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Symmetry Breaking in One Dimensional Directional Phtonic Crystal Wave Guide

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Abstract

We have studied symmetry breaking in the one dimensional directional crystal wave guide that holds a single nonlinear defect positioned on the centre line of the waveguide. When only the monopole eigen mode of the defect cavity belongs to the propagation band of photonic crystal waveguide. There are varieties of nonlinear optical processes mostly related to a bistability of light transmission. Two dipole resonant modes of the single non-linear defect made from a Kerr medium. The degenerated dipole modes have opposite parities relative to injected even light mode propagating in the waveguide. For the linear cavity the light would be coupled with the even dipole mode only to give rise to Breit-Wigner resonant peak at the eigen frequency of the cavity. Nonlinear coupling between the dipole modes may cause excitation of both dipole modes. For equal phases, the symmetry is broken by the light intensity relative to mirror reflection.

Keywords: Phtonic Crystal Wave, Light transmission, Eigen frequency

1. INTRODUCTION

Peschel et al [1] studied the phenomenon of symmetry breaking in the non-linear optics for one or more asymmetric states. Tasgal et al [2] and Gubeskeys et al [3] well correlated with studies in a non-linear dual core directional fiber. Ostrovskaya et al [4] presented the nonlinear Schrodinger equation in double well potential. Brazhnyi et al [5] showed a linear discrete chain with two nonlinear sites. The symmetry was broken because of different light intensities at the cavities. Bulgakov et al [6] found that the symmetry might be broken because of different phases of light oscillations in the nonlinear cavities that gave rise to a Josephson like poynting vector of power current between the cavities. Maier [7] and Gibbs [8] gave the concept of all optical switching is based on a discontinuous transition between the symmetry breaking solutions by a small change of the input. Boumaza et al [9] and Grigoriev et al [10] showed that many of these devices employ a configuration of two parallel coupled nonlinear waveguides. Recently Maes et al [11] demonstrated the all optical switching in the system of two nonlinear microcavities aligned along the single waveguide by the use of pulses of injected light. Bulgakov et al [12] studied that in the T-shaped wave-guide coupled with two nonlinear microcavities, it was shown that pulses of light injected into a bottom waveguide are capable to switch light outputs.

2. METHOD

The TM mode has the electric field component parallel to the infinitely long rods. Light propagating in the waveguide can excite only those eigen modes of the defect rod cavity whose eigen frequencies belong to the propagation band of the photonic crystal wave guide. By tuning of the radius of the defect rod or its dielectric constant, we have fitted the dipole eigen frequencies in to the propagation band of the waveguide. Suppose that there are two degenerated dipole modes $E_1(X)$ and $E_2(X)$ of the defect rod cavity. We can obtain the directional photonic crystal waveguide that holds the non linear defect rod named as the dipole defect. After opening the dipole eigen mode seize to be solutions of the Maxwell equations and decay into the arms of the waveguide. The principal role of the dipole modes for crosses talking in the x-shaped waveguide for the optical transistor.

Therefore, we can write for the electric field in the interior of the defect cavity

$$E(x,y) = A_1 E_1(x,y) + A_2 E_2(x,y) + \bar{\Psi}(x,y) \qquad \text{..... (1)}$$

Where the complex background function $\bar{\Psi}$ is a small contribution of the other non coherent defect modes. Assuming that the cavity defect rod is made from a Kerr medium. Then the perturbation theory is developed, we can write the following coupled mode theory equation for the amplitudes $A_m, m = 1,2:$

$$[\omega - \omega_0 - V_{11} + iy_l] A_1 - V_{12} A_2 = i\sqrt{y_1} E_{in} - V_{12} A_1 + [\omega - \omega_0 - V_{22}] A_2 = 0 \qquad \text{... (2)}$$

where

$$\langle m|V|n\rangle = -\frac{(\omega_m + \omega_n)}{4N_m} \int d^2\vec{r} \delta \in(\vec{r}) Em(\vec{r}).E_n(\vec{r}) \qquad \text{.... (3)}$$

$$\delta \in(\vec{r}) = \frac{n_o c n_2 |E(\vec{r})|^2}{4\pi} \approx n_o c n_2 |A_1 E_1(\vec{r}) + A_2 E_2(\vec{r})|^2 \qquad \text{.... (4)}$$

is the non linear contribution to the dielectric constant of the defect rod with instantaneous Kerr non linearity, $n_0 = \sqrt{\in_0}$ and n_2 are the linear and nonlinear refractive indexes of the defect rod, c is the light velocity. Equation (4) implies the normalization of the eigen modes as follows

$$N_m = \int d^2\vec{r} \in_{Phc} E_m^2(\vec{r}) = \frac{a^2}{c n_2} \qquad \text{.... (5)}$$

Where $\in_{Phc}$ is the dielectric constant of whole defect less photonic crystal. Because of symmetry $N_1 = N_2$ we can write coupled mode theory equations in the dimensionless form

$$\left[\omega = \omega_0 + \lambda_{11}|A_1|^2 + \lambda_{12}|A_2|^2 + iy_1\right]A_1 + 2\lambda_{12}\,\mathrm{Re}\left(A_1^* A_2\right)A_2 = i\sqrt{Y_1}\,Ein,$$
$$2\lambda_{12}\,\mathrm{Re}\left(A_1^* A_2\right)A_1 + \left[\omega - \omega_0 + \lambda_{22}|A_2|^2 + \lambda_{12}|A_1|^2\right]A_2 = 0 \quad \text{.... (6)}$$

Where E_{in} is the amplitude of the light injected into the left side of the waveguide.

3. RESULTS AND DISCUSSION

Fig (1) (a) Shows the symmetry preserving solution and demonstrates that the even dipole mode is excited only. Optical streamlines of the poynting vector are almost parallel to the waveguide. For the symmetry breaking solution fig (1) (c) shows that the symmetrical light transmitting through the wave guide excites both dipole modes to give rise to the breaking of the centre line mirror symmetry. As a result the light streamlines tilt in the interior of the defect cavity. The nodal lines coincide with the cavity that means we have no optical vortex there. Fig (1) (e) shows the phase symmetry solution and indicate that nodal line crosses the nodal line at the centre of the defect rod by the angle $\frac{\pi}{2}$ to give rise to an optical vortex as shown in fig (4) (f). The absolute value of light amplitude is fully symmetric relative to the centre line. The symmetry is broken because of the energy flow, which is vertical around the defect rod with the velocity $V = \nabla \times \mathrm{j}$ directed down. There is also the fully equivalent phase symmetry breaking solution with the vorticity directed up.

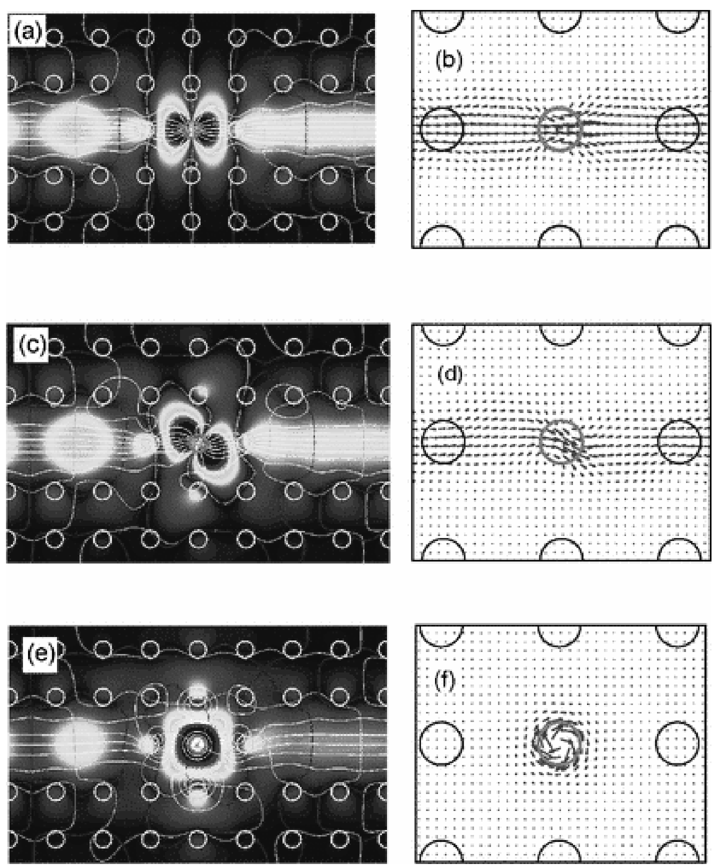

Figure: 1: Absolute value of light amplitude (electric field) and optical streamlines in the PhC waveguide with a single nonlinear defect.

4. CONCLUSION

We have found the domain of stability for the solutions of the non linear coupled mode equations that can be the basis for the all optical switching in the simplest photonic crystal architecture of a single wave-guide with a single non linear optical cavity. One of the most ambitious goals in nonlinear optics is the design of an all optical computer that well overcome the operation speeds in conventional computers. Vital in this respect is design of basic components such as all optical routing switches and logic gates. We have observed that the phenomenon of symmetry breaking can be achieved in a single non linear dipole defect. Such a system is the simplest optical circuit where the symmetry breaking could take place. We have shown that the mirror reflection symmetry of the system can be broken either by light intensity or light phase.

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