Çankırı Karatekin Üniversitesi
Karatekin Üniversitesi Fen Fakültesi Dergisi
ISSN:2980-0730
Yıl:**2024**, Clt:**03**, Sayı:**1**, Sayfa:**01-11**

Çankırı Karatekin University
Karatekin University Journal of Science
ISSN:2980-0730
Year:**2024**, Vol:**03**, Issue:**1**, Pages:**01-11**

Electronic and optical properties of a screened donor impurity in a two-dimensional quantum dot under THz laser field

THz lazer alanı altında iki boyutlu bir kuantum noktasında perdelenmiş donör safsızlığının elektronik ve optik özellikleri

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Eser Bilgisi / Article Info
Araştırma Makalesi / Research Article

Geliş tarihi / Received
06.09.2023
Kabul tarihi / Accepted
30.11.2023
Yayın tarihi / Published
31.12.2024

Anahtar kelimeler
Kuantum nokta, THz lazer, Optik özellikler, Perdelenmiş Coulomb safsızlık

Keywords
Quantum dot, THz laser, Optical properties, Screened Coulomb impurity

Abstract

Investigation of the intense THz laser field-related optical response of a two-dimensional parabolic quantum dot with on-center screened Coulomb impurity has been performed within the framework of high-frequency Floquet theory. The energy spectrum and wave functions of the system are obtained by using the finite element method while optical absorption coefficients and refractive index changes are calculated based on the compact-density matrix approach. Our results highlight the fact that action of intense laser field on the system leads to important modifications in the electronic and optical characteristics. Also, we found that the peak amplitude and position of optical coefficients can be adjusted by altering screening parameter and confinement strength. The controllability of these features could be useful for optimization of the optoelectronic devices.

Özet

Merkezde perdelenmiş Coulomb safsızlığına sahip iki boyutlu bir parabolik kuantum noktasının yoğun THz lazer alanına bağlı optik cevabının araştırılması, yüksek frekanslı Floquet teorisi çerçevesinde gerçekleştirilmiştir. Sistemin enerji spektrumu ve dalga fonksiyonları sonlu elemanlar yöntemi kullanılarak elde edilirken, optik soğurma katsayıları ve kırılma indisi değişiklikleri kompakt yoğunluk matrisi yaklaşımına göre hesaplanmaktadır. Sonuçlarımız, yoğun lazer alanının sistem üzerindeki etkisinin elektronik ve optik özelliklerde önemli değişikliklere yol açtığını vurgulamaktadır. Ayrıca, optik katsayıların pik genliği ve konumunun, perdeleme parametresi ve hapsetme şiddetinin değiştirilerek ayarlanabileceğini bulduk. Bu özelliklerin kontrol edilebilirliği optoelektronik cihazların optimizasyonunda faydalı olabilir.

1. INTRODUCTION

In recent years, studies on the electronic and optical properties of two-dimensional quantum dots (2DQDs), which possess extraordinary electronic and optical properties, have become important not only from the aspect of fundamental science but also for device applications (Barseghyan, 2015; Huang, 2013; Kumar, 2023; Mikhail, 2017; Shojaei, 2015). In particular, the physics of impurity states in QDs has become an important subject due to the modification of electronic and optical properties associated with impurity(Wang, 2019). Therefore, many researchers have focused on the intriguing impurity-related properties of QDs and have broadcasted a number of publications (Bera, 2016; Hashemi, 2015; Vala, 2017). Xie have investigated both the electric field and confinement effects on the impurity-related states and nonlinear optical rectification of a parabolic disc-like QD (Xie, 2009). Al-Hayek

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and Sandouqa have obtained the hydrogenic-like impurity binding energy of a Gaussian QD by using the method of the shifted 1/N expansion (AlHayek, 2015). The controllability of electronic properties and optical characteristics in an impurity doped quantum disc by magnetic field has been demonstrated by Niculescu and co-workers (Niculescu, 2017).

In most of the studies, the impurity potential in QDs is usually described by Coulomb potential (CP) (Coden, 2017; Kirak, 2022; Sheng, 2016) or Gaussian impurity (Ganguly, 2017; Halonen, 1996; Sarkar, 2016), while the Screened Coulomb (or the Debye-Yukawa) potential (SCP) (Varshni, 2001) is less preferred for impurity modeling. Although less studied in QDs, the SCP, which is a short-range potential and tends faster to zero than CP at $|\mathbf{r}| \to \infty$ limit (AlAhmadi, 2012; Poszwa, 2014), has been widely implemented in different areas such as atomic physics, nuclear physics, plasma physics, semiconductors, and quantum chemistry (Brum, 1984; Chang, 1988; Jiao, 2014; Soylu, 2008; Taseli, 1995). For instance, Ping and Jiang have investigated the effects of the charge screening on the exciton binding energy in GaAs-Al_xGa_{1-x} quantum wells (Ping, 1993). Villalba and Pino have presented the energy levels of a two-dimensional screened hydrogenic donor under a constant magnetic field (Villalba, 2002). They showed that the strength of screening parameter is considerably effective in consisting of the bounded states in 2D-screened hydrogen atom.

On the other hand, another important topic that is studied extensively is the effect of intense THz laser field (ITLF) on the behavior of impurity states in nanostructures. Due to the ability of ITLF on adjusting and controlling of electronic and optical properties of nanostructures, a great number of works have been reported by researchers (Aktas, 2016; Chakraborty, 2018; Ungan, 2019; Vinasco, 2019). Bejan and Niculescu have researched the influence of ITLF on the electronic and optical properties in an asymmetric double quantum dots (Bejan, 2016). Theoretical results given in Ref. (Brandi, 2004) show that the binding energies of donor impurities are affected by the intensity of the laser. The research of photoionization cross-section and impurity binding energy in GaAs-GaAlAs spherical quantum dots under electric and intense laser fields have been investigated by Burileanu and they found that increment in the electric and laser field intensities leads to diminishment in the magnitude of impurity binding energy (Burileanu, 2014). The other important research related to the effect of THz laser field on the shallow-donor impurity binding energy in GaAs semiconductors has been performed by Wang et al. and the obtained results show that the binding and transition energies depend on the laser field intensity and can be changed by tuning laser intensity (Wang, 2017).

As can be seen from the literature, many studies have been conducted on the optical and electronic properties of laser-driven QDs which include hydrogenic or Gaussian impurity. However, the effect of ITLF on the optical response of a 2DQD with an on-center screened Coulomb impurity has been not examined so far. The goal of this work is to investigate the electronic and optical properties of a 2DQD with impurity defined by SCP and irradiated by a THz laser. The structure of this paper is as follows: The theoretical framework is described in Section 2 and Section 3 is dedicated to discuss of the obtained results. Finally, a brief conclusion is given in Section 4.

2. MATERIAL AND METHOD

In this paper, we investigate the THz laser effect of an on-center donor impurity in a two-dimensional parabolic QD system. Presence of an impurity is described with SCP given as $V_{SC} = -e^{-\lambda r}/r$ where λ is screening parameter characterizing the shielding of the impurity ions. We assume that the system is irradiated by a non-resonant, monochromatic, circularly polarized ITLF of frequency Ω. Within the framework of non-perturbative theory, in the high-frequency regime the motion of electron is specified by the time-averaged dressed potential $\langle V_d(\mathbf{r}, \alpha_0)\rangle = \frac{1}{T}\int_0^T V(\mathbf{r} + \boldsymbol{\alpha}(t))dt$ where $T = 2\pi/\Omega$ is the period of ITLF. Here $\boldsymbol{\alpha}(t) = \alpha_0(\hat{x}\cos\Omega t + \hat{y}\sin\Omega t)$ corresponds to the motion of the electron in the ITLF and the $\alpha_0 = eA_0/m^*\Omega$ is the laser-dressing intensity parameter. Time-independent Schrödinger equation governing the effects of high-frequency radiation for the zeroth Floquet component (φ_{nm})

with corresponding quasienergy (ε_{nm}) is given:

$$\left[\frac{\mathbf{p}^2}{2m^*} + \langle V_{dP}(r,\alpha_0)\rangle + \langle V_{dSC}(r,\alpha_0)\rangle\right]\varphi_{nm}(r) = \varepsilon_{nm}\varphi_{nm}(r)\ . \tag{1}$$

Here the radial and magnetic quantum numbers are depicted by n and m, V_{dP} and V_{dSC} corresponds to the laser-dressed form of parabolic confinement and screened Coulomb impurity potentials, respectively. In this study, we have numerically carried out the calculation of eigen energies with corresponding eigen functions by using one-dimensional finite element method (FEM) based on Galerkin approach. This approach identified in a weak formulation is a variational expansion method and the basis functions are local, piecewise polynomials in real space. For the survey of the optical response of the system, we have considered the dipole transitions allowed only between states satisfying the selection rule $\Delta m = \pm 1$. Therefore, we have selected the energy levels and the wave functions participating in the transitions to be $E_0 = \varepsilon_{00}$, $E_1 = \varepsilon_{11}$ and $\psi_0 = \varphi_{00}$, $\psi_1 = \varphi_{11}$.

The linear and third-order nonlinear optical absorption coefficients (OACs) for intersubband transitions are obtained by means of the compact density matrix approach and iterative scheme:

$$\alpha^{(1)}(\omega) = \omega\sqrt{\frac{\mu}{\epsilon_r}}\frac{\sigma_s|M_{10}|^2\hbar\Gamma_0}{(E_{10}-\hbar\omega)^2+(\hbar\Gamma_0)^2} \tag{2}$$

$$\begin{aligned}\alpha^{(3)}(\omega,I) &= -\omega\sqrt{\frac{\mu}{\epsilon_r}}\left(\frac{I}{2n_r\epsilon_0 c}\right)\frac{\sigma_s\hbar\Gamma_0|M_{10}|^2}{[(E_{10}-\hbar\omega)^2+(\hbar\Gamma_0)^2]^2}\\ &\quad\times\Big\{4|M_{10}^2| - |M_{11}-M_{00}|^2\\ &\quad\times\frac{\left[3E_{10}^2 - 4E_{10}\hbar\omega + \hbar^2(\omega^2-\Gamma_0^2)\right]}{E_{10}^2+(\hbar\Gamma_0)^2}\Big\},\end{aligned} \tag{3}$$

and the total OAC can be written as $\alpha(\omega,I) = \alpha^{(1)}(\omega) + \alpha^{(3)}(\omega,I)$. Here ϵ_0 and μ are the electric and magnetic permeability, σ_s is the carrier density, I is the intensity of the incident light with x-polarization, n_r is the refractive index of medium, c is the vacuum speed of light, E_{10} denotes the transition energy between the states, $M_{ij} = |\langle\psi_i|er\cos\phi|\psi_j\rangle|$ $(i,j=0,1)$ are the off-diagonal matrix elements of the dipole moment and $\Gamma_0 = 1/T_0$ is phenomenological operator.

The expressions of linear and the third-order nonlinear relative refractive index changes (RICs) are given by, respectively:

$$\frac{\Delta n^{(1)}(\omega)}{n_r} = \frac{1}{2n_r^2\epsilon_0}|M_{10}|^2\sigma_s\left[\frac{E_{10}-\hbar\omega}{(E_{10}-\hbar\omega)^2+(\hbar\Gamma_0)^2}\right] \tag{4}$$

and

$$\begin{aligned}\frac{\Delta n^{(3)}(\omega,I)}{n_r} &= -\frac{\mu c}{4n_r^3\epsilon_0}|M_{10}|^2\frac{\sigma_s I}{[(E_{10}-\hbar\omega)^2+(\hbar\Gamma_0)^2]^2}\\ &\quad\times\big[4(E_{10}-\hbar\omega)|M_{10}|^2\\ &\quad-\frac{(M_{11}-M_{00})^2}{E_{10}^2+(\hbar\Gamma_0)^2}\{(E_{10}-\hbar\omega)\\ &\quad\times\left[E_{10}(E_{10}-\hbar\omega)-(\hbar\Gamma_0)^2\right]\\ &\quad-(\hbar\Gamma_0)^2(2E_{10}-\hbar\omega)\}\big]\,.\end{aligned} \tag{5}$$

The total magnitude of the RIC is written as $\Delta n(\omega,I)/n_r = \Delta n^{(1)}(\omega)/n_r + \Delta n^{(3)}(\omega,I)/n_r$.

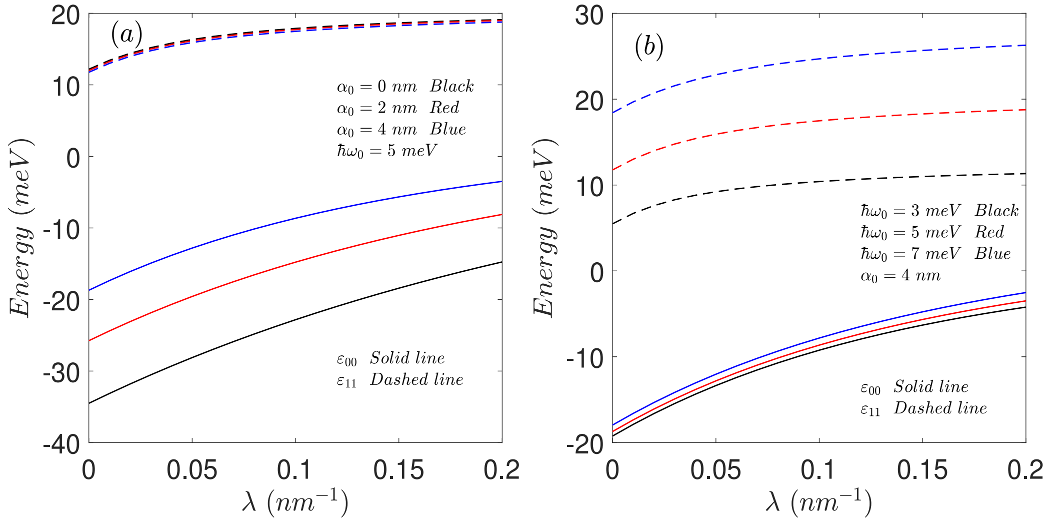

Fig. 1. Variation of energies of E_0 and E_1 as a function of the screening parameter for different values of (a) laser-dressing parameter and (b) confinement strength.

3. RESULTS

In this section, we present and discuss the numerical results concerning the influence of THz laser field on a typical GaAs quantum dot structure with an on-center screened impurity. The physical parameters used in our calculations are: $m^* = 0.067\,m_0$ (m_0 being the free electron mass), charge density of $\sigma_s = 5 \times 10^{24}\ m^{-3}$, $T_0 = 0.14$ ps, $\mu = 4\pi \times 10^{-7}$ Hm^{-1}, $n_r = 3.2$ and $I = 1.5 \times 10^{10}$ W/m^2.

Before discussing the optical response of the system, it would be beneficial to investigate the effect of screening parameter on the energy states. Hence, the dependence of energies E_0 and E_1 on $\lambda-$parameter for several values of laser-dressing parameter and confinement strength is presented in Fig. 1. As is apparent from Fig. 1 (a), the increase of α_0 leads to a significant rise in the E_0 whereas E_1 is less affected. In Fig. 1 (b), we can clearly see that augmentation in $\hbar\omega_0$ gives cause for a remarkable increase in E_1 while inducing relatively less increase in the ground-state energy. As is seen from both figures, the greater values of $\lambda-$screening parameter bring about a notable enhancement in the energies.

In attempt to understand the behavior of the ground-state binding energy of the laser-dressed system with screened Coulomb impurity, in Fig. 2 we present the variation of binding energy as a function of laser-dressing parameter for three values of λ and $\hbar\omega_0$. Binding energy is defined by $E_b = E_0^0 - E_0$ where E_0^0 states the ground state energy in the absence of impurity. Fig. 2 (a) displays an appreciable diminishment in the magnitude of binding energy for higher values of λ. Increment of screening effect brings about weakening interaction between impurity and electron which explains the behavior in Fig. 2 (a). On the other hand, strengthening in confinement potential brings about an increase in the binding energy as seen from Fig. 2 (b). The physical reason can be explained by the fact that the greater values of $\hbar\omega_0$ give rise to more localized impurity-related states because of stronger quantum confinement and increment of absolute Coulomb interaction. Moreover, from Fig. 2 (a) and (b) we observe that the magnitude of impurity binding energy demonstrates a remarkable decline with increasing laser-dressing parameter owing to increment in the electron-impurity distance, which causes weakening in the strength of the Coulomb interaction.

The investigation of the influences of λ and $\hbar\omega_0$ on the dipole matrix element ($|M_{10}|$) is important for better understanding of the optical response of the system under ITLF. Therefore, in Fig. 3 we exhibit the change of magnitude of $|M_{10}|$ as a function of α_0 for different values of λ and $\hbar\omega_0$. It is clear from Fig. 3 (a) that the magnitude of $|M_{10}|$ showing an increasing behavior up to specific value of α_0 is followed by a decrease. In addition, the augmentation of $\lambda-$parameter leads to an increment in the absolute value of $|M_{10}|$. Fig. 3 (b) depicts that the dipole matrix element declines considering higher values of $\hbar\omega_0$. In this figure, remarkable observation is that the magnitude of $|M_{10}|$ enhances

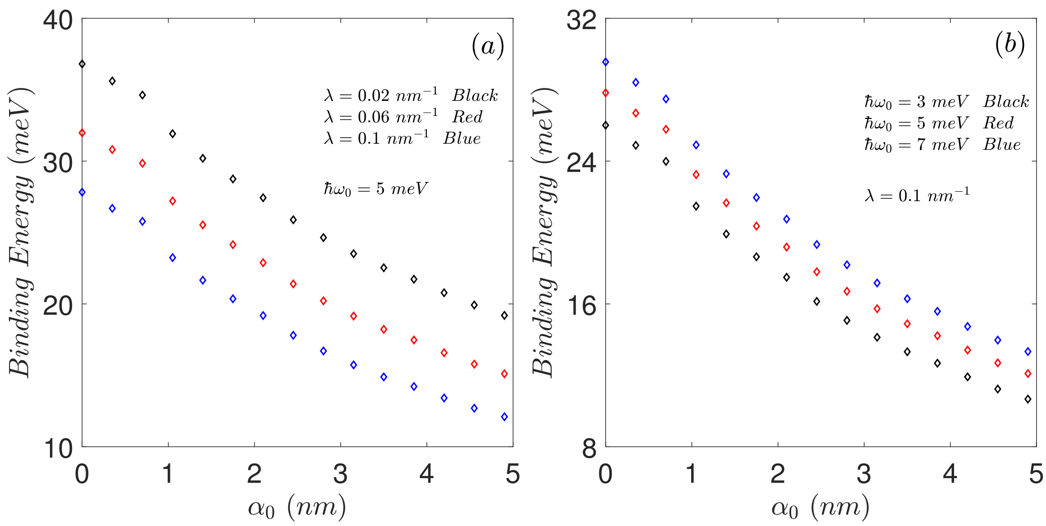

Fig. 2. Binding energy as a function of laser-dressing parameter for different values of (a) $\lambda-$parameter for confinement of 5 meV, (b) the confinement strength for a fixed $\lambda = 0.1$ nm^{-1}.

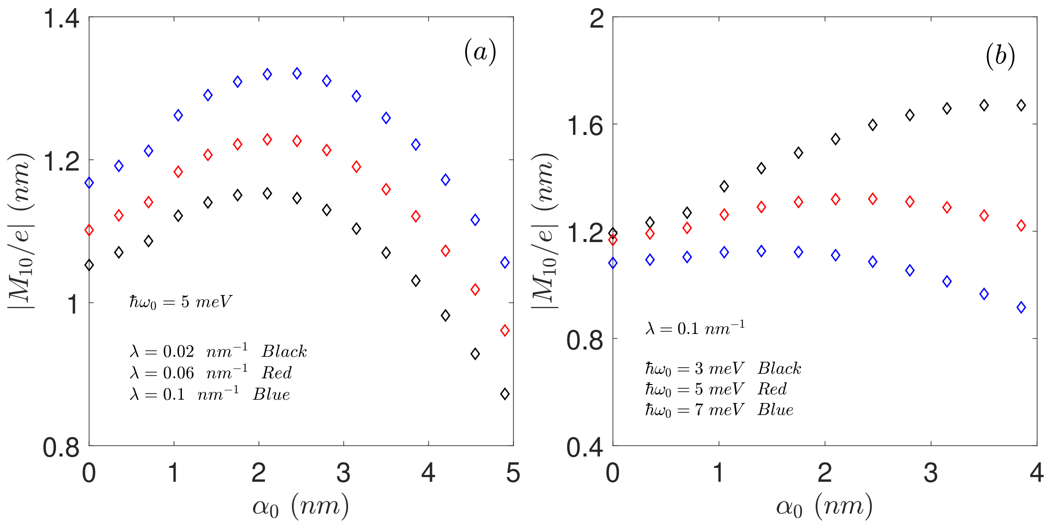

Fig. 3. Plot of $|M_{10}|$ as a function of the laser-dressing parameter for three values of (a) screening parameter and (b) confinement strength.

with increasing α_0 at the lowest value of $\hbar\omega_0$. However, for the greater values of $\hbar\omega_0$, the variation of $|M_{10}|$ depicts a similar behavior as Fig. 3 (a).

To investigate the effect of intense laser field on the optical response of the system, we display the variation of the OACs and RICs as a function of incident photon energy for $\lambda = 0.1$ nm^{-1} with $\hbar\omega_0 = 5$ meV in Fig. 4. It would be important to remark that the dashed, dotted and solid lines indicate the linear, third-order nonlinear and the total optical characteristics, respectively. The greater values of α_0 lead to a diminishment in the height of the resonance peaks of the OACs whereas cause an increment in the magnitude of RICs. The physical interpretation of Fig. 4 can be explained by the change in the absolute value of dipole matrix element by the increase in the α_0-parameter and this result is consonant with Fig. 3. The peak positions of OACs and RICs move to the lower energy values (red-shift) with increasing α_0 owing to diminishment in the energy interval between states E_0 and E_1, which could be easily seen in Fig. 1 (a).

Another important examination on the optical characteristics of the system is the effect of screening. Therefore, the variations of the optical coefficients as a function of incident photon energy for several values of $\lambda-$secreening parameter considering the fixed values $\alpha_0 = 4$ nm and $\hbar\omega_0 = 5$ meV are shown in Fig. 5 (a) and (b). It can be clearly observed that in compliance with the previously presented energy and $|M_{10}|$ data, increment in $\lambda-$parameter leads to an increase in the peak heights of the linear, third-order nonlinear and total OACs and RICs while the peak positions of OACs and RICs shift toward to the lower energy region.

Fig. 6 demonstrates the variation of optical absorption coefficients and refractive index changes versus the photon energy for different confinement strength for laser-dressing parameter of 4 nm. From both figures, we evidently observe that augmentation of confinement strength brings about a considerable reduction in the amplitudes of OACs and RICs. Besides, strengthening in confinement causes a blue-shift in the optical response on account of enhancement in the transition energy.

It may be significant also to examine the effects of the screening parameter and confinement frequency in the magnitude of resonant peak values of total OAC and RIC. Hence, Fig. 7 (a) and (b) depict the changes in the peak values of OAC and RIC at resonance frequency as a function of α_0 for different values of λ and $\hbar\omega_0$.

The main figures of Fig. 7 (a) and (b) shows that the resonant peak values of OAC and RIC increase for greater values of λ and exhibit a decreasing behavior for stronger laser field. From the inset figure of Fig. 7 (a), the noticeable behavior for the maximum value of total absorption coefficient is readily seen. The highest value of $|\alpha_{tot}|_{max}$ is obtained for a specific confinement strength value ($\hbar\omega_0 = 7$ meV) at lower laser dressing parameters whereas it is highest for $\hbar\omega_0 = 3$ meV at greater values of α_0. From the inset figure of Fig. 7 (b), it can be readily seen that the maximum value of total RIC decrease for higher values of $\hbar\omega_0$. Further, the resonant peak of RIC increases for lower values of α_0 value but this magnitude starts to decline with the strengthening in the ILF.

4. DISCUSSION AND CONCLUSION

In this work, investigation on the electronic and optical properties of a laser-driven 2DQD including a screened Coulomb impurity has been performed. The influence of non-resonant, circularly polarized ITLF has been tackled within the framework of Floquet approach and effective mass approximation. The numerical solution of Schrödinger equation of system is achieved by the use of FEM. The numerical results demonstrate that exposing an ITLF onto a 2DQD system results in remarkable changes in the impurity binding energy, dipole moment matrix elements and the optical characteristics of the system. By altering the magnitude of confinement frequency, laser-dressing and $\lambda-$screening parameter, shifts in the resonant peak positions of OACs and RICs are observed. On the other hand, enhancement in the peak amplitudes of OACs and RICs is observed for the lower values of α_0 and $\hbar\omega_0$ while this increment is seen with increasing the screening effect. In brief, results of this work reveal that the confinement

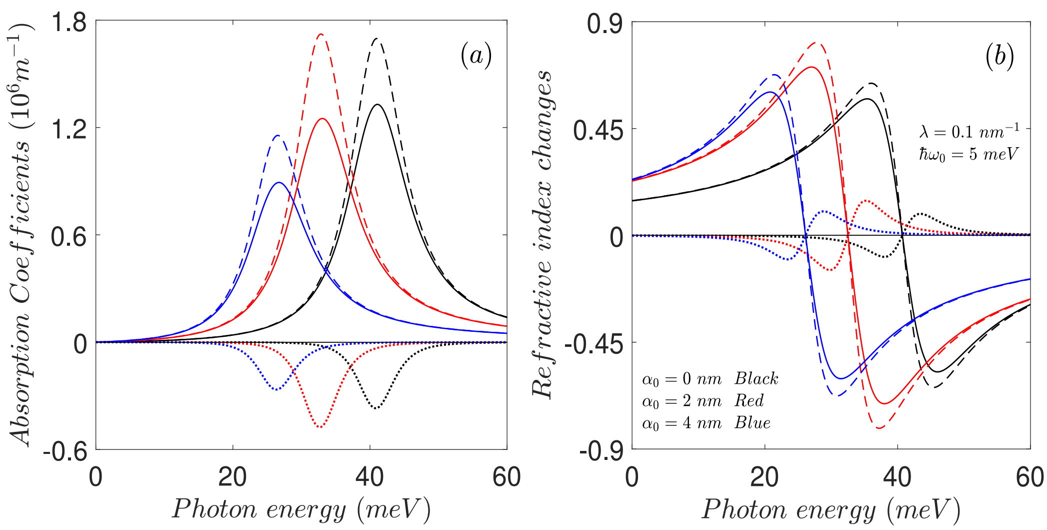

Fig. 4. The change in the linear, third-order nonlinear and total (a) OACs and (b) RICs as a function of the photon energy for three values of α_0 with $\lambda = 0.1$ nm^{-1} and $\hbar\omega_0 = 5$ meV.

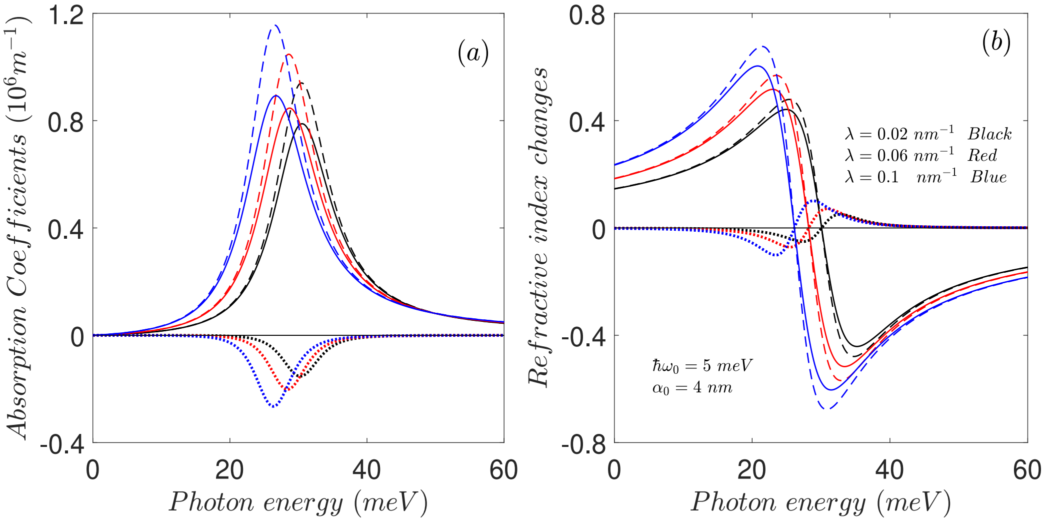

Fig. 5. (a) Optical absorption coefficients and (b) refractive index changes versus incident photon energy for different values of $\lambda-$screening parameter.

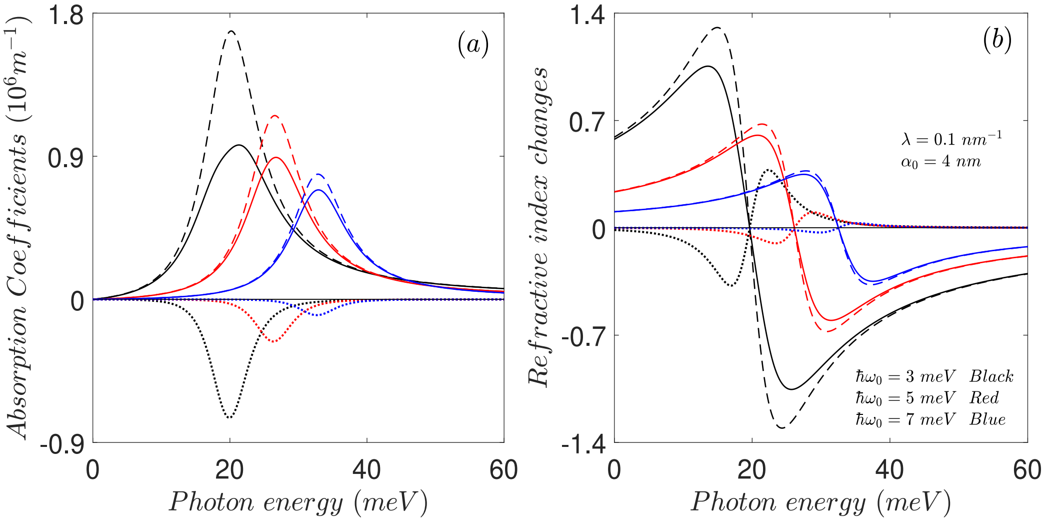

Fig. 6. (a) OACs and (b) RICs vs the photon energy for different values of $\hbar\omega_0$. We set $\alpha_0 = 4$ nm and $\lambda = 0.1$ nm^{-1}.

strength, screening and laser-dressing parameters can be used to control the optical response of the system which can provide an assistance to impurity-doped QD device applications.

Author Contributions

All authors contributed equally to this work. They all read and approved the last version of the paper.

Conflicts of Interest

All authors declare no conflict of interest.

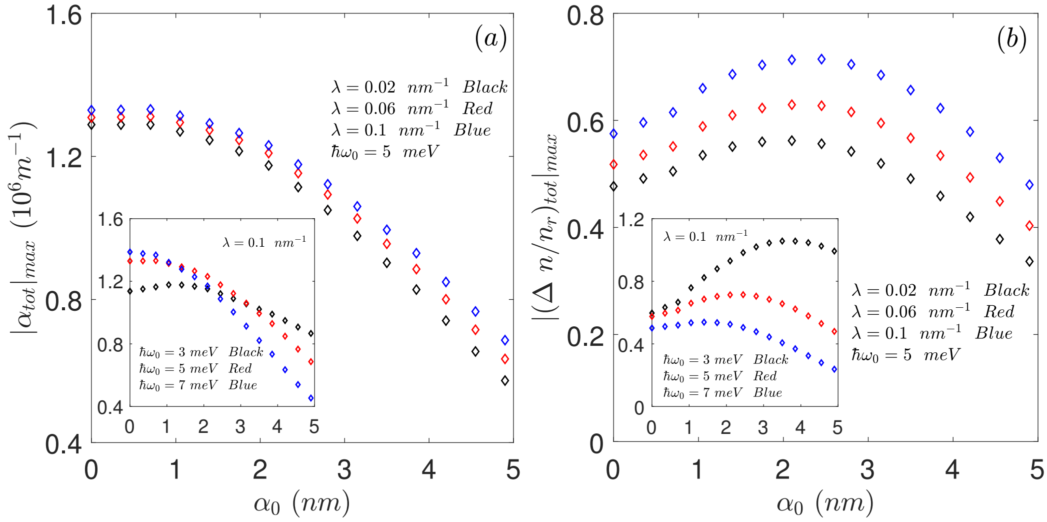

Fig. 7. The maximum values of OACs and RICs versus α_0 for varying values of λ. The insets show the dependence of $\hbar\omega_0$ on the maximum values of OACs and RICs as a function of α_0.

Acknowledgement

This work is derived from the PhD thesis of Dilara GÜL KILIÇ, who was a student at Dokuz Eylül University. Authors would like to thank Prof. İsmail Sökmen for his generous support and valuable contributions.

References

Aktas, S., Kes, H., Boz, F.K. (2016). Control of a resonant tunneling structure by intense laser fields. Superlattices and Microstructures, 98, 220-227.

Al-Ahmadi, A. Fingerprints in the Optical and Transport Properties of Quantum Dots (1st ed.) Croatia: InTech. (2012).

Al-Hayek, I., Sandouqa, A.S. (2015). Energy and binding energy of donor impurity in quantum dot with Gaussian confinement. Superlattices and Microstructures, 85, 216-225.

Barseghyan, M.G. (2015). Physica E, 69, Electronic states of coupled quantum dot-ring structure under lateral electric field with and without a hydrogenic donor impurity. 219-223.

Bejan, D., Niculescu, E.C. (2016). Intense laser effects on the optical properties of asymmetric GaAs double quantum dots under applied electric field. The European Physical Journal B, 89, 138.

Bera, A., Ganguly, J., Saha, S., Ghosh, M. (2015). Interplay between noise and position-dependent dielectric screening function in modulating nonlinear optical properties of impurity doped quantum dots. Optik, 127, 6771-6778.

Brandi, H.S., Latge, A., Oliveira, L.E. (2004). Laser effects on donor states in low-dimensional semiconductor heterostructures. Physical Review B, 70, 153303.

Brum, J.A., Bastard, G., Guillemot, C. (1984). Screened Columbic impurity bound states in semiconductor quantum wells. Physical Review B, 30, 905-908.

Burileanu, L.M. (2014). Photoionization cross-section of donor impurity in spherical quantum dots under electric and intense laser fields. Journal of Luminescence, 145, 684-689.

Chakraborty, T., Manaselyan, A., Barseghyan, M., Laroze, D. (2018). Controllable continuous evolution of electronic states in a single quantum ring. Physical Review B, 97, 041304.

Chang, E., Hone, D. (1988). Screened Coulomb interaction and melting in two dimensions. Journal de Physique France, 49, 25-34.

Coden, D.S.A., Romero, R.H., Ferron, A., Gomez, S.S. (2017). Optimal control of a charge qubit in a double quantum dot with a Coulomb impurity. Physica E 86, 36-43.

Fanyao, O., Fonseca, A.L.A., Nunes, O.A.C. (1996). Intense laser field effect on confined hydrogenic impurities in quantum semiconductors. physica status solidi (b), 197, 349-357.

Ganguly, J., Saha, S., Bera, A., Ghosh, M. (2017). Exploring electro-optic effect and third-order nonlinear optical susceptibility of impurity doped quantum dots: Interplay between hydrostatic pressure, temperature and noise. Optics Communications, 387, 166-173.

Halonen, V., PietilAainen, P., Chakraborty, T. (1996). Optical-absorption spectra of quantum dots and rings with a repulsive scattering centre. Europhysics Letters, 33, 377-382.

Hashemi, G., Rezaei, G. (2015). Effects of external fields, the hydrostatic pressure and temperature on the electronic Raman scattering of a hydrogenic impurity in a two-dimensional parabolic quantum dot. Superlattices and Microstructures, 85, 161-172.

Huang, J. (2013). Effect of the charges of impurity on the refractive index changes in parabolic quantum dot. Physica B, 409, 16-20.

Jiao, L., Ho, Y.K. (2014). Calculation of screened Coulomb potential matrices and its application to He bound and resonant states. Physical Review A, 90, 012521.

Kilic, D.G., Sakiroglu, S., Sokmen, I. (2018). Impurity-related optical properties of a laser-driven quantum dot. Physica E, 49, 50-57.

Kirak, V., Bhardwaj, S.B., Singh, R.M., Chand, F. (2023). Optical properties and effect of magnetic field on energy spectra of a GaAs spherical quantum dot. Applied Physics A, 128, 459.

Kumar, V., Bhardwaj, S.B., Singh, R.M., Chand, F. (2023). Optical properties and effect of magnetic field on energy spectra of a GaAs spherical quantum dot. The European Physical Journal Plus, 138, 191.

Kwon, Y.D. (2006). Theory of the screened Coulomb field generated by impurity ions in semiconductors. Physical Review B, 73, 165210.

Li, N., Guo, K.X., Shao, S., Liu, G.H. (2012). Polaron effects on the optical absorption coefficients and refractive index changes in a two-dimensional quantum pseudodot system. Optical Materials, 34, 1459-1463.

Lima, F.M.S., Amato, M.A., Nunes, O.A.C., Fonseca, A.L.A., Enders, B.G. (2009). Unexpected transition from single to double quantum well potential induced by intense laser fields in a semiconductor quantum well. Journal of Applied Physics, 105, 123111.

Liu, G., Guo, K., Wang, C. (2012). Linear and nonlinear optical properties in a disk-shaped quantum dot with a parabolic potential plus a hyperbolic potential in a static magnetic field. Physica B, 407, 2334-2339.

Mikhail, I.F.I., Shafee, A.M. (2017). Optical absorption in a disk-shaped quantum dot in the presence of an impurity. Physica B, 507, 142-146.

Mora-Ramos, M.E., Duque, C., Kasapoglu, E., Sari, H., Sokmen, I. (2012). Linear and nonlinear optical properties in a semiconductor quantum well under intense laser radiation: Effects of applied electromagnetic fields. Journal of Luminescence, 132, 901-913.

Niculescu, E.C., Stan, C., Tiriba, G., Truşca, C. (2017). Magnetic field control of absorption coefficient and group index in an impurity doped quantum disc. The European Physical Journal B, 90, 100.

Ping, E.X., Jiang, H.X. (1993). Effect of charge-carrier screening on the exciton binding energy in GaAs/AlxGa1-xAs quantum wells. Physical Review B, 47, 2101-2106.

Pont, M., Gavrila, M. (1990). Stabilization of atomic hydrogen in superintense, high-frequency laser fields of circular polarization. Physical Review Letters, 65, 2362-2365.

Poszwa, A. (2014). Dirac electron in the two-dimensional Debye–Yukawa potential. Physica Scripta, 89, 065401.

Sarkar, S., Ghosh, A.P., Mandal, A., Ghosh, M. (2016). Modulating nonlinear optical properties of impurity doped quantum dots via the interplay between anisotropy and Gaussian white noise. Superlattices and Microstructures, 90, 297-307.

Sheng, W., Yun, K., Xianli, L. (2016). Donor impurity-related optical absorption coefficients and refractive index changes in a rectangular GaAs quantum dot in the presence of electric field. Journal of Semiconductors, 37, 112001.

Shojaei, S., Vala, A.S. (2015). Nonlinear optical rectification of hydrogenic impurity in a disk-like parabolic quantum dot: The role of applied magnetic field. Physica E, 70, 108-112.

Soylu, A., Boztosun, I., (2008). Asymptotic iteration method solution of the energy spectrum of two-dimensional screened donor in a magnetic field. Physica E, 40, 443-448.

Taseli, H., Eid, R. (1995). Eigenvalues of the Two-Dimensional Schrodinger Equation with Nonseparable Potentials. International Journal of Quantum Chemistr, 59, 183-201.

Ungan, F., Bahar, M.K. (2019). Optical specifications of laser-induced Rosen-Morse quantum well. Optical Materials, 90, 231-237.

Soltani-Vala, A., Barvestani, J. (2017). Effects of anisotropy on the optical rectification of a disk-like quantum dot with donor impurity in external electric and magnetic fields. Physica B, 518, 88-93.

Varshni, Y.P. (2001). Superlattices and Microstructures, 29, 233-238.

Villalba, V.M., Pino, R. (2002). Energy spectrum of a two-dimensional screened donor in a constant magnetic field of arbitrary strength. Physica B, 315, 289-296.

Vinasco, J.A., Radu, A., Restrepo, R.L., Morales, A.L., Mora-Ramos, M.E., Duque, C.A., (2019). Magnetic field effects on intraband transitions in elliptically polarized laser-dressed quantum rings. Optical Materials, 91, 309-320.

Wang, W., Xu, L., Wu, B., Zhang, S., Wei, X. (2017). Effect of intense terahertz laser and magnetic fields on the binding energy and the transition energy of shallow impurity in a bulk semiconductor. Physica B, 521, 122-127.

Wang, W., Duppen, B.V., Peeters, F.M. (2019). Intense-terahertz-laser-modulated magnetopolaron effect on shallow-donor states in the presence of magnetic field in the Voigt configuration. Physical Review B, 99, 014114.

Xie, W. (2009). Nonlinear optical rectification of a hydrogenic impurity in a disc-like quantum dot. Physica B, 404, 4142-4145.

Xiao, J-L. (2016). Effects of temperature and hydrogen-like impurity on the coherence time of RbCl parabolic quantum dot qubit. Superlattices and Microstructures, 90, 308-312.

Xie, W. (2010). Laser radiation effects on optical absorptions and refractive index in a quantum dot. Optics Communications, 283, 3703-3706.

Yuan, J-H., Zhang, Y., Guo, X., Zhang, J., Mo, H. (2015). The low-lying states and optical absorption properties of a hydrogenic impurity in a parabolic quantum dot modulation by applied electric field. Physica E, 68, 232-238.