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A THEORETICAL STUDY OF LIGHT SOLITON PRODUCED BY SEMICONDUCTOR QUANTUM DOT WAVEGUIDES AND PROPAGATION IN OPTICAL FIBERS

O.P. Swami[1] omg1789@gmail.com
V. Kumar[2] vijendrasaini2009@gmail.com
B. Suthar[3] bhuvneshwer@gmail.com
A.K. Nagar[2] ajaya.nagar@gmail.com

[1] **Government College, Loonkaransar, Rajasthan, India**
[2] **Government Dungar College, Bikaner, Rajasthan, India**
[3] **Government M.L.B. College, Nokha, Rajasthan, India**

Abstract

In this paper, the propagation of light soliton is studied in nonlinear optical fiber. We propose the external excitation of SQD waveguides through an optical source that allows the generation of solitary waves that are propagated through a non-linear optical fiber. The soliton formation is studied theoretically from the non-linear interaction between the external optical excitation and SQDs, considering SQDs as a quantum system of three energy levels. In this study, the Fourier Split-Step (FSS) method is used to solve numerically continuous nonlinear Schrödinger equation (NLSE) to evolution of the soliton pulse emitted by the SQDs inside an optical fiber with real physical parameters. The effect of SQDs density and electric field on the pulse width is also studied. Phase plane portraits are drawn for the stability of soliton in fiber and SQDs using software Matcont

Keywords

Quantum dots, nonlinear optics, optical solitons, nonlinear guided waves

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Introduction. Semiconductor quantum dots (SQDs) are model systems for investigation of nonlinear light-matter interaction have attracted much interest. SQDs are referred to zero-dimensional systems that restrict the movement of charge carriers in the three spatial dimensions, which results in atom like discrete energy spectra and strongly enhanced carrier lifetimes [1]. These atoms like structures have been proposed for the use as qubits in quantum information processing [2] as well as for laser devices [3]. Some of the most recent investigations indicate that this type of heterostructures can undergo abrupt changes in the spectral response with minimal variations in their size and morphology, offering important applications to optics, among which are the lasers of new generations, diodes, light emitters, optical multiplexers, biosensors, spectral tuners, quantum computing, logic gates, among others [4–12]. Due to their large dipole moments reaching values on the order of 10^{-17} esu cm [13], the interaction between SQDs and optical light fields is strongly enhanced in comparison with atomic systems, making them good candidates to study nonlinear optical propagation effects. Nowadays, it has been possible to combine nanostructures with other polymeric materials such as optical fibers, giving rise to nanocomposites, which are generally composed of several phases such as SiO_2, where one or several of its dimensions are found at the nanoscale [14–22]. The optical fibers are important elements for the propagation of light wave signals with water and for the propagation of electromagnetic waves in the optical, ultraviolet and infrared range. In an optical fiber, it is necessary to consider a theory of propagation of waves in dispersive media. Nonlinear Schrödinger equation (NLSE) gives a complete description of a variety of localized non-linear effects that have been extensively studied in various contexts of the sciences and that the theory can link directly with the propagation of intense optical pulses in non-linear optical fibers that give rise to the optical solitons. Although there are many experimental advances in the propagation of solitons in optical fibers, in practice the propagation of solitary pulses to large distances at a commercial level has not been possible due to the different technical functions [23–26]. The study allows us to propose a general model that allows coupling the solitons from the set of quantum dots with specific characteristics in an optical fiber with non-linear optical characteristics. As a result, a numerical simulation is developed to study the evolution of the soliton inside the non-linear optical fiber with the Fourier Split-Step numerical technique with the real parameters associated with the SQD and the optical fiber. Phase planes represent the stability/ instability of solitons.

Theoretical analysis. SQD can confine the movement of charge carriers in all dimensions due to their zero dimensional nanosized structures, which exhibits a discrete energy system. We consider a two-dimensional sheet of inhomogeneously broadened SQDs which forms a transition layer on one of the surfaces of the planar waveguide. The waveguide soliton satisfies the Maxwell – Bloch equations with nonlinear boundary conditions. The purpose of the present article is to theoretically investigate the processes of formation of optical solitons under the condition of SIT in a semiconductor waveguide.

A SQD of three-level energy system (Fig. 1) is considered, whose ground state is $\left|\psi_1\right\rangle$ and has energy $\varepsilon_{\psi_1} = 0.$ The states $\left|\psi_2\right\rangle$ and $\left|\psi_3\right\rangle$ have energies

$\varepsilon_{\psi_2} = h\upsilon_0 = \varepsilon_x + \delta_x/2$ and $\varepsilon_{\psi_2} = h\upsilon_0^l = 2\varepsilon_x + \delta_{xx}$, respectively. Where the quantities $\varepsilon_x = \left(\varepsilon_{\psi_2} + \varepsilon^l_{\psi_2}\right)/2$ and ε_{ψ_3} describe the energies of the single-excitonic and biexcitonic states, respectively.

Energy of exciton fine structure splitting is denoted by $\delta_x = \varepsilon_{\psi_2} - \varepsilon'_{\psi_2}$ and biexciton binding energy is denoted by δ_{xx}; h is Planck constant. The Hamiltonian of system is described by

$$H = H_0 + H_0^l, \tag{1}$$

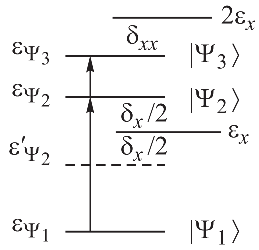

Fig. 1. Schematic diagram of energy structures of semiconductor quantum dots

where $H_0 = h\upsilon_0 |\psi_2\rangle\langle\psi_2| + \frac{1}{2} h\upsilon_0^l |\psi_3\rangle\langle\psi_3|$ is called the Hamiltonian of single excitonic state $|\psi_2\rangle$ and biexcitonic state $|\psi_3\rangle$. Additional term H_0^l in Hamiltonian is occurred due to interaction of light pulse with SQDs and $H_0^l = -\vec{P}\cdot\vec{E}$. During the excitation of the SQDs, an external light source is considered, composed of a linear optical wave polarized high intensity from a laser and we will study the formation of non-linear optical waves that are re-emitted by the SQDs. Figure 2 represents a schematic of a linearly polarized plane wave incident on SQDs.

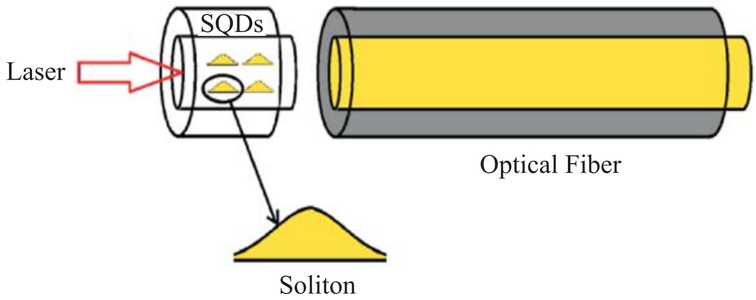

Fig. 2. Schematic arrangement of SQDs and optical fiber with an external light source

In the process, due to the interaction of the light with the SQDs, the light is re-emitted in the form of a non-linear wave with special characteristics that will depend on the morphology of the quantum dot and the incident wave. In the analytical treatment the electric field vector of incident light beam is taken as below

$$\vec{E} = -\vec{e}E, \tag{2}$$

where

$$\vec{e} = \frac{1}{\sqrt{2}}\left(\vec{x} + i\vec{y}\right); \tag{3}$$

$\vec{x}$ and $\vec{y}$ are the unit vector along the x and y axes. The incident light is considered linearly polarised in TE mode and has a width T and angular frequency $\omega \geq T^{-1}$ propagating along z direction and vector of polarization in direction y. When an external light beam interacts with SQDs then secondary dipolar field is produced in same direction as incident field and can be written as

$$-c^2 \frac{\partial^2 \vec{E}}{\partial z^2} + \eta^2 \frac{\partial^2 \vec{E}}{\partial t^2} - \frac{\partial^2 \vec{E}}{\partial x^2} = -4\pi \frac{\partial^2 \vec{P}}{\partial t^2}, \tag{4}$$

where the polarization vector is the following

$$\vec{P}(x, z, t) = \frac{1}{2} n_0 \int g\left(\upsilon_{01}\right)(\mu_{12}\rho_{21} + \mu_{23}\rho_{32})(\upsilon, x, z, t)d\upsilon + c \cdot c \tag{5}$$

and $g\left(\upsilon_{01}\right)$ is a function of the distribution of frequencies; $\upsilon_{01} = \upsilon_0 - \upsilon_1$ is the detuning, η is the refractive index of semiconductor and n_0 is the density of quantum dots; ρ_{ij} are the matrix elements of the density matrix and ρ can be determined from Liouville equation

$$i\hbar\dot{\rho}_{mn} = \sum\left(\langle n|H|l\rangle \rho_{lm} - \rho_{nl}\langle l|H|m\rangle\right), \tag{6}$$

where $n, m, l = 1, 2, 3$.

The electric field of the pulse is considered of the form

$$\vec{E} = \sum_{l=\pm 1} \hat{E}_l \phi_l, \tag{7}$$

where $\hat{E}_l$ is the complex amplitude of slow envelope of the electric field and $\phi_l = e^{il(kz - \upsilon_l t)}$. To guarantee that E is a real number we choose slow envelope approach, it is considered that $\hat{E}_l$ of pulse is very smooth in space and time and can be written as

$$\left|\frac{\partial \hat{E}_t}{\partial t}\right| \ll \upsilon_l \left|\hat{E}_l\right| \tag{8}$$

and

$$\left|\frac{\partial \hat{E}_t}{\partial z}\right| \ll \hat{k}\left|\hat{E}_l\right| \tag{9}$$

then non-linear carrier wave equation can be written as following form

$$\sum_{l=\pm 1}\phi_l\left[l^2\left(c^2k^2-\eta^2\upsilon_1^2\right)\hat{E}_l-2iklc^2\frac{\partial\hat{E}_l}{\partial z}-2il\eta^2\upsilon_1\frac{\partial\hat{E}_l}{\partial t}\right]=$$

$$=-2\pi l^2\upsilon_1^2 n_0\left[\mu_{12}\hat{\rho}_{21}+\mu_{23}\hat{\rho}_{32}\right]e^{i(kx-\upsilon_1 t)}+c\cdot c. \tag{10}$$

The diagonal elements ρ_{12}, ρ_{22} and ρ_{33} give rise to the populations in the states $|\psi_1\rangle$, $|\psi_1\rangle$, and $|\psi_1\rangle$ respectively. Non-diagonal elements $\rho_{mn}(n\neq m)$ contain the relative phase between the states that describe the atomic coherence. In the absence of phase modulation $\hat{E}_l=\hat{E}_{-l}=\hat{E}_l^*=\hat{E}$. Therefore the system of equations for the slowly varying amplitudes

$$\begin{gathered}
i\hbar\dot{\rho}_{11}=\left(\hat{\rho}_{21}^*-\hat{\rho}_{21}\right)\mu_{12}\hat{E};\\
i\hbar\dot{\rho}_{22}=\left(\hat{\rho}_{21}-\hat{\rho}_{21}^*+\delta\hat{\rho}_{32}^*-\delta\hat{\rho}_{32}\right)\mu_{12}\hat{E};\\
i\hbar\dot{\rho}_{33}=\left(\hat{\rho}_{32}-\hat{\rho}_{32}^*\right)\mu_{12}\hat{E};\\
i\hbar\dot{\rho}_{21}=h\left(\upsilon_0-\upsilon\right)\hat{\rho}_{21}-\left[\left(\hat{\rho}_{11}-\hat{\rho}_{22}\right)+\delta\hat{\rho}_{31}\right]\mu_{12}\hat{E};\\
i\hbar\dot{\rho}_{32}=h\left(\upsilon_0^l-\upsilon_0-\upsilon\right)\hat{\rho}_{32}+\left[\delta\left(\hat{\rho}_{33}-\hat{\rho}_{22}\right)+\hat{\rho}_{31}\right]\mu_{12}\hat{E};\\
i\hbar\dot{\rho}_{31}=h\left(\upsilon_0^l-2\upsilon\right)\hat{\rho}_{31}+\left[\hat{\rho}_{32}-\delta\hat{\rho}_{21}\right]\mu_{12}\hat{E}.
\end{gathered}\tag{11}$$

In the above equations, rotating wave approximation has been applied and $\delta=\mu_{23}/\mu_{12}$. The solution of the system of equations (11), allows the calculation of the elements of the right side of equation (10). As the diagonal elements of matrix give rise the populations in the states, for ground state $\rho_{11}=1$, $\rho_{22}=0$ and $\rho_{33}=0$, the equations (11) take the form

$$\begin{aligned}
\hat{\rho}_{21}&=\frac{i}{2d^3}\left(\sin(2Ad)+2\delta^2\sin(Ad)\right);\\
\hat{\rho}_{32}&=\frac{i\delta}{2d^3}\left(\sin(2Ad)-2\sin(Ad)\right),
\end{aligned}\tag{12}$$

where $d=\sqrt{1+\delta^2}$ and $A=\dfrac{2\pi\mu_{12}}{h}\displaystyle\int_{-\infty}^{t}E(z,t)dt$, which is called the area of nonlinear optical pulse.

Applying dispersion law for linear wave guide modes, wave equation (4) will take following form

$$(2\psi)_{tt}+\frac{c}{\eta}(2\psi)_{zt}+\frac{2\pi^2\upsilon\mu_{12}^2 n_0}{h\eta^2}\sin(2\psi)=0, \tag{13}$$

where

$$\psi=Ad. \tag{14}$$

Equation (13) can be written in the form of electric field as below

$$\left(\frac{d\hat{E}}{d\xi}\right)=\frac{\hat{E}^2}{T^2}-\frac{\pi^2\mu_{12}^2\hat{E}^4}{h^2} \tag{15}$$

with $\xi = t - z/V$ and constant phase velocity V. The solution of equation (15) for the envelope function has the form (16)

$$\hat{E}=\frac{h}{\sqrt{2}\pi\mu_{12}T}\sec h\left(\frac{\xi}{T}\right), \tag{16}$$

which is well-known Solitonic solution, with width of the pulse remitted by SQD,

$$T=\sqrt{\frac{h\eta^2}{4\pi^2\upsilon n_0\mu_{12}^2}\left(\frac{c-\eta V}{\eta V}\right)}. \tag{17}$$

These soliton became stable when the speed of light (phase velocity) in SQD media c/η remains greater than the phase velocity V.

Results and discussion. The theoretical result of wave equation (4) is solitonic. In other words, the excitation of SQDs from an intense non-linear wave can produce optical solitons as a result of light-SQDs interaction. During the non-linear interaction process, the SQDs are considered as a three-level energy quantum system, in which the optical transitions are given from the ground state to the biexcitonic and excitonic states. The allowed transitions between the ground state and the biexcitonic and excitonic states have very low dipole moment rather than the transition between the ground state and the background of the exciton band. On the other hand, the characteristics of the light re-emitted by the sheets of quantum dots in the form of optical solitons will depend on the intensity of the incident light, whose minimum value to form the optical solitons could be determined specifically depending on the nature of the SQDs. In this way, the soliton remitted will depend on the refractive index of the semiconductor η, the dipole moment corresponding to the transitions between the ground state and the excitonic state or between the biexcitonic state and the excitonic state μ_{12}, taking into account that we have considered an energy system of three equidistant levels. On the other hand, there is also a dependence on the external excitation frequency υ and the density of quantum dots n_0. For the study of the propagation of short optical pulses through non-linear optical fibers, the non-linear Schrodinger equation (NLSE) is used, which takes into account the effects of the length of the fiber, the dispersion effect of group speed and non-linear optical effects as a consequence of the high intensity of light. The Fourier Split-Step method is a pseudo-spectral technique that is extremely useful due to its rapid and good accuracy in calculations. In general, this method obtains an approximate solution of the propagation equation, assuming that dispersion effects and non-linear effects act independently along the fiber in very small steps. This technique was used to simulate the evolution of solitaires that are re-emitted by the SQD.

In the results, it is observed that the peak intensity and pulse width decays at higher density values. An explanation to this effect can realize that it can increase the QDs per unit of volume, it can increase the effects of the absorption of the SQD, re-emitting with a lower intensity. On the other hand, we must bear in mind that the mathematical modelling proposed requires that the density n_0 of quantum dots is lower, so that the interactions of QDs in the Hamiltonian are omitted. For the simulation we have proposed SQDs with pyramidal morphology of InAs manufactured with a cylindrical symmetry with the parameters $\eta = 2.11$, $\mu_{12} = 1.92 \cdot 10^{-28} C - m$ and $V = 1.37 \cdot 10^{8}$ m/s.

Figures 3, *a–h* represent the simulation of solitons created by SQDs arrays with different densities of SQDs according to following Table 1. It is clear from equation (17) that pulse width is decreased as n_0 increased. In many optical fiber communications systems FWHM is required 1 ps or below, which can be achieved by increasing the density of SQDs. Simulated data also summarised in Table 1.

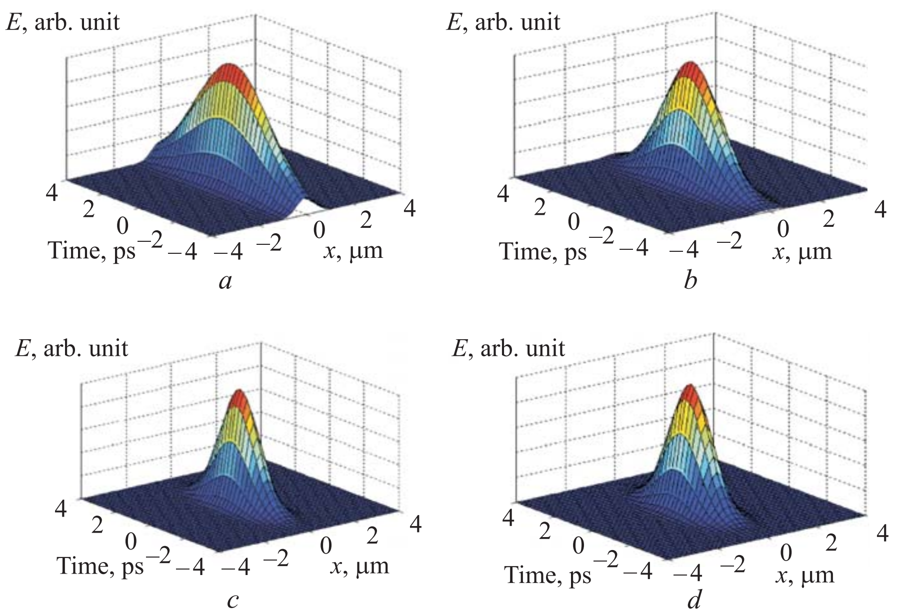

Fig. 3 (part 1). Simulation of soliton generated by SQDs system with different densities of QDs:

a) $n_0 = 2.59 \cdot 10^{12}$ cm^{-3}; *b*) $n_0 = 5.16 \cdot 10^{12}$ cm^{-3}; *c*) $n_0 = 8.00 \cdot 10^{12}$ cm^{-3}; *d*) $n_0 = 14.22 \cdot 10^{12}$ cm^{-3}

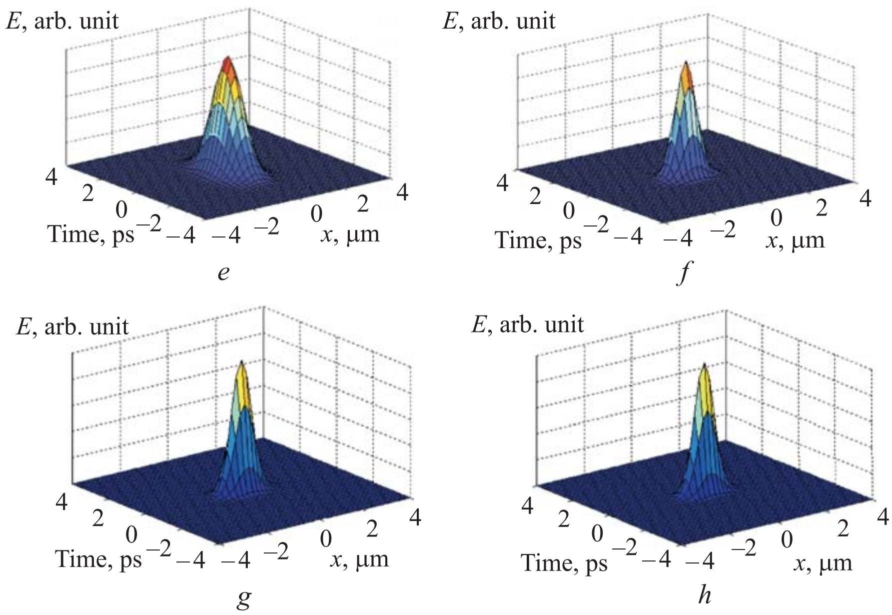

Fig. 3 (part 2). Simulation of soliton generated by SQDs system with different densities of QDs:
e) $n_0 = 23.35 \cdot 10^{12}$ cm^{-3}; *f*) $n_0 = 64.46 \cdot 10^{12}$ cm^{-3}; *g*) $n_0 = 88.50 \cdot 10^{12}$ cm^{-3}; and *h*) $n_0 = 99.12 \cdot 10^{12}$ cm^{-3}

Table 1

Relation between the density of SQDs and FWHM of solitons

No.	Density of SQD (10^{12}, cm^{-3})	FWHM, ps
1	2.59	6.18
2	5.16	4.38
3	8.00	3.52
4	14.22	2.64
5	23.35	2.06
6	64.46	1.24
7	88.50	1.12
8	99.12	1.00

Figures 4, *a*–*h* represent that the soliton width as determined from equation (16) is decreased as electric field *E* is increased. According to Table 2, it is clear that when amplitude of electric field of wave is increased then the FWHM of TM mode of wave is decreased, which is basic requirements in many optical fiber communications systems.

Figures 5, *a*–*d* represent the evolution of soliton profiles in SQDs for different values of refractive index of material of SQDs and their respective soliton profiles as taking $V = 1.37 \cdot 10^8$ m/s constant.

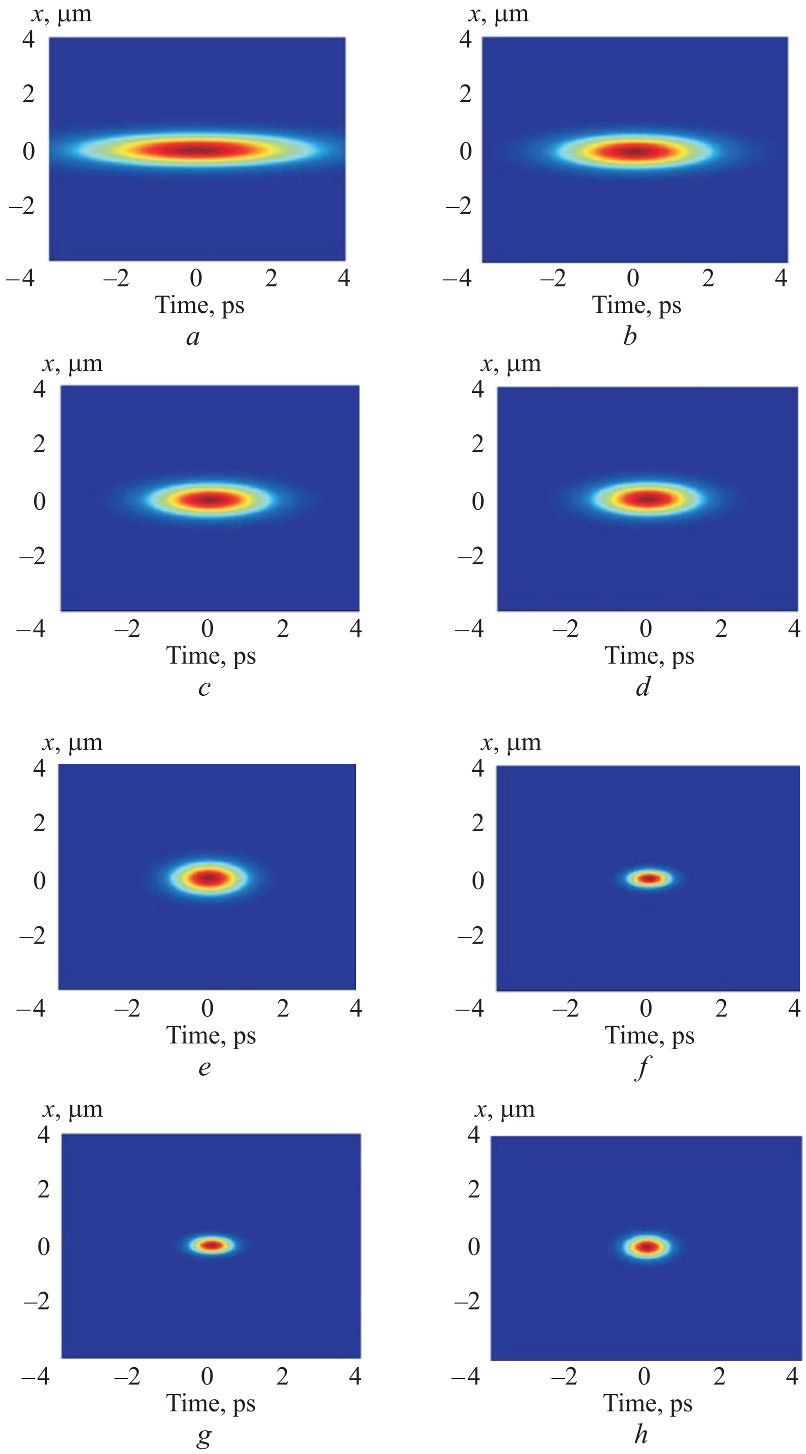

Fig. 4. Transverse view of soliton in SQD with electric field:

a) $E = 6.00 \cdot 10^8$ V/m; *b*) $E = 4.38 \cdot 10^8$ V/m; *c*) $E = 3.46 \cdot 10^8$ V/m; *d*) $E = 2.60 \cdot 10^8$ V/m; *e*) $E = 2.10 \cdot 10^8$ V/m; *f*) $E = 1.18 \cdot 10^8$ V/m; *g*) $E = 1.14 \cdot 10^8$ V/m; *h*) $E = 1.00 \cdot 10^8$ V/m

Table 2

Relation between the strength of electric field and FWHM of TM mode of solitons

No.	Amplitude of electric field, 10^8, V/m	FWHM, ps
1	0.96	6.26
2	1.37	4.38
3	1.73	3.46
4	2.30	2.60
5	2.86	2.10
6	5.08	1.18
7	5.26	1.14
8	6.00	1.00

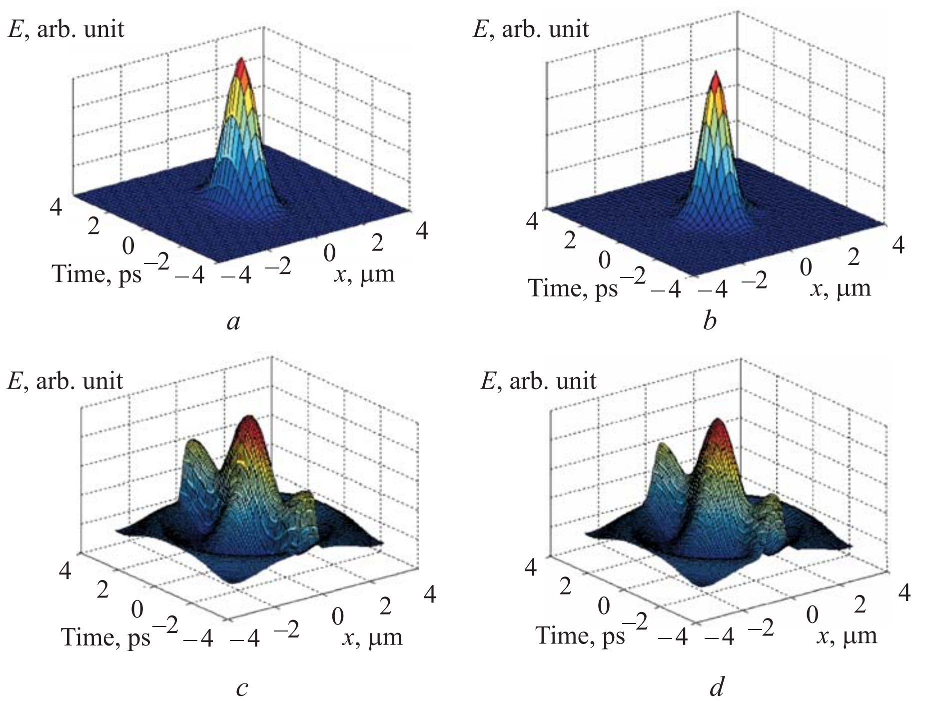

Fig. 5. Simulation of soliton generated by SQDs system with different refractive indices of QDs:
a) 2.05; *b*) 2.11; *c*) 2.40; *d*) 3.50 taking $V = 1.37 \cdot 10^8$ m/s

Figures 6, *a*–*d* represent the phase plane portraits for Fig. 5, *a*–*d* respectively for stability analysis. Closed limit cycles of phase plane structures clearly indicate to stable soliton while a spiral like phase plane structures indicates to instability of soliton. It is clear from below table that when c/η became less than V, then soliton became unstable. It is summarised in Table 3.

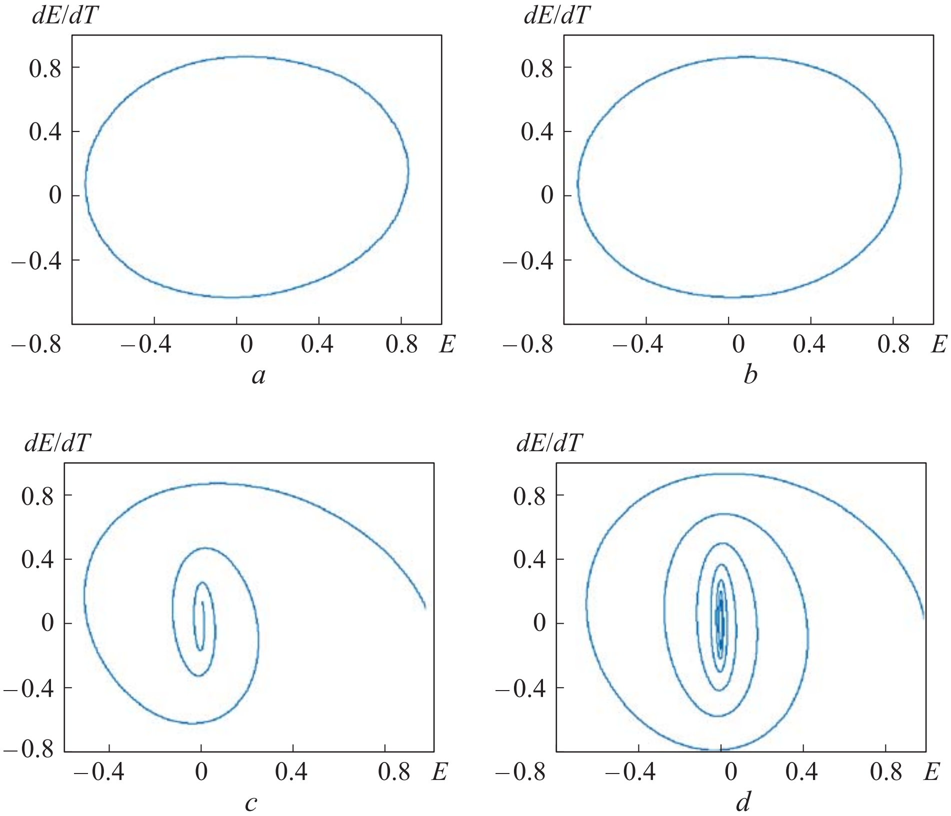

Fig. 6. Phase plane portraits for solitons for different refractive indices of QDs: *a*) 2.05; *b*) 2.11; *c*) 2.40; *d*) 3.50 taking $V = 1.37 \cdot 10^8$ m/s

Table 3

Relation between refractive index of material of SQDs and (in)stability of soliton

No.	Refractive index η of SQDs	c/η, 10^{-8}, m/s	Nature of soliton
1	2.05	1.46	Stable
2	2.11	1.42	Stable
3	2.40	1.25	Unsable
4	3.50	0.86	Unstable

Figure 7*a* represents the soliton profiles for input pulse in optical fiber and the Fig. 7*b* represents the pulse in optical fiber after travelling the distance of z = 1000 m using Fourier Split-Step method with the parameters: nonlinear fiber parameter $\gamma = 0.32$ W/m, fiber attenuation constant $\alpha = 0.2$ dB/km and second order dispersion coefficient $\gamma = -2 \cdot 10^{-26}$ s^2/m.

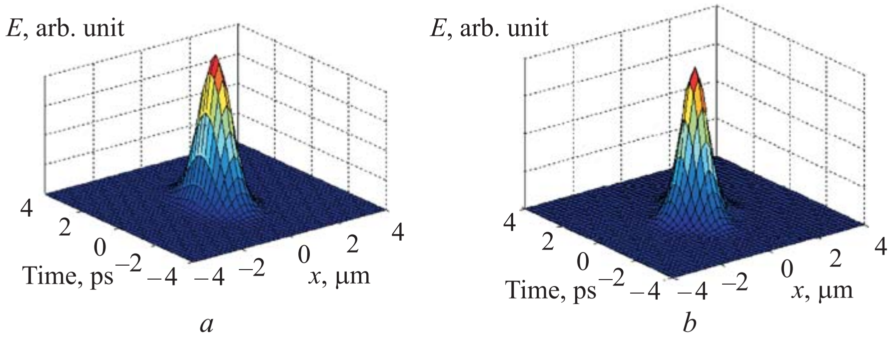

Fig. 7. Evolution of soliton through nonlinear optical fiber at $z = 0$ (*a*) and $z = 1000$ m (*b*)

Conclusion. In this paper, it is investigated to produce solitonic pulses in three level semiconductor quantum dots embedded in nonlinear optical fibers for propagation of fields without losses over long distances. A theoretical formulaton is computed in this work, would guarantee the generation of solitonic optical pulses, which would be modulated according to the amplitude of the pulse and its morphology. The FWHM of solitonic pulses can be modulated according to densities of SQDs and field intensity. Moreover the stability/instability of generated solitons is dependent on the refractive indices of SQDs material, which also studied. Likewise, it is proposed the manufacture of this type of nanostructures with different morphologies inserted in optical fibers that allow the propagation of solitons without losses over the long distances.

REFERENCES

[1] Pavesi L., Dal Negro L., Mazzoleni C., et al. Optical gain in silicon nanocrystals. *Nature*, 2000, vol. 408, pp. 440–444. DOI: 10.1038/35044012

[2] Hu Y.M., Yang W.L., Feng M., et al. Distributed quantum-information processing with fullerene-caged electron spins in distant nanotubes. *Phys. Rev. A*, 2009, vol. 80, iss. 2, pp. 022322 (1–13). DOI: https://doi.org/10.1103/PhysRevA.80.022322

[3] Máximo L., Mendez Victor H. Autoensamblado de puntos cuánticos. *Cinvestav*, 2008, vol. 27, pp. 44–49.

[4] Hanewinkel B., Knorr A., Thomas P., et al. Optical near-field response of semiconductor quantum dots. *Phys. Rev B*, 1997, vol. 55, iss. 20, pp. 13715 (1–10). DOI: https://doi.org/10.1103/PhysRevB.55.13715

[5] Aknmanov S.A., Visloukh V.A., Chirkin A.S. Optics of femtosecond laser pulses. New York, American Institute of Physics, 1992.

[6] Klimov V.I., Mikhailovsky A.A., Xu S., et al. Optical gain and stimulated emission in nanocrystal quantum dots. *Science*, 2000, vol. 290, pp. 314–317.

[7] Yang W.X., Chen A.X., Lee R.K., et al. Matched slow optical soliton pairs via biexcition coherence in quantum dots. *Phys. Rev. A*, 2011, vol. 84, iss. 1, pp. 013835 (1–11). DOI: https://doi.org/10.1103/PhysRevA.84.013835

[8] Hu L., Wu H., Du L., et al. The effect of annealing and photoactivation on the optical transitions of band-band and surface trap states of colloidal quantum dots in PMMA. *Nanotechnology*, 2011, vol. 22, pp. 125202 (1–8).
DOI: 10.1088/0957-4484/22/12/125202

[9] Adamashvili G.T., Weber C., Knorr A. Optical nonlinear waves in semiconductor quantum dots: solitons and breathers. *Phys. Rev. A,* 2007, vol. 75, iss. 6, pp. 063808 (1–9). DOI: https://doi.org/10.1103/PhysRevA.75.063808

[10] Newell A.C. Solitons in mathematics and physics. Philadelphia, Society for Industrial and Applied Mathematics, 1985.

[11] Ajayan P.M., Schadler L.S., Braun P.V. Nanocomposite science and technology, Weinheim, Germany, Wiley, 2003.

[12] Rothenberg J.E., Grischkowsky D., Balant A.C. Observation of the formation of the 0π pulse. *Phys. Rev. Lett.*, 1984, vol. 53, iss. 5, pp. 552–555.
DOI: https://doi.org/10.1103/PhysRevLett.62.531

[13] Chen M., Kaup D.J., Malomed B.A. Three-wave solitons and continuous waves in media with competing quadratic and cubic nonlinearities. *Phys. Rev. E*, 2004, vol. 69, iss. 5, pp. 056605 (1–17). DOI: https://doi.org/10.1103/PhysRevE.69.056605

[14] Bimberg D., Grundmann M., Ledentsov N.N. Quantum dot heterostructures. Chichester, Wiley, 1999.

[15] Schneider S., Borri P., Langbein W., et al. Self-induced transparency in InGaAs quantum-dot waveguides. *Appl. Phys. Lett.*, 2003, vol. 83, pp. 3668–3670.
DOI: 10.1063/1.1624492

[16] Panzarini G., Hohenester U., Molinari E. Self-induced transparency in semiconductor quantum dots. *Phys. Rev. B,* 2002, vol. 65, iss. 16, pp. 165322 (1–6).
DOI: https://doi.org/10.1103/PhysRevB.65.165322

[17] Klimov V.I. Nanocrystal quantum dots. *Los Alamos Science*, 2003, no. 28, pp. 214–220.

[18] Chen Y., Herrnsdorf J., Guilhabert B., et al. Colloidal quantum dot random laser. *Opt. Express*, 2011, vol. 19, iss. 4, pp. 2996–3003.
DOI: https://doi.org/10.1364/OE.19.002996

[19] Akhmediev N., Ankiewicz A. Solitons: nonlinear pulses and beams. London, Chapman and Hall, 1997.

[20] Kevrekidis P.G., Rasmussen K.O., Bishop A.R. Two-dimensional discrete breathers: construction, stability, and bifurcations. *Phys. Rev. E*, 2000, vol. 61, iss. 2, pp. 2006 (1–7). DOI: https://doi.org/10.1103/PhysRevE.61.2006

[21] Blum K. Density matrix theory and applications. New York, Plenum Press, 1996.

[22] Adamashvili G.T., Knorr A., Weber C. Optical solitons in semiconductor quantum dots. *Eur. Phys. J. D,* 2008, vol. 47, iss. 1, pp. 113–117.
DOI: 10.1140/epjd/e2008-00042-2

[23] Malomed B.A., Kevrekidis P.G. Discrete vortex solitons, *Phys. Rev. E*, 2001, vol. 64, iss. 2, pp. 026601 (1–6). DOI: https://doi.org/10.1103/PhysRevE.64.026601

[24] Lamb Jr.G.L. Elements of soliton theory. New York, Wiley, 1980.

[25] Lamb Jr.G.L. Optical waves in crystals. New York, Wiley, 1980.

[26] Öster M., Johansson M. Stable stationary and quasiperiodic discrete vortex breathers with topological charge *S* = 2. *Phys. Rev. E*, 2006, vol. 73, iss. 6, pp. 066608 (1–6). DOI: https://doi.org/10.1103/PhysRevE.73.066608

Swami O.P. — M. Sc. (Phys.), Research Scholar (Phys.), Assist. Professor of Physics, Department of Physics, Government College (Loonkaransar, Bikaner, Rajasthan, 334603 India).

Kumar V. — M. Phil. (Phys.), Research Scholar (Phys.), Medical physicist and radiation safety officer in radiation oncology, Command Hospital Air Force (Bangalore, Karnataka, 560014 India).

Suthar B. — Ph. D. (Phys.), Assist. Professor of Physics, Department of Physics, Government M. L. B. College (Nokha, Bikaner, Rajasthan, 334803 India).

Nagar A.K. — Ph. D. (Phys.), Assoc. Professor of Physics, Department of Physics, Government Dungar College (Bikaner, Rajasthan, 334001 India).

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