Proc. Natl. Conf. Theor. Phys. **36** (2011), pp. 290-295

BISTABLE CHARACTERISTIC OF SIGNAL TRANSMITTED THROUGH THE SYMMETRIC NONLINEAR MICHELSON INTERFEROMETER

NGUYEN VAN HOA
Faculty of Technology, Hong Duc University
HO QUANG QUY
Academy of Military Science Technology

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.*

I. INTRODUCTION

Close Nonlinear Michelson Interferometer (CNMI) operating as optical bistable device has been studied in previous works [4, 6]. In the that works we used CNMI have the splitter with transmission through coefficient is T = 50% ; 2 mirrors M_1, M_2 with reflection coefficient is 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) the signal transmitted by SNMI (go out from the mirror M_2) also have Bistable characteristic or not? This work will answer that question.

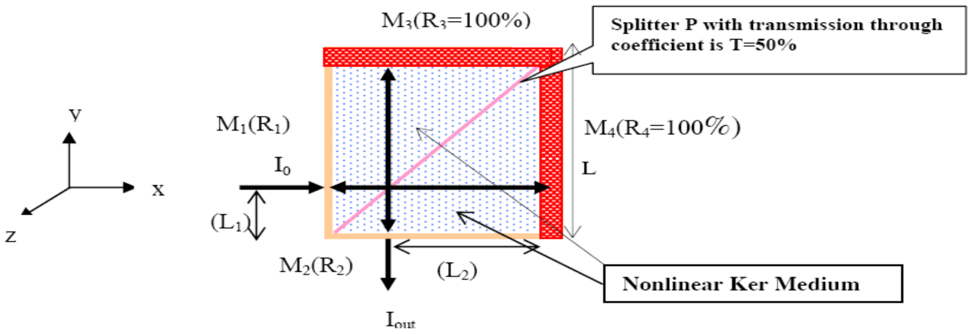

Fig. 1. Symmetric Nonlinear Michelson Interferometer.

II. INPUT-OUTPUT EQUATION OF INTENSITY

From the classical Michelson interferometer as in Figure 1 with two mirrors M_3, M_4 have the reflection coefficient is 100% and the splitter P with transmission coefficient is $\frac{1}{2}$ we added two mirrors M_1, M_2 have the reflection coefficients, respectively R_1, R_2; 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 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 $I_0 = \frac{1}{2}\varepsilon_0 c E_0^2$ after passing through and go out SNMI from mirror M_2 then the light will be intensity is:

$$I_{out} = \frac{\frac{1}{2}\left(1 - R_1\right)\left(1 - R_2\right) e^{-2\alpha L} I_0}{1 - \frac{1}{2}\left(R_1^{\frac{1}{2}} + R_2^{\frac{1}{2}}\right) e^{-\alpha L} F(R_1, R_2, L, \alpha, \delta_0)} \tag{1}$$

Here:

$$\begin{aligned} F(R_1, R_2, L, \alpha, \delta_0) \quad &= \quad 2\sqrt{2}\cos\left\{\frac{4\pi n_2 L \left(R_1 + R_2\right) e^{-\frac{1}{2}\alpha L_1}\left(1 - e^{-\alpha L}\right) I_{out}}{\alpha L \lambda \left(1 - R_2\right)} + \delta_0\right\} \\ &\quad + \left[R_1^{\frac{1}{2}} + R_2^{\frac{1}{2}}\right]^{\frac{1}{2}} e^{-\alpha L} \end{aligned}$$

- 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 is 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 become classical Michelson interferometer [1].

II.1. Influence of the reflection coefficient of the mirror M_1

By selecting the parameters: $\mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, \mathrm{R}_2 = 0.5; \mathrm{n}_2 = 10^{-4}; \mathrm{L}_1 = \mathrm{L}/3; \alpha = 10^3$ and R_1 change with the values of $R_1 = 0.35, 0.45, 0.55, 0.65, 0.75$ 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 react very sensitive 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/cm^2).

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" $= 250 w/cm^2$ and $I_{out} = 5.2 w/cm^2$ even if $R_1 = 0.75$,

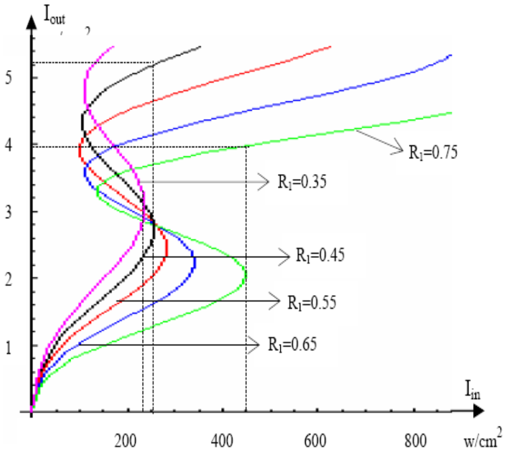

Fig. 2. Out-input chacteristics of SNMI with $\delta_0 = -0.1\pi; L = 1\text{mm}; \lambda = 0.85\mu\text{m}, \text{R}_2 = 0.5; \text{n}_2 = 10^{-4}; \text{L}_1 = \text{L}/3; \alpha = 10^3$ and R_1 change with the values of $R_1 = 0.35, 0.45, 0.55, 0.65, 0.75$

.

the "threshold jump" $= 450w/cm^2$ and $I_{out} = 4w/cm^2$. So the device to work effectively with the parameter $\delta_0 = -0.1\pi; \text{L} = 1\text{mm}; \lambda = 0.85\mu\text{m}, \text{R}_2 = 0.45; \text{n}_2 = 10^{-4}; \text{L}_1 = \text{L}/3; \alpha = 10^3$ is fixed we should choose the reflectivity of the mirror M_1 as small as possible. Thus reflectivity coefficients of the mirror $M_1(R_1)$ 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 $220w/cm^2$, while the intensity of the signal reaches the maximum value $I_{out} = 8.5w/cm^2$ (Fig. 3) and performance of devices = 4%.

II.2. Influence of the reflection coefficient of the mirror M_2

In the structure of SNMI, the role of mirror M_2 is generated feedback signal, so that reflection coefficient of it have influence on bistable characteristics of SNMI. In fig 4 is 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: With 5 different values of R_2 is 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 output value 5 different $((I_{out} = 4.8, 4.6, 4.3, 4.0, 3.82w/cm^2)$.

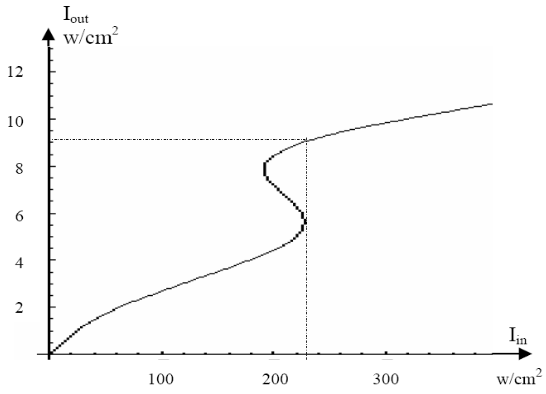

Fig. 3. Out-input chacteristics of SNMI with $\delta_0 = -0.1\pi; \mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, \mathrm{R}_2 = 0.5; \mathrm{n}_2 = 10^{-4}; \mathrm{L}_1 = \mathrm{L}/3; \alpha = 10^3$ and $R_1 = 0$.

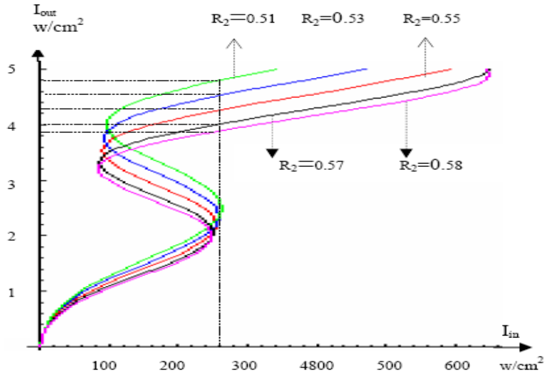

Fig. 4. Out-input chacteristics of SNMI with $\delta_0 = -0.1\pi; \mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, \mathrm{R}_1 = 0.5; \mathrm{n}_2 = 10^{-4}; \mathrm{L}_1 = \mathrm{L}/3; \alpha = 10^3$ and R_2 change with the values of $R_2 = 0.55, 0.53, 0.51, 0.57, 0.58$.

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 intensity becomes stronger as the reflectivity of the mirror M_2 smaller. As shown in Figure 5, when $R_2 = 0$ persists bistable effects but at the "threshold jumps" output intensity to achieve a relatively large value $I_{out} = 12.5w/cm^2$.

II.3. Influence of the position of the light when it passes into SNMI

With its dependence on the reflectivity R_1 and R_2, the graph of input-output relationship depends very clear on the position of light as it passes into SNMI. As shown in Figure 5b when the light rays into SNMI at five different positions on mirror M_1: At

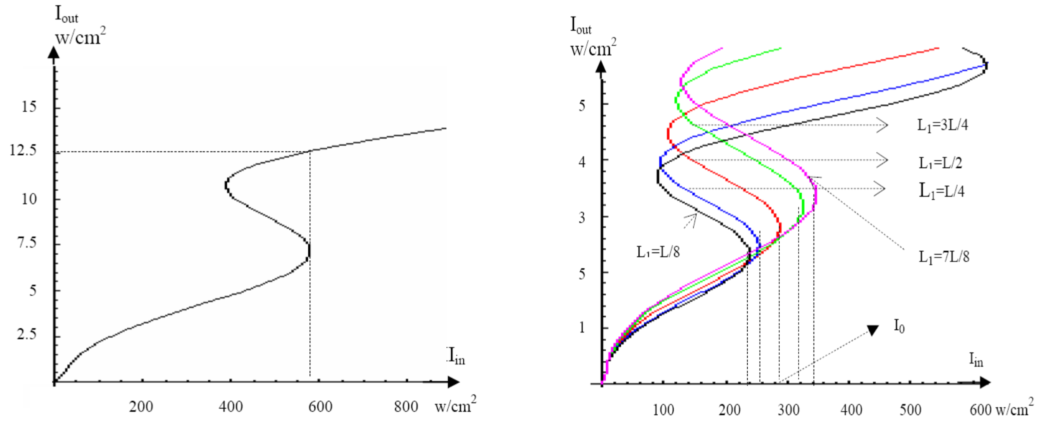

Fig. 5a

Fig. 5b

Fig. 5. Out-input chacteristics of SNMI with $\delta_0 = -0.1\pi; \mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, R_1 = 0.75; \mathrm{n}_2 = 10^{-4}; \mathrm{L}_1 = \mathrm{L}/3; \alpha = 10^3; \mathrm{R}_2 = 0.$.(Fig. 5a) and Out-input chacteristics of SNMI with $\delta_0 = -0.1\pi; \mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, \mathrm{R}_1 = \mathrm{R}_2 = 0.5; \mathrm{n}_2 = 10^{-4}; \alpha = 10^3$ and L_1 change with the values of $\mathrm{L}_1 = \mathrm{L}/8; \mathrm{L}/4; \mathrm{L}/2; 3\mathrm{L}/4; 7\mathrm{L}/8$ (Fig. 5b)

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 curve with 5 "threshold jumps" different. First beam goes from the center of mirror M_1 has "threshold jump" $I_0 = 290w/cm^2$, beam 2 (position $L_1 = L/4$) for "threshold jumps" 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 "threshold jumps" is $320w/cm^2$, beam 4 (position $L_1 = L/8$) for "threshold jumps" 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 "threshold jumps" is $340w/cm^2$. Thus the beam is 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 results is because from the different position, light passing through nonlinear medium (inside SNMI) with different distances so that there are different phase shifts and lead to the intensity of the light sum will vary and then with the different output intensity will for the "threshold jumps" different.

When changing the position of the light rays in addition to changing "threshold jumps", it also do changes the spatial distribution of the "Transfer function" ($F = I_{out}/I_{in}$). Figure 6 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 F is a 'bell' one of the conditions to confirm SNMI act as a device for optical bistability.

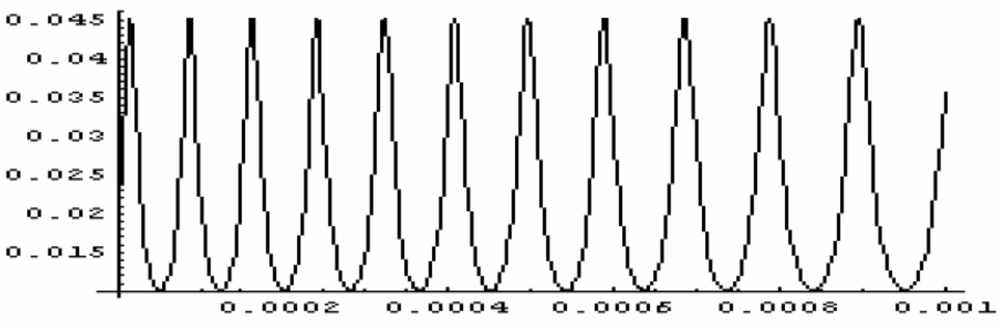

Fig. 6. The dependence of the "Transfer function" ($F = I_{out}/I_{in}$) on the position of the input light (L_1) with $\delta_0 = -0.1\pi; \mathrm{L} = 1\mathrm{mm}; \lambda = 0.85\mu\mathrm{m}, \mathrm{R}_1 = 0.45; \mathrm{R}_2 = 0.5; \mathrm{n}_2 = 10^{-4}; \alpha = 10^3 \mathrm{and} \mathrm{I}_0 = 100\mathrm{w/cm}^2$.

III. CONCLUSION

Starting from the Classical Michelson interferometer, Symmetry Nonlinear Michelson Interferometer (SNMI) have 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 will be obtained SNMI with the bistable properties as desired.

REFERENCES

[1] Demtroder W., *Laser Spectroscopy*, New York.
[2] Sakata H., *Photonic analog-to digital conversion by use of nonlinear Fabry-Perot resonators*, *Appl. Phys.* **40** (2001) 240-248.
[3] N. V. Hoa, H. Q. Quy, *Proc. of The GVS6, Chemnitz*, (2003).
[4] H. Q. Quy, V. N. Sau, N. V. Hoa, *Commun.in Phys.* **13**, (2003) 157-164.
[5] H. Q. Quy, N. V. Hoa, *Proc. of The GVS7,* (2004), Ha Long.
[6] N. V. Hoa, H. Q. Quy, V. N. Sau, *Comm. Phys* **15**, (2005) 6-12.

Received 30-09-2011.