第79回応用物理学会秋季学術講演会 講演予稿集 (2018 名古屋国際会議場 (愛知県名古屋市))

Multistability in directional coupler with negative index material channel

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Abstract: We observe optical mulistability in opposite directly coupler (ODC) with negative index material channel. The emergence of multiple stable states is a result of combined action of nonlinear saturation and opposite directionality of phase velocity and energy flow in the ODC.

1. Introduction

The concept of nonlinear directional couplers (NDCs) proposed in the early 1980's brought a new paradigm in the ultrafast long haul optical communication system. The transmission characteristics of NDC differ according to the design architecture of the coupler. For instance, 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. Optical Multistability (OM) is a phenomenon, where the system exhibits more stable states for the same input power, as a result of the combined effects of nonlinearity and feedback. The importance of optical OM arises due to its potential application for the development of devices such as optical switches, memories, and amplifiers. The primary requirements of OM 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 OM 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 Multistability in ODC

The model that describe the propagation of light wave in saturable ODC with NIM channel is given by

$$i\,\sigma_1\frac{\partial u_1}{\partial z}+\frac{i}{v_{1g}}\frac{\partial u_1}{\partial t}-\frac{\beta_{21}}{2}\frac{\partial^2 u_1}{\partial t^2}+k_{12}u_2e^{i\delta z}+\gamma_1\frac{f(\Gamma|u_1|^2)}{\Gamma}u_1=0.$$

following coupled nonlinear Schrodinger equations
Where β, γ and k are the dispersion, Kerr and coupling coefficients and Γ is the saturation parameter

2.1 Numerical analysis

Using Langrangian variational method, one can construct the solution using Gaussian ansatz. 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 $z=L$.

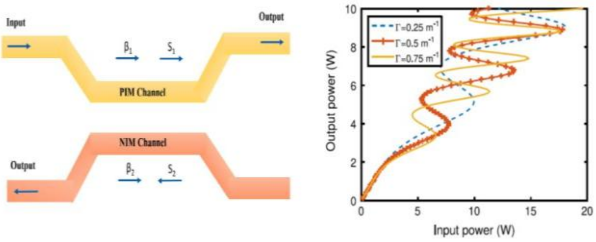

Fig.1 (a) shows the schematic of the ODC and (b) depict OM as a function of input power

The OM in saturable ODC with NIM channel can be explained using the expression for transmission coefficient. As it is known, the OM 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. Also the presence of nonlinear saturation further enhance the multistable behavior. 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 OM as illustrated in Fig. (1)

3. Conclusion

We conclude that the ODC with saturable nonlinearity lead to multistability, as a result of the combined action of the nonlinear saturation and opposite directionality of the phase velocity and energy flow in the negative index materials.

References

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