BISTABLE CHARACTERISTIC OF SIGNAL TRANSMITTED THROUGH THE SYMMETRIC NONLINEAR MICHELSON INTERFEROMETER

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Abstract: *Symmetric Nonlinear Michelson Interferometer (SNMI) operating as optical bistable device has been theoretically investigated. The general output-input intensity relation is introduced for case the output signal transmitted through SNMI. The bistable characteristic (hysteresis) is calculated and presented for some cases the structural parameters were selected specifically.*

Keywords: *SNMI, bistable, Kerr nonlinear medium, splitter, reflection coefficient, transmission coefficient.*

1. Introduction

Close Nonlinear Michelson Interferometer (CNMI) operating as optical bistable device has been studied in previous works [4, 6, 7]. In those works, we used CNMI as the splitter with transmission through coefficient T = 50%; 2 mirrors M_1, M_2 with reflection coefficient R_1 and R_2; Kerr nonlinear medium only half the space inside interferometer (limited by the splitter P, mirror M_4 and mirror M_2). The question is if nonlinear medium occupies the entire space inside CNMI (then CNMI becomes Symmetric Nonlinear Michelson Interferometer-SNMI) Does the signal transmitted by SNMI (go out from the mirror M_2) have bistable characteristic or not? This work will answer that question.

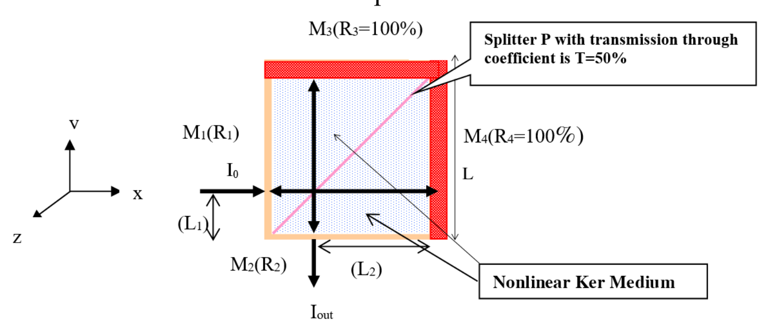

Figure 1. *Symmetric Nonlinear Michelson Interferometer*

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2. Input-output equation of intensity

From the classical Michelson interferometer as in Fig.1 with two mirrors M_3, M_4 which have the reflection coefficient 100% and the splitter P with transmission coefficient ½ we added two mirrors M_1, M_2 to have the reflection coefficients, R_1, R_2 respectively; space between the four mirrors M_1, M_2, M_3 and M_4 is a nonlinear medium with absorption coefficient α and refractive index comply with Kerr optical effect $n = n_0 + n_2 I_{ctr}$, where n_0 is the linear refractivity index, n_2 is the nonlinear index coefficient, directly relating to third-order susceptibility $\chi^{(3)}$ (electrostatic unit) by the relation [2]: $n_2 = \frac{4\pi^2 R_e\left[\chi^{(3)}\right]}{cn_0}$ and $\mathbf{I_{ctr}}$ is the average intensity of light transmitted through nonlinear medium is called control intensity. Assume that light travels to mirror M_1 with equation $E_0 = A_0 e^{i(\omega t-\phi)}$ equivalent to the intensity of $I_0 = \frac{1}{2}\varepsilon_0 c E_0^2$, after passing through and go out SNMI from mirror M_2 the intensity will be:

$$I_{out} = \frac{\frac{1}{2}(1-R_1)(1-R_2)e^{-2\alpha L} I_0}{1-2^{\frac{1}{2}}\left(R_1^{\frac{1}{2}}+R_2^{\frac{1}{2}}\right)e^{-\alpha L}\cos\left\{\frac{4\pi n_2 L}{\lambda}.\frac{(R_1+R_2)e^{-\frac{1}{2}\alpha L_1}}{\alpha L(1-R_2)}\left(1-e^{-\alpha L}\right)I_{out}+\delta_0\right\}+\frac{1}{2}\left[R_1^{\frac{1}{2}}+R_2^{\frac{1}{2}}\right]^2 e^{-2\alpha L}} \quad (1)$$

Here:

L_1 is the transmission distance of light in nonlinear medium from mirror M_1 to the split P.

L_2 is the transmission distance of light in nonlinear medium from the split P to mirror M_2.

$$L = L_1 + L_2$$

δ_0 is the phase shift of light caused by the mirror to be called the initial phase.

Easy to see that if $R_1=R_2=0$, $\alpha=0$ infer $\delta_0=0$, then $I_{out} = \frac{1}{2}I_0$ and SNMI becomes classical Michelson interferometer [1].

2.1. Influence of the reflection coefficient of the mirror M_1

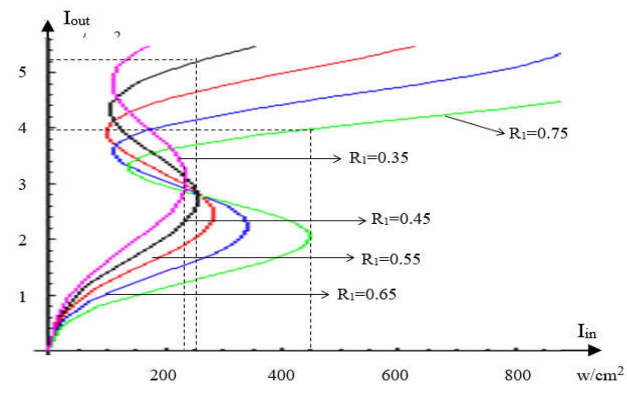

Figure 2. *Out-input characteristics of SNMI with $\delta_0=-0.1\pi$; L=1mm; $\lambda=0.85\mu m$, $R_2=0.5$; $n_2=10^{-4}$ cm^2/w $L_1=L/3$; $\alpha=10^3$ and R_1 change with the values of R_1 = 0.35, 0.45, 0.55, 0.65, 0.75*

By selecting the parameters:

L = 1mm; λ = 0.85μm, R_2 = 0.5; $n_2 = 10^{-4}$ cm²/w; L_1 = L/3; $\alpha=10^3$ and R_1 change with the values of R1 = 0.35, 0.45, 0.55, 0.65, 0.75 we obtain the graph of (1) shown in Figure 2. From the graph we see that the curves are S-shaped. This confirms SNMI operating as optical bistable device with control parameter I_{in} and separate parameter R_1. Input-output characteristic of SNMI reacts very sensitively to changes of R_1: with R_1 = 0.35, 0.45, 0.55, 0.65 and 0.75 have five "threshold jump" on the five curves respectively: 230, 250, 280, 340, 450 (w/cm²).

Thus, the value of "threshold jump" is proportional to the reflectivity R_1 of the mirror M_1. From the graph we also see, then the output intensity I_{out} decreases: if R_1=0.45, the "threshold jump" =250 w/cm² and I_{out}=5.2 w/cm² even if R_1=0.75, the "threshold jump" =450 w/cm² and $I_{out}\approx 4$ w/cm². So the device to work effectively with the parameter $\delta_0=-0.1\pi$; L=1mm; λ=0.85μm, R_2=0.45; $n_2=10^{-4}$cm²/w; L_1=L/3; $\alpha=10^3$ is fixed we should choose the reflectivity of the mirror M_1 as small as possible. Thus reflectivity coefficients of the mirror M_1 has a strong influence to the bistable characteristic of input-output relations; in addition to generating feedback signal (one of two factors for bipolar stability) it was decided to set the value of "threshold jumps" and the height of the jump from that decision to the performance of the device. In addition to generating feedback signal (one of two factors for bipolar stability) it was decided to set the value of "threshold jumps" and the height of the jump from that decision to the performance of the device. With the parameters selected, the device working in optimal mode when R_1=0, then "jump threshold" is minimal and almost 220 w/cm², while the intensity of the signal reaches the maximum value I_{out} = 8.5w/cm² (Fig. 3) and performance of devices = 4%.

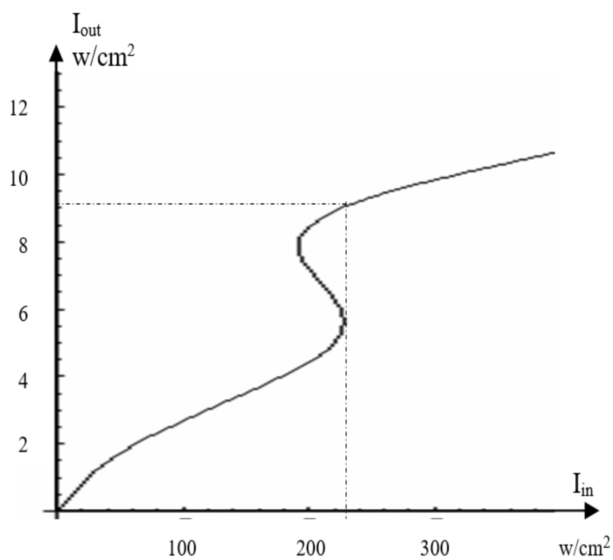

Figure 3. *Out-input characteristics of SNMI with $\delta_0 = -0.1\pi$; L=1mm; λ = 0.85μm, R_2 = 0.5; $n_2 = 10^{-4}$ cm²/w L_1=L/3; $\alpha=10^3$ and R_1 = 0*

2.2. Influence of the reflection coefficient of the mirror M_2

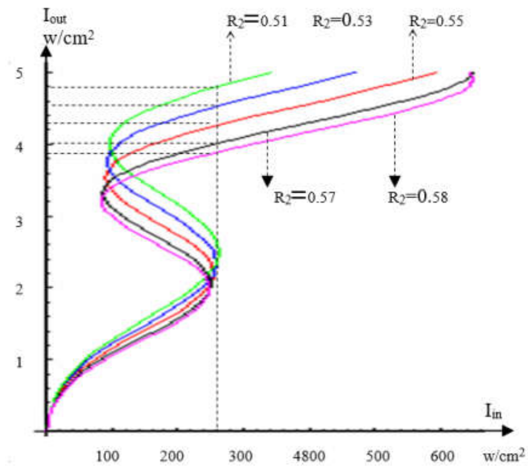

Figure 4. *Out-input characteristics of SNMI with δ_0=-0.1π; L=1mm; λ=0.85μm, R_1=0.5; n_2=10^{-4}cm^2/w; L_1=L/3; α=$10^3$and R_2 change with the values of R_2 = 0.55, 0.53, 0.51, 0.57, 0.58*

In the structure of SNMI, the role of mirror M_2 is generated feedback signal, so that the reflection coefficient of it has influence on bistable characteristics of SNMI. In Fig. 4 the bistable curves for the case of reflection coefficient of mirror M_2 changes, the parameters used in calculations are given in caption under the figure. We found that:

5 different values of R_2 which are very small (0.51, 0.53, 0.55, 0.57, 0.58) will have five bistable curve, but five "threshold jump" nearly equal (I_{in} ≈260w/cm^2) corresponding to 5 different output values (I_{out} ≈4.8, 4.6, 4.3, 4.0, 3.82 w/cm^2).

Thus, the influence of reflection coefficient of the mirror M_2 (R_2) to input-output relationship is not strong as reflection coefficient of mirror M_1 (R_1); It only works to adjust the output intensity. Output in tensity becomes stronger when the reflectivity of the mirror M_2 is smaller. As shown in Figure 5, when R_2=0 persists bistable effects but at the "threshold jumps" output intensity achieves a relatively large value I_{out}= 12.5w/cm^2.

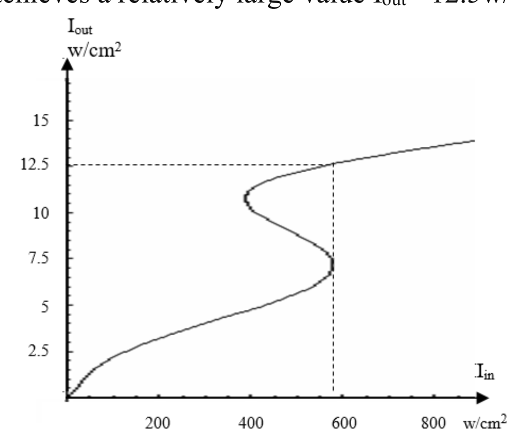

Figure 5. *Out-input characteristics of SNMI with δ_0 = -0.1π; L=1mm; λ = 0.85μm; R_1 = 0.75; n_2 = 10^{-4}cm^2/w; L_1 = L/3; α = 10^3 and R_2=0*

2.3. Influence of the position of the light when it passes into SNMI

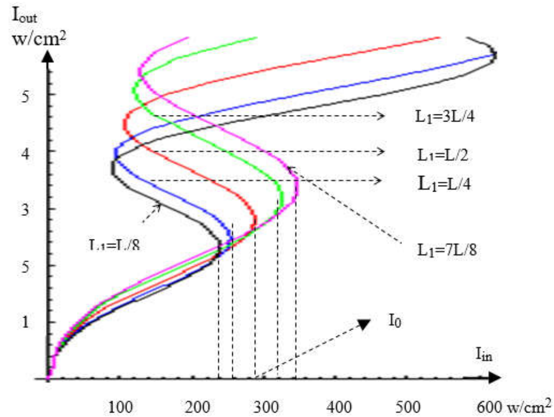

Figure 6. *Out-input characteristics of SNMI with δ_0=-0.1π; L=1mm; λ=0.85μm, R_1=R_2=0.5; n_2=10^{-4}cm^2/w; α=$10^3$and L_1 change with the values of L_1=L/8; L/4; L/2; 3L/4; 7L/8*

With its dependence on the reflectivity R_1 and R_2, the graph of input-output relationship depends very clearly on the position of light as it passes into SNMI. As shown in Fig. 6, when the light rays into SNMI at five different positions on mirror M_1: At the center (L_1=L/2), the four remaining positions symmetrical with each other through the center (each pair a - L_1 = L/8, 7L/8 and L_1 = L/4, 3L/4); we have 5 bistable curves with 5 different “threshold jumps”. First beam going from the center of mirror M_1 has “threshold jump” I_0 = 290w/cm^2, beam 2 (position L_1 = L/4) for “jump threshold” is 260w/cm^2, beam 3 (positions symmetrical with positions of beam 2 through the center of mirror M_1, L_1 = 3L/4) to “jump threshold” is 320w/cm^2, beam 4 (position L_1 = L/8) for “jump threshold” is 240w/cm^2, beam 5 (positions symmetrical with positions of beam 4 through the center of mirror M_1, L_1 = 7L/8) to “jump threshold” is 340w/cm^2. Thus the beam located symmetrically with each other through the center of the mirror M_1 will value the “threshold jumps” symmetrical to each other through I_0. This result is because from the different positions, light passes through nonlinear medium (inside SNMI) with different distances so that there are different phase shifts and lead to the intensity of the light sum which will vary and then with the different output intensity for the different “threshold jumps”.

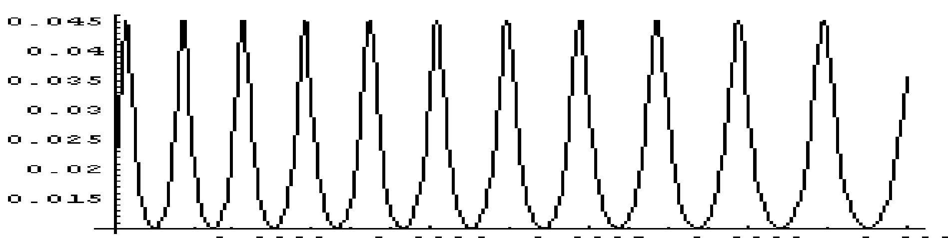

Figure 7. *The dependence of the "Transfer Function" (F = Iout / Iin) on the position of the input light (L1). With δ0=-0.1π; L=1mm; λ=0.85μm, R1=0.45; R2=0.5; n2=10-4cm^2/w; α=103 and Iout=100 w/cm^2*

When changing the position of the light rays in addition to changing "threshold jumps", it also changes the spatial distribution of the "Transfer Function" ($F = I_{out}/I_{in}$). Figure 7 shows the dependence of the "Transfer Function" ($F = I_{out}/I_{in}$) on the position of the input light(L_1) when L_1 changes from 0 to L. We see that Fisa "bell", one of the conditions to confirm SNMI to act as a device for optical bistability.

3. Conclusions

Starting from the classical Michelson interferometer, Symmetry Nonlinear Michelson Interferometer (SNMI) has been proposed and studied. Input-output relationship of the intensity of SNMI has been established on the basis of interference theory. From this relationship, the role of the reflectors and the input position of the light was discussed and simulated by numerical methods. Results showed that could change the design parameters which obtained SNMI with the bistable properties as desired.

References

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