Incoherently Coupled Grey Solitons in Photorefractive Multiple Quantum Well Planar Waveguides

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Abstract: Incoherently coupled grey spatial solitons are predicted for the first time in semi-insulating multiple quantum well structures. The effect of external bias and the overlap of the quantum wells layer on the optical mode of the waveguide is studied on the self trapping mechanism.

INTRODUCTION

The movement and recombination of photo generated free carriers give rise to photorefractive(PR) effect. A beam of light with spatial variation of intensity creates a space charge electric field in the sample by stimulating these processes. This space charge field can change the local index of refraction of material by the electro-optic effect. The nonlinear effects in semi insulating multiple quantum well(MQW), with the wavelength close to the absorption band edge provide a type of fast PR response, unlike conventional PR materials[1]. Incoherent coupling of PR solitons is a much studied topic in conventional PR materials[2,3]. In this paper, we have predicted the existence of incoherently coupled grey-grey soliton pairs in PR-MQW waveguides. We have also studied how the self trapping is affected by the external electric field and the overlap parameter of the optical mode of the waveguide.

THEORETICAL MODEL

The structure comprises a multilayer core region which is composed of alternating layers of GaAs and AlGaAs. We shall assume the thickness of PR-MQW region and refractive index of encompassing materials is such that this structure works as a single- mode planar waveguide. The external bias field is considered to be applied along the planes of quantum well in Franz-Keldysh geometry shown in Fig.1.

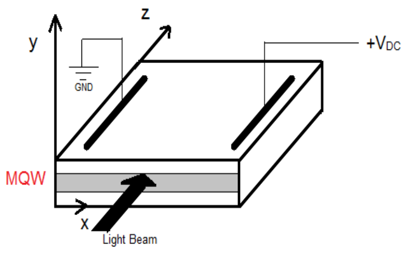


FIGURE 1. The geometry of photorefractive MQW[4]

For induced modification in refractive index be much smaller than the difference of refractive index between the waveguide layer(along y axis), the form of electric field be in TE guided mode provided the polarization of beam along x-axis and propagation along the z-direction is $\mathrm{E}_i(x,y,z)=A_i(x,z)\psi(\mathrm{y})\exp(i\omega t-ikz); i=1,2$,

where $A_i(x,z)$ is the slowly varying amplitude of the i^{th} beam and satisfies paraxial diffraction equation,

$$\left(\frac{\partial}{\partial z}-\frac{i}{2k}\frac{\partial^2}{\partial x^2}\right)A_i(x,z)=\left(\frac{ik}{n}\right)(\Delta n)A_i(x,z); i=1,2 \tag{1}$$

where, $k=k_0n$ is linear effective propagation constant, n is the equivalent refractive index of MQW structure[1],[5]. The change in effective refractive index is [1] $\Delta n=-(1/2)\mathrm{n}^3rE_{sc}^2M$ where, r is the quadratic electro-optic coefficient, E_{sc} is the space charge electric field in the structure[1], $\mathrm{E}_{sc}=\mathrm{E}_0\left[(I_\infty+I_d)/(I+I_d)\right]$ is space charge electric field and $\mathrm{M}=\int_{MQW}|\psi(y)|^2\,dy\Big/\int_{-\infty}^{\infty}\left|\psi(y)^2\right|dy$ describe the overlap between quantum well structure and optical mode of waveguide . Using the value of Δn, E_{sc} and converting the equation into dimensionless co-ordinates we get,

$$i\frac{\partial U_i}{\partial\xi}+\frac{1}{2}\frac{\partial^2U_i}{\partial s^2}-\frac{\beta(1+\rho)^2U_i}{(1+\left|U_1\right|^2+\left|U_2\right|^2)^2}=0, i=1,2 \tag{2}$$

where,

$$A_1=(2\eta_0I_d/n)^{1/2}U_1, A_2=(2\eta_0I_d/n)^{1/2}U_2, \xi=z/kx_0^2, s=x/x_0, \beta=(1/2)(k_0x_0)^2rn^4E_0^2M, I=n/2\eta_0\left(\left|A_1\right|^2+\left|A_2\right|^2\right)$$

RESULTS AND DISCUSSION

We can express the incoherently coupled grey-grey soliton pair in usual manner[3],

$$U_1=\rho^{1/2}\mathrm{y(s)}\cos(\theta)\exp[i(c\xi+\int_0^s\frac{\Gamma d\tilde{s}}{y^2(\tilde{s})})],\qquad \mathrm{U}_2=\rho^{1/2}\mathrm{y(s)}\sin(\theta)\exp[i(c\xi+\int_0^s\frac{\Gamma d\tilde{s}}{y^2(\tilde{s})})] \tag{3}$$

where c and Γ are constants to be determined. Substituting (3) and (4) in (2) we get,

$$\ddot{y}=2cy+\frac{\Gamma^2}{y^3}+\frac{2\beta(1+\rho)^2}{(1+\rho y^2)^2}y \tag{4}$$

The boundary conditions for grey solitons are $y^2(0)=m(0<m<1), y(\pm\infty)=1, \dot{y}(0)=0, \dot{y}(\pm\infty)=0, \ddot{y}(\pm\infty)=0$

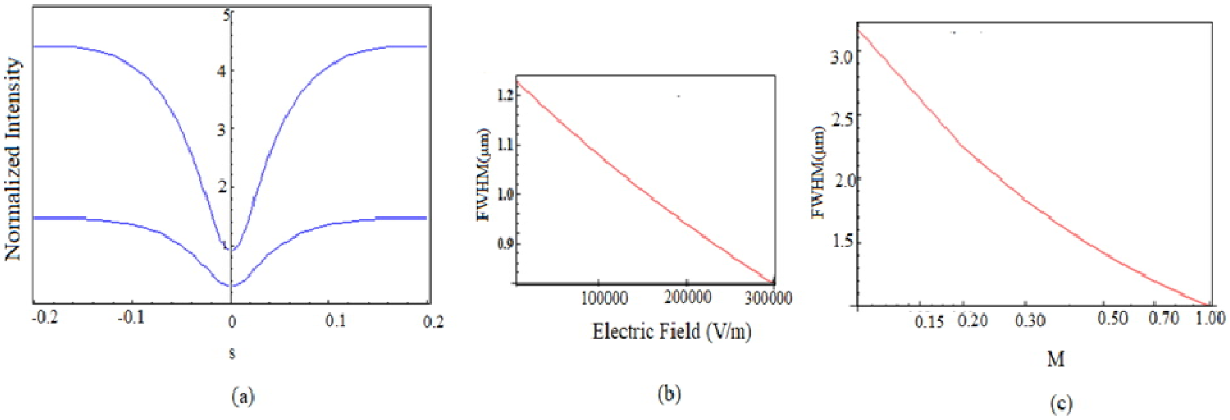
By integrating equation (4) twice and using the boundary conditions for the grey solitons, we get ,

$$s=\pm\int_y^{\sqrt{m}}\left(2c(\tilde{y}^2)-\Gamma^2(\frac{1}{\tilde{y}^2})-\frac{2\beta(1+\rho)^2}{\rho}(\frac{1}{1+\rho\tilde{y}^2})+d\right)^{-1/2}d\tilde{y} \tag{5}$$

with

$$c=-\frac{\Gamma^2}{2m}-\frac{\beta(1+\rho)}{(1+\rho m)}, d=\frac{\Gamma^2(1+m)}{m}+2\beta(1+\rho)\left(\frac{(1+\rho)-m(1+\rho m)}{\rho(1+\rho m)(1-m)}\right) \tag{6}$$

By solving (5), and using value of c and d we can find the normalized intensity profile of incoherently coupled grey-grey soliton pair as shown in Fig.2(a) .We shall take the parameters[1,5], n = 3.57, λ=860 nm., r = -12×10^{-15}, E_o= 2×10^5 V/m, x_0= 20 µm, M=2/3.Since the value of electro optic coefficient is negative ,we expect a defocusing nonlinearity which will support grey solitons[1]. Fig.2(c) shows the variation of FWHM of soliton pair with M. As the overlap of the quantum well layers increases , the FWHM decreases due to the enhancement of self trapping nonlinearity. From Fig. 2(b), we can conclude that FWHM of the soliton pair decreases with an increase in external bias field strength signifying an increase in the self trapping.



(a) (b) (c)

FIGURE 2. (a) Normalized Intensity profile for incoherently coupled grey soliton pair with $\theta = \pi/3$, $m = 0.2$ and $\rho = 5$ (b) Dependence of FWHM on bias electric field (c) Dependence of FWHM on overlap parameter *M*.

CONCLUSIONS

We have predicted for the first time that MQW planar waveguide structure can support grey soliton pairs. We also study how the self trapping is modified due to the effect of the external electric field and the overlap of the optical mode on the wave guide.

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