Observation of Optical Bistability in Oppositely Directed Coupler

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1. Introduction

Nonlinear directional couplers (NDCs) find wide interest in optical communication system because of its potential application in signal processing including optical switching and logic operation. In couplers, if any one of the channel of NDCs is replaced with negative index material (NIM), then the coupler is called as oppositely directed coupler (ODC) because of the opposite direction of input and output fields. The electromagnetic wave entering in one channel of the coupler leave through other channel in opposite direction. Optical bistability (OB) is a nonlinear phenomenon observed in optical systems such that, the system possesses two output intensities for the same input intensity. The importance of optical bistability arises due to its potential application for the development of devices such as optical switches, memories, and amplifiers. The primary requirements of OB are the intensity dependent refractive index and optical feedback mechanism. A two core directional coupler with channels made of nonlinear and homogeneous materials is not bistable. However, ODC shows the phenomenon of OB and admit gap solitons due to effective feedback mechanism in NIM channel arising as a result of opposite directionality of phase velocity and energy flow.

2. Optical Bistability in ODC

The model that describe the propagation of light wave in the ODC with NIM channel is given by following coupled nonlinear Schrodinger equations

$$i\sigma_j \frac{\partial u_j}{\partial z} + i\frac{1}{v_{jg}}\frac{\partial u_j}{\partial t} - \frac{\beta_{2j}}{2}\frac{\partial^2 u_j}{\partial t^2} + k_{j(3-j)}u_{(3-j)}e^{-i\delta z} + \gamma_j |u_j|^2 u_j = 0$$

Where β is the dispersion coefficient, γ and k are the Kerr and coupling coefficient, respectively.

2.1 Numerical analysis

Using Langrangian variational method, we construct the solution using Gaussian ansatz. After some mathematical manipulation, one can write the variation equation as follows

$$\left(\frac{dP_1}{dz}\right)^2 = a_1 P_1(P_1 - F) + a_2 P_1^2 (P_1 - F)^2) - a_3 P_1^2 (a_3 + 2\sqrt{a_2}(P_1 - F))$$

The periodic solution of the above equation can be obtained through Jacobian elliptic function by considering a solution of $P_1(z) = A\,cn[\Omega(z-L), m]$

Then the transmission coefficient T for nonlinear ODC can be written as

$$T = \frac{P_1(L)}{P_1(0)} = \frac{1}{cn[\Omega L, m]}$$

Where, $P_1(0)=P0$, $P_2(L)=0$ then $F=P_1^2(L)$, i=1,2 indicate the values of power at $z=0$ and $z=L$.

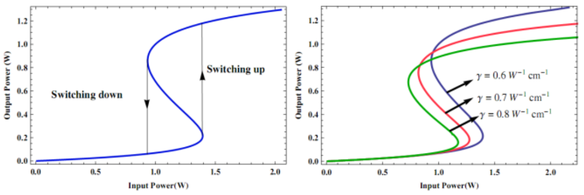

Fig.1 (a) showing the evidence of OB and (b) OB as a function of nonlinear coefficient

The OB in ODC with NIM channel can be explained using the expression for transmission coefficient. As it is known, the OB is a manifestation of nonlinearity and optical feedback, such as in cavity. Here, in the case of periodic structures like optical fibers like ODC, the effective feedback is due to the existence of bandgap in the ODC. It is known from the theory of left-handed materials, that NIM possess opposite directionality of the phase and energy velocities, therefore, the Poynting vector corresponding to the energy flow point in the opposite direction. As a result of which, the propagating light in the PIM channel couples with the NIM channel, where it flows in the backward directions. This is similar to the feedback mechanism; thus the presences of NIM channel in ODC possess distributed feedback mechanism, and thereby meet the requirement for OB as illustrated in Fig. (1)

3. Conclusion

We conclude that the ODC show a novel optical bistability. This property arises due to effective feedback mechanism as a result of opposite directionality of the phase velocity and energy flow in the negative index materials.

References

[1] K. Nithyanandan and K. Porsezian, "Observation of two state behavior in the instability spectra of saturable noninear medi", 222, 821-825 (2013).