out in a numerical study of absorptive bistability in a good cavity limit (where the cavity lifetime is more than the material life time,$\tau_c >> T_1$) and was analytically proved by Mandel through a asymptotic analysis published in 1985 [5]. The switch-ON of intrinsic optical bistable devices with external pulse was demonstrated by other research groups [6,7], while to achieve the switch-OFF time, the input intensity must be reduced below the switch-OFF intensity. Obviously, the switching of the devices in either direction of ON or OFF with external pulses and keeping the input intensity constant is very desirable in many applications.

In this investigation, the simulated set-up consists of two laser beams; the first one is continuous (CW) and considered as a biasing beam that is capable of holding the bistable system for a certain range, which we are interested in, from a point that is very close to self-switching to a point where the switching is unachievable [8].

In this research, we obtained the bistable loop by applying the conditions where $\alpha = 20 cm^{-1}$, D = 110μm, $R_f = 0.6$, and $R_b = 0.95$. The steady state characteristic for $\varphi_0 = 1.8$ was studied at the condition where there is $M_{(t)} = 0$, and switching takes place at $I_{s(ON)} = 0.57 mW$ and $I_{s(OFF)} = 0.4 mW$.

Optical Bistability System Simulation

As stated before, the first beam of our simulated set-up is continuous (CW) and considered as a biasing beam. The other beam is modulated by one of two approaches. First, by passing the first beam through an acousto-optic modulator (AOM) to produce pulses with a minimum rise time, which is used as an external source (coherent switching), as shown in Figure-1.Second, by using another pulsed laser source as an external source (incoherent switching), as shown in Figure-2. The two laser beams are coincident on the Fabry-Perot etalon [9].

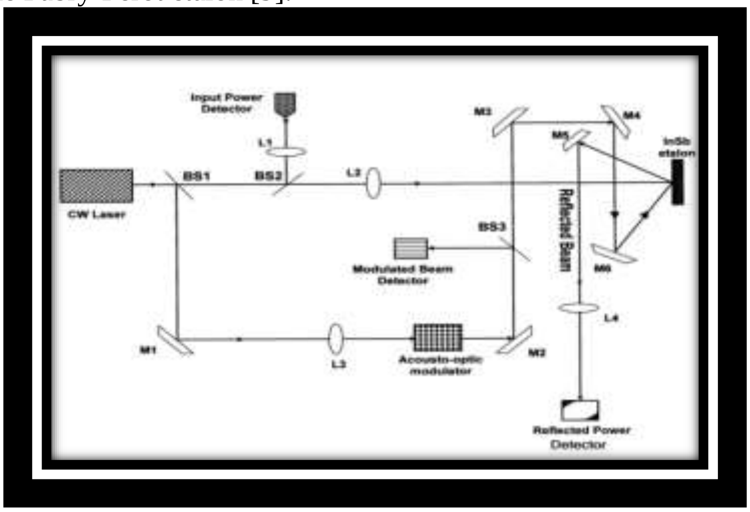

Figure1- Set-up arrangement used for coherent external switching source [9,10].

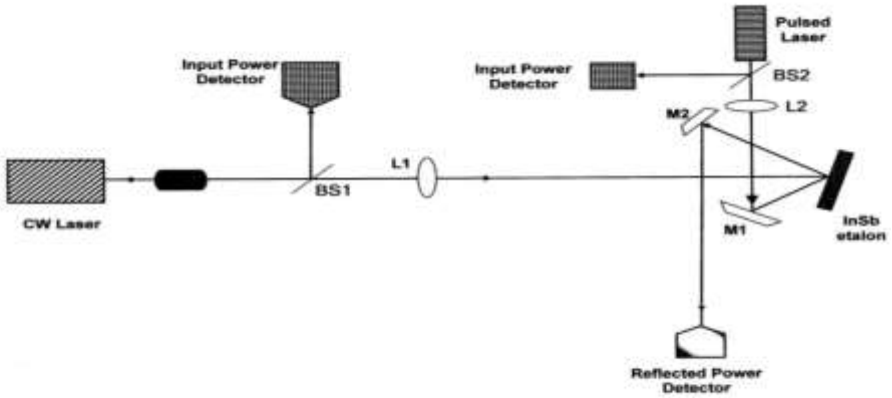

Figure 2- Set-up arrangement used in the incoherent external switching dynamic study.

Results and Discussion

When an external pulse from a laser source represented by M(t) is assumed to be incoherent with the holding laser beam and non-resonant with the cavity, then the dynamical equation for φ for a Fabry-Perot etalon (F-P. etalon) filled with a nonlinear medium is given by [11,12]:

$$\tau_R \frac{\partial \varphi_{(t)}}{\partial t} + \varphi_{(t)} = \frac{I_{in}}{1 + R^2 - 2R\cos\left(\varphi_o - \varphi_{(t)}\right)} + M_{(t)} \quad \text{.. (1)}$$

where τ_R is the material response rate, $M_{(t)}$ is the external pulse intensity, $R = \sqrt{R_f R_b}\exp(-\alpha D)$ R_f and R_b are the front and back face reflectivities of the etalon, α is the linear absorption coefficient, and D is the length of the sample. The reflected intensity from the etalon becomes:

$$I_R(t) = I_{in} \frac{R_f + R_b e^{-2\alpha D} - 2R\cos 2\left(\varphi - \varphi_{(t)}\right)}{1 + R^2 - 2R\cos^2\left(\varphi_o - \varphi_{(t)}\right)} \quad \text{..... (2)}$$

where R_f (R_b) is the front (back) face reflectivity of the etalon.
The steady state solution of equation (1) can be written (for zero modulation) as:

$$\varphi_s\left(1 + R^2 - 2R\cos\left(\varphi_o - \varphi_s\right)\right) = I_{in} \quad \text{............. (3)}$$

where I_{in} represents the incident intensity and the switching point satisfies the condition $dI/d\varphi = 0$ By taking, e.g., , $\alpha = 20cm^{-1}$, D = 110μm, $R_f = 0.6$, and $R_b = 0.95$, we obtain the usual bistable loop.
In Fig.3- a, curve 1 shows the steady state characteristic for $\varphi_0 = 0$ at the condition of no external pulse ($M_{(t)}=0$) and where switching takes place at $I_{s(ON)}= 0.57mW$ and $I_{s(OFF)} = 0.4mW$.
Because the external pulse $M_{(t)}$ is incoherent with the holding beam, the most significant effect of this perturbation is to alter the φ_0 and the nonlinear phase so that the resultant effect should be a reduction in the effective value of φ_0. The steady state characteristic, after the external pulse is ON, is shown in Fig.3- a, in which curves 2, 3, and 4 correspond to the external pulse intensities of $M_{(t)}$= 0.2, 0.4 and 0.6, respectively. The same behavior can be obtained for different values of initial detuning φ_0 = 2.2, as shown in Figure-(3 b).

Table-1 shows the resultant switching ON intensity as a function of external pulse intensity for different values of dark mistuning. The results indicate that as the external pulse intensity ($M_{(t)}$) increases, the switch-ON intensity is reduced, as shown in Figure-4.

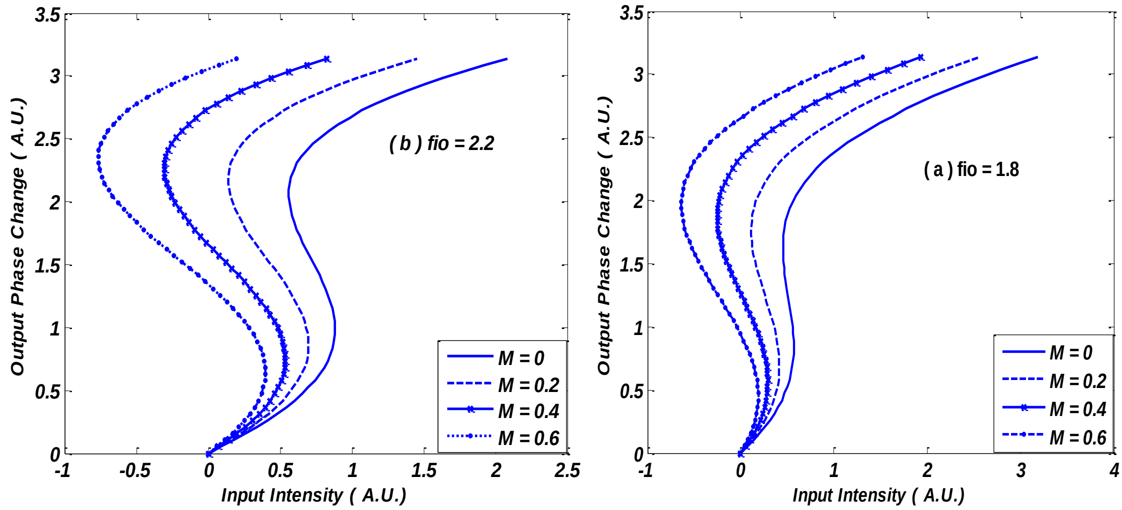

Figure 3- The steady state numerical solution, curve 1 shows the characteristic before the introduction of the external pulse ($M_{(t)}$=0); curves 2,3 and 4 show the characteristic with external pulse ON ($M_{(t)}$=0.2 , 0.4 and 0.6, respectively).

Table 1- The effect of the external switching input pulse on the value of the switching (ON) intensity of different bistable loops.

$M_{(t)}$	I_s(ON)			
	φ_o = 1.8	φ_o = 2	φ_o = 2.2	φ_o = 2.4
0	0.57	0.72	0.88	1.07
0.1	0.48	0.65	0.78	0.975
0.2	0.42	0.55	0.7	0.875
0.3	0.35	0.47	0.62	0.775
0.4	0.29	0.4	0.54	0.69
0.5	0.25	0.35	0.45	0.62
0.6	0.19	0.28	0.4	0.54

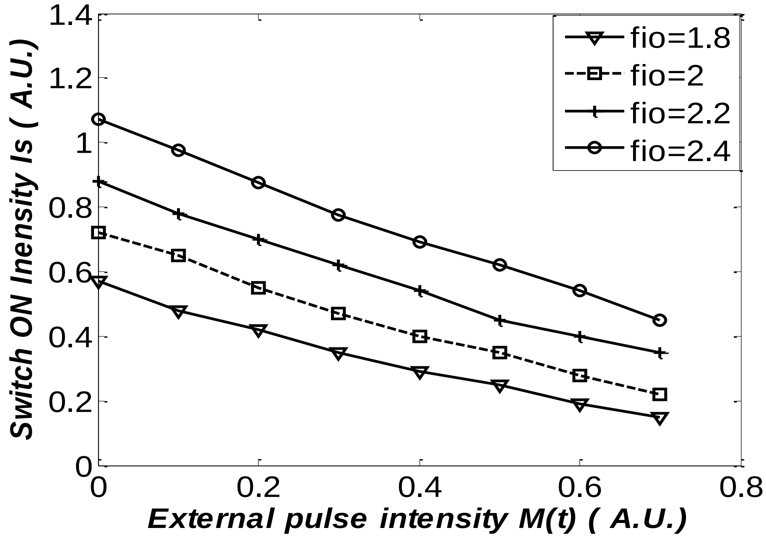

Figure 4- The external pulse intensity $M_{(t)}$ as a function of the switch-ON intensity.

Conclusions

We studied the optical bistability for a Fabry-Perot etalon containing a nonlinear refraction material, which gives various nonlinear relations between the input and output intensity and leads to different switch ON and OFF points depending on the initial detuning, switching time on the external pulse intensity, and the cavity finesse values. The dynamic response of the nonlinear cavity allows the selection of optimal operating conditions for particular potential applications.

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