Sumer Journal for Pure Science (ISSN: 2790-7031)

SJPS 2024 (August), Vol. 3, No. 1, p.p.: 21-38

Laser Field Effect on the Electronic Properties of a Coupled Quantum Dot System (NM-QD-NM)

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Abstract

In this work, a mathematical model is developed to investigate the electronic properties of a system where a laser field is directed at a quantum dot and the dot is placed between two nonmagnetic (NM) leads. To test the electronic properties of the device and evolve a spin-dependent analytical equations for the occupancy numbers and quantum dot energy levels. The dealings within research are built on the time-independent Anderson-Newns model. All of these formulas have self-consistent solutions by the Fortran program, and the density of states is computed using them in the two regimes ($\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$ and $\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma}$). All the parameters included in our studies can be tuned experimentally. It is found that the electronic properties (density of states) of the system are decreasing, and the energy windows increase as the parameter of laser effect (frequency W_s=0.1,0.2,0.3 eV and broadening due to the laser field $\Delta_s = 0.01, 0.015, 0.02$ eV) increase. The peaks of the density of states are shifted to positive energy for the system when the gate voltages V_g increase. These findings have significant implications for nanotechnology, and the laser can be employed as a tool to facilitate the movement of electrons throughout the system.

Keywords: quantum dots, laser field, nonmagnetic (NM) leads, Density of States, Gate Voltages.

تأثير مجال الليزر على الخواص الالكترونية لنظام نقطة كمية مقترنة (NM−QD−NM)

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الخلاصة

في هذا الدراسة، تم تطوير نموذج رياضي لدراسة الخصائص الإلكترونية لنظام يتكون من نقطة كمية مقترنة وضعت بين قطبين غير مغناطيسيين (NM) حيث يتم توجيه مجال الليزر على نقطة كمومية. و لغرض فحص الخصائص الإلكترونية للجهاز تم اشتقاق معادلات تحليلية تعتمد على الدوران لأعداد الإشغال ومستويات طاقة النقطة الكمومية. إن المعالجة داخل البحث مبنية على نموذج أندرسون-نونز غير معتمد عن الزمن. مجموعة المعادلات تم حلها حلاً توافقياً ذاتياً، ويتم حساب كثافة الحالات في النظامين ($\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$ and $\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma}$) .يمكن ضبط جميع المعلمات المدرجة في دراساتنا بشكل تجريبي. لقد وجد أن الخصائص الإلكترونية (كثافة الحالات) للنظام آخذة في التناقص، وتزداد نوافذ الطاقة مع زيادة معاملات الليزر المسلط (التردد W_s =0.1,0.2,0.3 eV و التعريض بسبب مجال الليزر $\Delta_s = 0.01, 0.015, 0.02$ eV). يتم تحرك قمم كثافة الحالات إلى باتجاه قيم الطاقة الموجبة للنظام عند زيادة فولتية البوابة V_g. هذه النتائج لها آثار كبيرة على تكنولوجيا النانو، ويمكن استخدام الليزر كأداة لتسهيل حركة الإلكترونات في جميع اجزاء النظام.

1. Introduction

Mesoscopic physics is a branch of the physics of condensed materials that focuses on the properties of solids of medium size between individual atoms and bulk materials [1]. Scientists' motivation has recently increased to explore the possibility of making materials with smaller nanoscale dimensions due to interest in new applications and characteristics that arise when the material reaches the nanoscale, and quantum dots attract significant interest in nanotechnology [2]. Quantum dots can be defined as small nano-conducting semiconductors or crystals with quantitative and mechanical properties [3]. The density of time-impacted cases is important in clarifying the probability of ion-equivalent surface ion rectangulation and is equivalent to the time rate of energy-dependent transit current through the system. As noted at high values (w), we note a striking decline in the likelihood of parity since the increase in (w) indicates an improvement in the overall expansion of the atomic level [4]. The volumetric effects of quantum dots on the energy gap have been studied, as the energy gap has become dependent on size, as the energy gap has increased as volume has decreased, and therefore the energy gap is inversely commensurate with size (quantitative dot radius square) [5]. Thus, quantum dots (0-D), quantum wires (1-D), quantum wells (2-D), and (3-D) dimensional bulks are examples of nanomaterials having size-dependent properties [6]. Quantum dots, quantum wells, and quantum wires exhibit the features of normal atomic physics. Due to the movement of connectivity range electrons and parity bar gaps being limited to a small region of nano-metric-sized space [7]. The conveyor material is larger than the ball; at the semiconducting radius of the ball, it is small, so that it becomes equal to the half diameter of Bor for the charge, and the ball is tested by quantitative confinement [3]. Quantitative limitation can be defined as a spatial limitation by one or more dimensions, such as pairs of electron holes or separate electronic energy levels, within the material [8] The smaller the box, the energy gap between parity and empty status increases, as does the kinetic energy of electrons [9]. It has been found at the nanometer scale that materials and molecules get new properties, dependent on size, which can be exploited in new applications [10]. Quantitative points have gained considerable attention because of their characteristics and applications in different fields, such as optoelectronics, biomedicine, quantitative encryption, synthesis, and rotational electronics. The qualification of quantitative points has made significant progress and has improved electronic and visual characteristics due to progress in quantitative dots. Generally, quantitative points have the potential to make significant progress in various areas [11].

The purpose of this work is to examine how the electron transport process via a linked quantum dot between two non-magnetic leads is affected by the laser field. In this work, a mathematical model of electron transport through a device with two nonmagnetic (NM) leads coupled to a quantum dot is presented. Current and differential conductance are examined to look at the laser field effect.

2. The Mathematical Model

In this paragraph, we will discuss the building of a mathematical model to investigate the effect of a laser field applied to a quantum dot. It is embedded between two nonmagnetic leads (NM). The interaction between the left lead and quantum dot is V_{Ld}, and the right lead interacts with the quantum dot by V_{Rd}. As shown in Fig. (1).

The properties of the system will be determined by the electron transport mechanism in that system, which depends on multiple factors. For example, the frequency of the laser field W_S, the broadening due to the laser in the quantum-dot energy level Δ_S, the electrochemical potential for the leads (left μ_L and right μ_R),), the broadening in the energy levels because of the presence of the leads $\Delta_{\alpha}^{\pm\sigma}$and the energy levels of the quantum dot E_d, as well as the energy beam properties (bandwidth and density of electronic states) for left and right leads. The properties of the quantum dot play an important role in determining the dynamics of electron transport between the two leads (see Fig. (1)). The dynamics of the system will also be examined in the presence of a bias voltage eV_{bias} applied to the two leads, which is given by $eV_{bias} = \mu_L - \mu_R$ [12] .

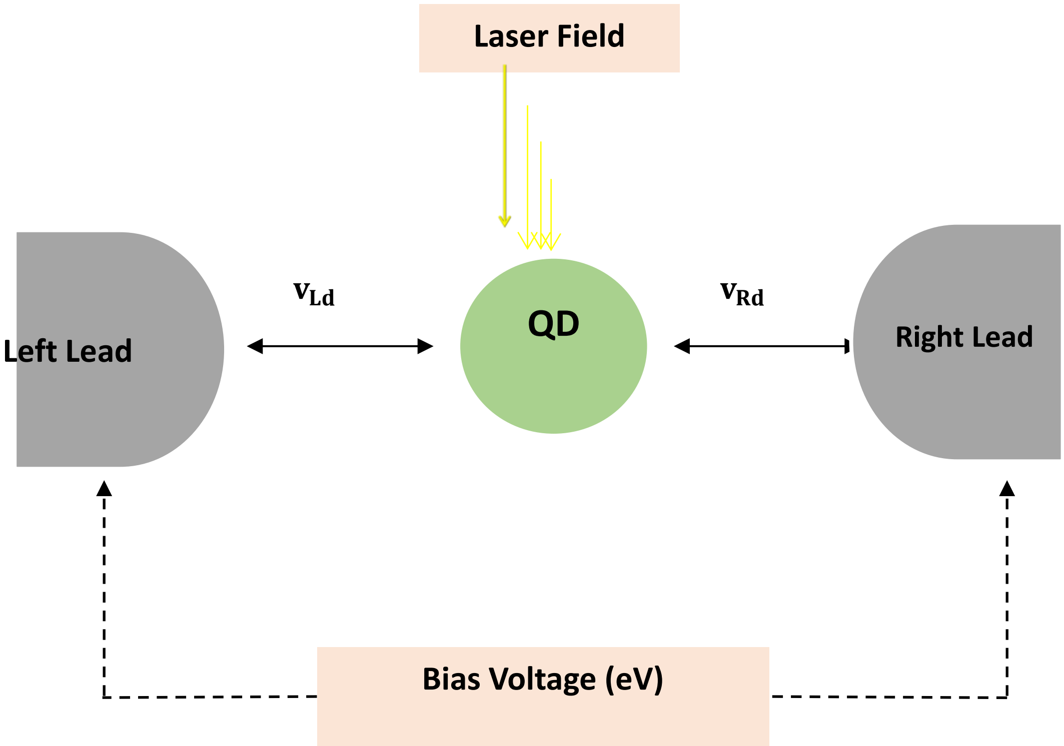

Figure-1 represents a quantum-dot (QD) coupled to two nonmagnetic leads

3. Electron transport through a quantum dot coupled to the presence of a laser field

3.1 The Hamiltonian Model

The system under investigation (left lead- quantum dot- right lead) may be characterized by using the Andersen model by taking the coupling interactions [13-16]. The time-independent Hamiltonian is expressed as follows:

$$H = H_{QD} + H_{Leads} + H_{QD-Leads} \tag{1}$$

The first term in the eq. (1) represents the Hamiltonian of the quantum dot, which is given by the following [17, 18]:

$$H_{QD} = \sum_{\sigma}(E_d^{\sigma}\, n_d^{\sigma} + U\, n_d^{\sigma} n_d^{-\sigma}) \tag{2}$$

E_d^σ represents the energy levels of the quantum dot with the spin σ and is given by the following relationships [13]:

$$E_d^{+\sigma} = E_d + Un_d^{-\sigma}$$

$$E_d^{-\sigma} = E_d + Un_d^{+\sigma} \tag{3}$$

The quantum dot's effective energy level is denoted by E_d, $E_d^{-\sigma}, E_d^{+\sigma}$ The energy of the two quantum dot levels represented by it, and the repulsion between electrons with opposing spins is represented by the Coulomb interaction energy U. Furthermore, n_d^σ represents the occupation numbers .

$n_d^{+\sigma} = C_d^{+\sigma\dagger}\, C_d^{+\sigma}$

$$n_d^{-\sigma} = C_d^{-\sigma\dagger}\, C_d^{-\sigma} \tag{4}$$

In contrast, the effects of the generation and destruction of quantum dot orbitals are represented by $C_d^{\sigma\dagger}$ and $C_d^{-\sigma}$.

The second term of eq. (1) represents the Hamiltonian for the leads, which is given by [19, 20]:

$$H_{Leads} = \sum_\sigma \sum_\alpha \sum_{K_\alpha} E_{K_\alpha}^\sigma n_{K_\alpha}^\sigma \tag{5}$$

Where $n_{K_\alpha}^\sigma$ represents the number of occupancies corresponding to the energy levels of the lead and $E_{K_\alpha}^\sigma$ represents the energy level of the lead $\alpha(\alpha = (L, R))$ with quantum numbers K and spin σ. In our study, non-magnetic leads (nonmagnetic leads) were taken, the spin of the leads was not taken into account. The Hamiltonian for the interaction of a quantum dot with the leads is represented by the third term of eq. (1).

$$H_{QD-Leads} = \sum_\sigma \sum_\alpha \sum_{K_\alpha} (V_{dK_\alpha}\, C_d^{\sigma\dagger}\, C_{K_\alpha} + H.C\,) \tag{6}$$

V_{dK_α} : Represents the matrix elements of the coupling between the quantum dot and the leads.

3.2 The Occupation Number Calculation in the Presence of laser Field

According to the Anderson model, when the temperature of the leads is equal to zero, the occupancies number $n_d^{\pm\sigma}$ for the quantum dot can be computed by the following [21]:

$$n_d^\sigma = \int_{u_{0\alpha}}^{\mu_\alpha} \rho_{d\alpha}^\sigma\,(E)dE \tag{7}$$

where $u_{0\alpha}$ denotes the bottom of the beam for lead α and $\rho_{d\alpha}^\sigma$ is the density of electronic states for the quantum dot on lead α and spin σ for the system in Fig.(1), which is related to the Green function $G_r^\sigma(E)$ according to the following [22]:

$$\rho_{d\alpha}^\sigma = -\frac{1}{2\pi}\, \mathrm{Im}\big(G_r^\sigma(E)\big) \tag{8}$$

Where as $G_r^\sigma(E)$ is given by:

$$G_r^\sigma(E) = \frac{1}{E - E_d^\sigma + i\Delta} \tag{9}$$

After substituting for $G_r^\sigma(E)$ in Equation (8) and multiplying by the complex conjugate, we take only the Imaginer part. We can obtain a formula for the density of states in the absence of a laser field directed at the quantum dot.

$$\rho_{d\alpha}^\sigma(E) = \frac{1}{2\pi} \frac{(\Delta_c^\sigma)}{(E - E_d^\sigma)^2 + (\Delta_c^\sigma)^2} \tag{10}$$

Where Δ_c^σ represents the total broadening occurring in the energy level of the quantum dot due to the coupling with the leads. It can be found by $\Delta_c^\sigma = \Delta_{dL}^\sigma + \Delta_{dR}^\sigma$, where Δ_{dL}^σ and Δ_{dR}^σ are the broadening in the energy levels of the quantum dot because of the presence of leads (left and right), respectively, which are a function of the energy of the system and the distance between the quantum dot and the leads α. Since the wide band approximation was utilized in our computations for the left and right leads, the broadening functions $\Delta_{dR}^\sigma, \Delta_{dL}^\sigma$ are energy-independent. [23, 24]:

When a laser field is directed at the coupled quantum dot between the normal leads (non-magnetic leads) and by taking advantage of the dynamic treatment to reach a static formula presented by [4, 25, 26], which includes the laser field effects on the chemisorption process, and the study presented by [27-29], which includes studying the laser field effect on the chemisorption process of a diatomic molecule on a solid surface, the density of states of the coupled quantum dot became:

$$\rho_n^\sigma(E) = \sum\nolimits_{n=0,\pm 1} \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nW_s)^2 + (\Delta_T^\sigma)^2} \tag{11}$$

$$\rho_{d\alpha}^\sigma(E) = \sum_n g_n \, \rho_n^\sigma(E)$$

$$\rho_{d\alpha}^\sigma(E) = \sum\nolimits_n g_n \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nW_s)^2 + (\Delta_T^\sigma)^2} \tag{12}$$

Where $\Delta_T^\sigma = (\Delta_{dL}^\sigma + \Delta_{dR}^\sigma) + 2\Delta_S$ and that Δ_S represents the broadening at the energy level of the quantum dot due to the presence of the laser field. W_s is the frequency of the laser field, and n =0,±1 represents the energy level number of the quantum dot after the laser field is applied, and $\rho_d^\sigma(E) = \sum_\alpha \rho_{d\alpha}^\sigma(E)$. We substitute (12) into (7) and obtain a formula for the occupation numbers with an applied laser field.

$$n_{d\alpha}^\sigma = \sum\nolimits_\sigma \sum\nolimits_{n=0,\pm 1} g_n \int_{u_{0\alpha}}^{\mu_\alpha} \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nw_s)^2 + (\Delta_T^\sigma)^2} dE \tag{13}$$

The functions g_n^σ are given by:

$$g_0^\sigma = \frac{1}{2\pi} \frac{\Delta_c^\sigma}{\Delta_T^\sigma}$$

$$g_{+1}^\sigma = g_{-1}^\sigma = \frac{1}{2\pi} \frac{\Delta_S}{\Delta_T^\sigma} \tag{14}$$

By substituting the functions (14-2) into equation (13-2), we find:

$$n_d^\sigma = \frac{1}{2\pi} \left[\frac{\Delta_c^\sigma}{\Delta_T^\sigma} \int_{u_{0\alpha}}^{\mu_\alpha} \frac{\Delta_T^\sigma}{(E - E_d^\sigma)^2 + (\Delta_T^\sigma)^2} dE + \frac{\Delta_S}{\Delta_T^\sigma} \int_{u_{0\alpha}}^{\mu_\alpha} \frac{\Delta_T^\sigma}{(E - E_d^\sigma + w_S)^2 + (\Delta_T^\sigma)^2} dE + \frac{\Delta_S}{\Delta_T^\sigma} \int_{u_{0\alpha}}^{\mu_\alpha} \frac{\Delta_T^\sigma}{(E - E_d^\sigma - w_S)^2 + (\Delta_T^\sigma)^2} dE \right] \tag{15}$$

By integrating and inserting the integration limits, we derive a formula for the occupation numbers in the presence of a laser field directed at the quantum dot.

$$n_d^{+\sigma} = \left[\sum_{n=0,\pm1} g_n^{+\sigma}\left(\tan^{-1}\frac{\mu_\alpha - E_d^{+\sigma} + nw_S}{\Delta_T^{+\sigma}} - \tan^{-1}\frac{u_{0\alpha} - E_d^{+\sigma} + nw_S}{\Delta_T^{+\sigma}}\right)\right]$$

$$n_d^{-\sigma} = \left[\sum_{n=0,\pm1} g_n^{-\sigma}\left(\tan^{-1}\frac{\mu_\alpha - E_d^{-\sigma} + nw_S}{\Delta_T^{-\sigma}} - \tan^{-1}\frac{u_{0\alpha} - E_d^{-\sigma} + nw_S}{\Delta_T^{-\sigma}}\right)\right] \tag{16}$$

To obtain the number of occupancies $n_d^{\pm\sigma}$ and the corresponding energy levels $E_d^{\pm\sigma}$, the system of equations (3) and (16) must be solved as a self-consistent solution.

3.3 The Tunneling Current

The current flowing through the active region (a coupled quantum dot) in an unbalanced case for the system is due to a bias voltage being applied to the leads, as given in the relationship [30]:

$$I = \frac{e}{\hbar}\sum_\sigma \int_{\mu_R}^{\mu_L} \Delta^\sigma\, \rho_d^\sigma(E)\, (f_L(E) - f_R(E))dE \tag{17}$$

Where $f_L(E)$ and $f_R(E))$ are Fermi distribution functions for the left and right leads, respectively. The density of states $\rho_d^\sigma(E)$ is defined by equation (12), and Δ^σ is defined by:

$$\Delta^\sigma = \frac{\Delta_L^\sigma\, \Delta_R^\sigma}{\Delta_L^\sigma + \Delta_R^\sigma} \tag{18}$$

By substituting eq. (12) into eq. (17), we obtain an analytical formula for the tunnel current as a function of the bias voltage in the presence of the laser field:

$$I = \frac{e}{\hbar}\sum_\sigma \int_{\mu_R}^{\mu_L} \Delta^\sigma \sum_n g_n \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nw_s)^2 + (\Delta_T^\sigma)^2}\, (f_L(E) - f_R(E))dE \tag{19}$$

To obtain a formula for the current as a function of the bias voltage in the presence of a laser field, we will discuss the following two cases:

The first case: When $\mu_L > \mu_R$ the values of the Fermi functions at the leads temperature T=0 K^o for the system energy values $\mu_L \geq E \geq \mu_R$ will take the following values:

$f_L(E) = 1$

$f_R(E) = 0$

Therefore, the current can be written in the following form:

$$I = \frac{e}{\hbar}\sum_\sigma \int_{\mu_R}^{\mu_L} \Delta^\sigma \sum_n g_n \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nw_s)^2 + (\Delta_T^\sigma)^2}\, dE \tag{20}$$

By solving the integral in eq. (20) analytically, we obtain

$$I = \frac{e}{\hbar}\sum_\sigma \Delta^\sigma \sum_n g_n \left\{\tan^{-1}\left(\frac{\mu_L - E_d^\sigma + nw_s}{(\Delta_T^\sigma)^2}\right) - \tan^{-1}\left(\frac{\mu_R - E_d^\sigma + nw_s}{(\Delta_T^\sigma)^2}\right)\right\} \tag{21}$$

The second case: When $\mu_L < \mu_R$, the values of the Fermi functions at the lead temperature T=0 K^o for the system energy values $\mu_L \leq E \leq \mu_R$ will take the following values:

$f_L(E) = 0$

$f_R(E) = 1$

Thus, the current can be written in the following form:

$$I = -\frac{e}{\hbar}\sum_\sigma \int_{\mu_L}^{\mu_R} \Delta^\sigma \sum_n g_n \frac{\Delta_T^\sigma}{(E - E_d^\sigma + nw_s)^2 + (\Delta_T^\sigma)^2}\, dE \qquad (22)$$

By solving the integral in equation (22) analytically, we obtain

$$I = -\frac{e}{\hbar}\sum_\sigma \Delta^\sigma \sum_n g_n \left\{\tan^{-1}\left(\frac{\mu_R - E_d^\sigma + nw_s}{(\Delta_T^\sigma)^2}\right) - \tan^{-1}\left(\frac{\mu_L - E_d^\sigma + nw_s}{(\Delta_T^\sigma)^2}\right)\right\} \qquad (23)$$

3.4 Differential Conductance

To investigate the system's functional characteristics, the Differential Conductance needs to be computed, and this can be done using the relationship that follows [30]:

$$G_{diff} = \frac{\partial I}{\partial (eV_{bias})} \qquad (24)$$

Whereas:

$\mu_L = eV_{bias}$

$\mu_R = -eV_{bias}$

Differential conductance was obtained using the finite differences method. The unit of current in our calculations is in atomic units (e= $\hbar$ =1), meaning that in eq. (18), it is divided by 27.21.

4. Results and Discussion

In this paragraph, we will calculate the electronic properties of the system under study (NM-QD-NM). The mathematical model derived in section 2 included equations to calculate the density of states (DOS) for the quantum dot placed between the two non-magnetic leads. The equations were derived for the density of states in the presence of a laser field affecting the quantum dot. The special equations to describe the system under study included a set of factors, including the effective energy level of the quantum dot E_d and its location, Relative to the measurement reference, where it is set at the Fermi level, the coupling strength ($\Delta_\alpha^{\pm\sigma}$) ($\alpha = R, L$) between the quantum dot and the non-magnetic leads is dependent on the spin, the bias voltage applied to the leads eV_{bais}, the gate voltage is applied to the quantum dot, the effect of the laser field directed to the quantum dot through the parameters (the frequency of the directed laser w_s and the broadening at the energy level of the quantum dot due to the presence of the laser field Δ_S independent of the spin), leads temperature at T=0 K°, and the splitting of the energy level due to the presence of the laser field, where only n = -1, 0, +1 was taken. In our accounts.

The density of states of the quantum dot will be calculated as a function of the energy system E (eV) to study the electronic properties of the system. In our calculation, we have taken the effect of the laser field frequency W_s=0.1,0.2,0.3 eV for the broadening values $\Delta_s =$

0.01,0.15 , 0.02 eV and the bias voltage eV_{bais}, the energy window edge of the $\mu_L = -\mu_R = 1$ eV, into account. $V_g = -0.2, -0.1, 0.0, 0.1, 0.2$ eV was taken to represent the effect of the gate voltage on the quantum dot. The degree of coupling between the quantum dot and the non-magnetic leads also played a significant role; the coupling strength between the quantum dot and the non-magnetic leads was taken into account. in the first case, $\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$ ($\Delta_\alpha^{+\sigma} = 0.01$ eV, $\Delta_\alpha^{-\sigma} = 0.02$ eV), and in the second, $\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma}$ ($\Delta_\alpha^{+\sigma} = 0.02$ eV, $\Delta_\alpha^{-\sigma} = 0.01$ eV).

4.1 Calculating the density of states in the absence of a laser field $w_s = 0eV$, $\Delta_s = 0$ eV

In the absence of a laser field effect, the density of states of the quantum dot (QD) will be computed as a function of the energy system E (eV), as in Eq. (12). where the density of states for various gate voltage levels ($V_g = -0.2, -0.1, 0.0, 0.1, 0.2$ eV). was computed. For my case of coupling strength:

1) When $\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$

The density of states was calculated in this case ($\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$) and at the energy window $\mu_L = \mu_R = -1$eV We notice that the density of state values outside the energy window are zero, and this result is logical, as the density of state represents the probability of the presence of an electron per unit volume, and since the bias falls within the energy window, the DOS values are only within the window at $E_d = -0.2$ eV , as shown in Fig.(2A). After that, the gate voltage was increased. V_g to $E_d = -0.1$ eV where the energy level was raised to the highest level, and for the same coefficients, we notice that the DOS values did not change, but there was a shift towards the positive energy values of the system, as in Fig.(2B) . Then the energy level was set at the measurement reference E = 0.0 eV and higher than the measurement reference $E_d = 0.1, 0.2$ eV. We notice an increase in the shift towards positive energy values for the system, as in Figs. (2C,D,E).

2) When $\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma}$

The density of states was calculated and is the same as in the first case, but the coupling strength of the spin-up is greater than the coupling strength of the spin-down for the same gate voltage values. We note that the density of states has not changed, and the reason for this is that the system is symmetrical, as shown in Fig. (3).

4.2 The Density of States Calculation in the Presence of a Laser Field

The density of states will be calculated as a function of the energy system E (eV) in the presence of an applied laser field frequency $W_s = 0.1, 0.2, 0.3$ eV on the quantum dot and for different gate voltage values, where $E_d = -0.2, -0.1, 0, 0.1, 0.2$ eV and for three values of broadening due to the presence of the laser field $\Delta_s = 0.01, 0.015, 0.02$ eV , and the bias voltage between the two non-magnetic leads is $\mu_L = -\mu_R = 1$eV, and for two cases of coupling strength, the first case is when the coupling with the leads of the spin up $\Delta_\alpha^{+\sigma}$ was less than the coupling with the leads of the spin down ($\Delta_\alpha^{+\sigma} = 0.01$ eV, $\Delta_\alpha^{-\sigma} = 0.02$ eV) and the second case is ($\Delta_\alpha^{+\sigma} = 0.02$ eV, $\Delta_\alpha^{-\sigma} = 0.01$eV). The calculations were performed based on the equations that were derived in Section 2, where the system of equations was solved in a self-consistent solution, as we can see from Figure (4). Calculating the density of states at the gate voltage value $E_d = -0.2$eV and for the two cases of the coupling interaction ($\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma}$) Fig. (4,a,b,c) and for the case ($\Delta_{\alpha}^{+\sigma} > \Delta_{\alpha}^{-\sigma}$) for Fig.(4,d,e,f), and for values of the laser field frequency $W_s = 0.1, 0.2, 0.3 eV$ when the laser field frequency W_s increases There is a decrease in the density of states, and at the same time, new peaks appear on both sides, and the exposure of those peaks increases with increasing frequency. This result is logical, as by increasing the frequency of the applied laser field, the interaction between the quantum dot and the leads increases [4], and thus the probability of the electron moving through the system increases. When Δ_s the frequency due to the presence of the laser field, is increased, the behavior remains the same, but there is a decrease in the density of states for the same frequency. This is also a positive indicator, as it indicates an increase in the interaction process, as shown in figs..(4,a,b,c).

The same calculations were repeated for the same value of $E_d = -0.2$ eV and the same values of the laser field frequency w_s, and for the second case of the coupling strength ($\Delta_{\alpha}^{+\sigma} > \Delta_{\alpha}^{-\sigma}$), where we observed that the behavior of the density of states as a function of the energy system remains The same is true for the frequency $w_s = 0.1, 0.2eV$, and for all broadening values due to the laser field Δ_s , but at the frequency $W_s = 0.3eV$ the density of state values do not change for broadening. $\Delta_s = 0.01, 0.015eV$, and for both cases, the coupling strength values change, but when broadening $\Delta_s = 0.02eV$ The three values are almost equal., as in Figs.(4,d,e,f).

The calculations were repeated for the same values of the laser field (frequency w_s and the (broadening due to it Δ_s), for the two cases of coupling strength ($\Delta_{\alpha}^{+\sigma} < \Delta_{\alpha}^{-\sigma}$) and ($\Delta_{\alpha}^{+\sigma} > \Delta_{\alpha}^{-\sigma}$) in the same order, but different values of E_d, as they were taken less than the measurement reference $E_d = 0eV$ and higher than the measurement reference $E_d = 0.1, 0.2eV$, the results of which were reviewed in Figs. (5) to (8) where it was observed that they behave in the same way and the gate voltages V_g only affect the shift of the beam towards the peaks positive energy, and the result is logical, as by increasing the gate voltage V_g, the effective energy level of the quantum dot is shifted to positive energy. By observing all the figures, we noticed that all the density of state values, under the influence of the laser field, fall within the energy window, that is, within the bias region between the leads affecting the quantum dot.

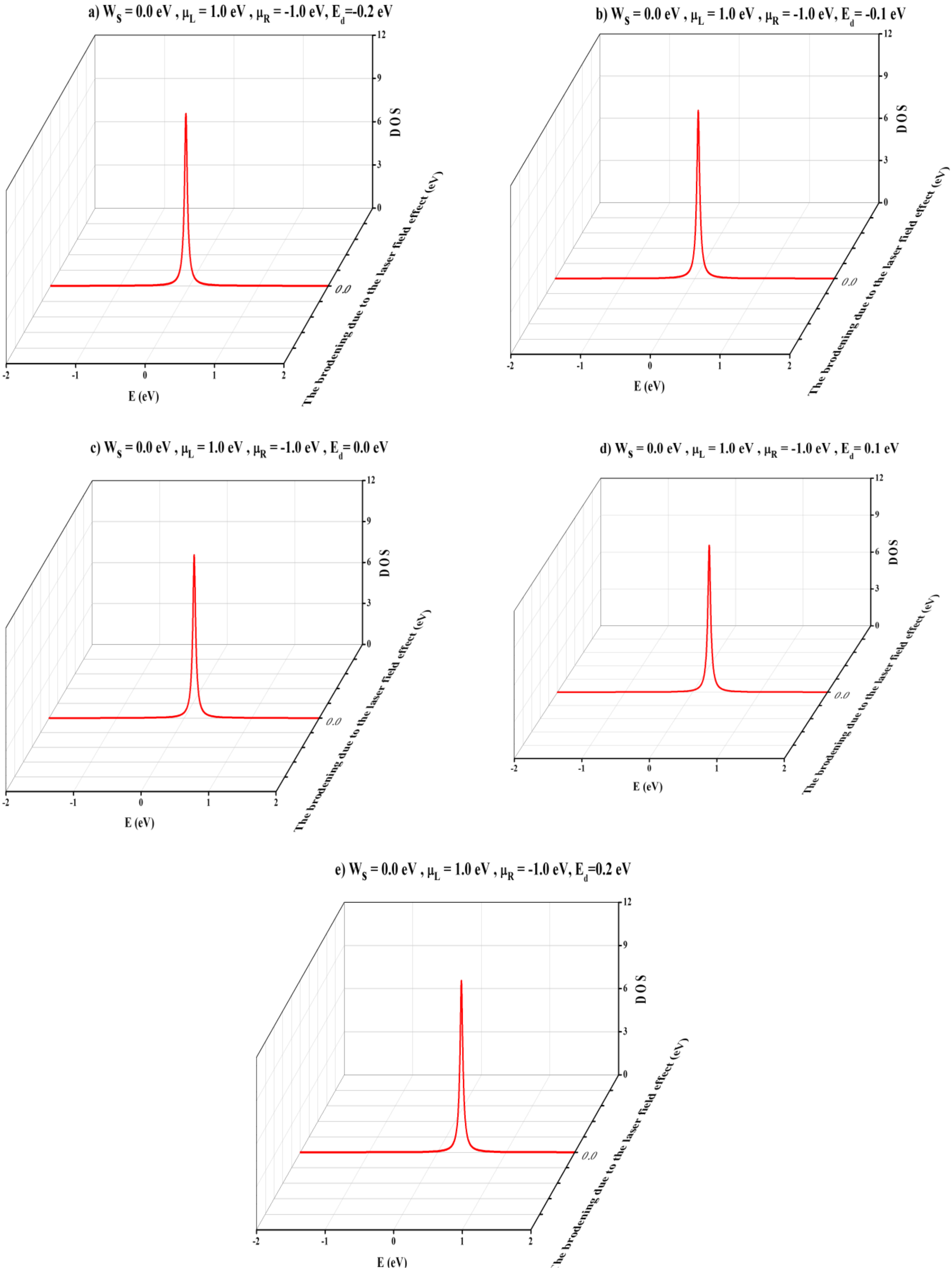

Figure-2 The Density of states (DOS) as a function of the energy system in the absence of laser field, in the case $< \Delta_{\alpha}^{-\sigma}$ and ($E_d = -0.2, -0.1, 0.0, 0.1, 0.2$ eV).

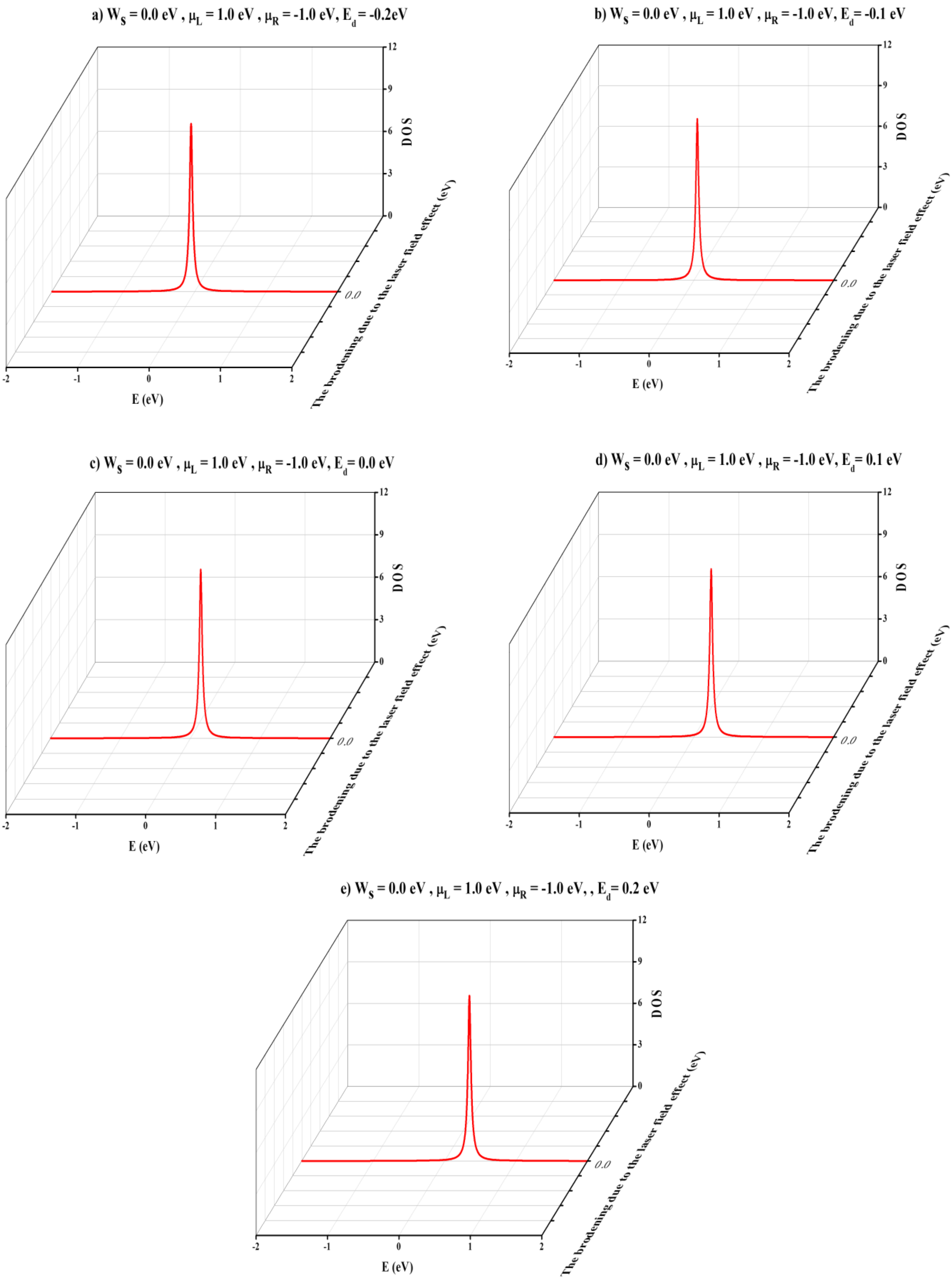

Figure-3 The Density of states (DOS) as a function of the energy system in the absence of laser field, in the case $\Delta_{\alpha}^{+\sigma} > \Delta_{\alpha}^{-\sigma}$ and ($E_d = -0.2, -0.1, 0.0, 0.1, 0.2$ eV).

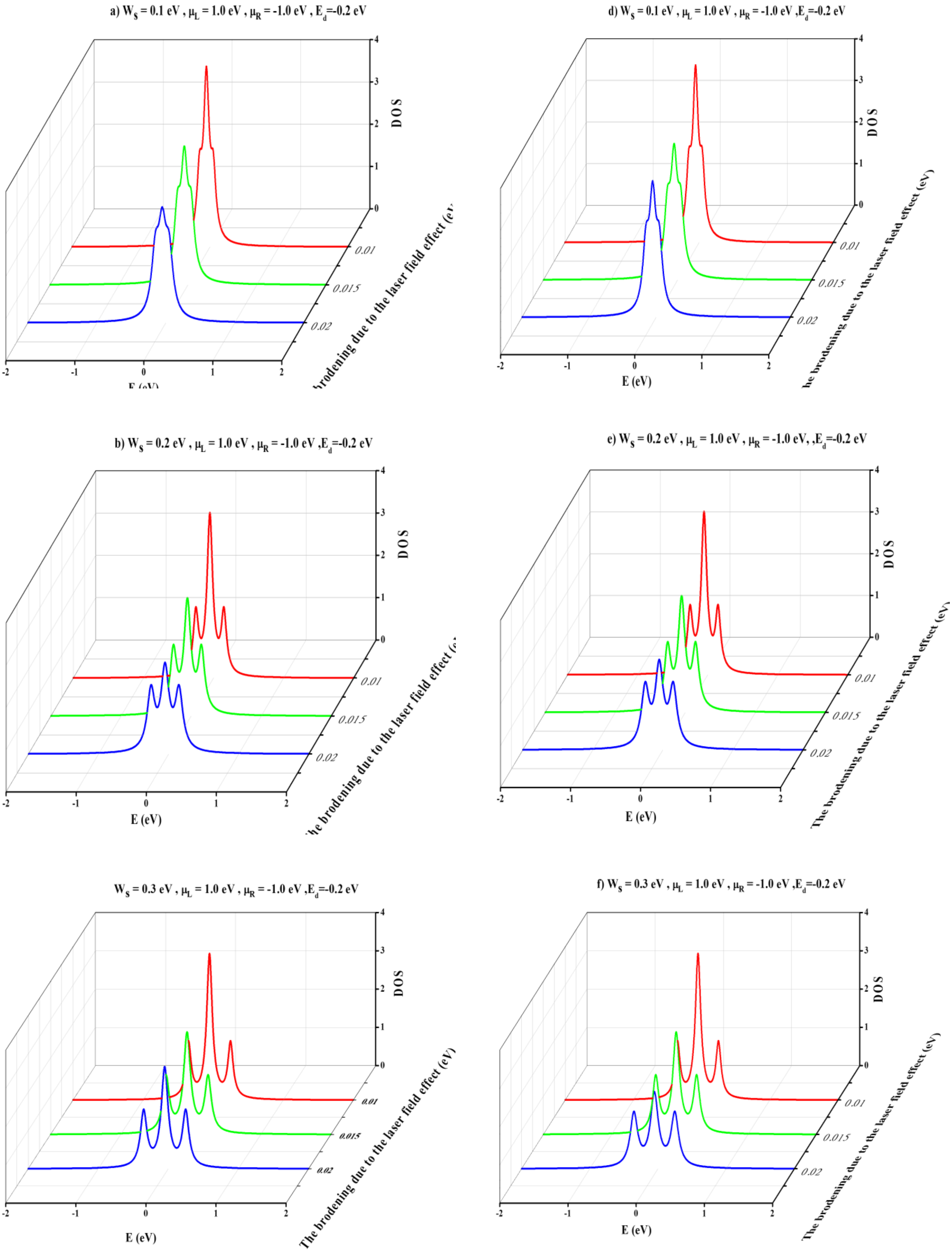

Figure-4 The density of states DOS as a function of the system energy E(eV) in the presence of a laser field with frequency $W_S = 0.1, 0.2, 0.3$ eV and broadening $\Delta_s = 0.01, 0.015, 0.02$ eV when $E_d = -0.2$ eV for the cases $(\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma})$ in a,b, and c $(\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma})$ in d,e, and f

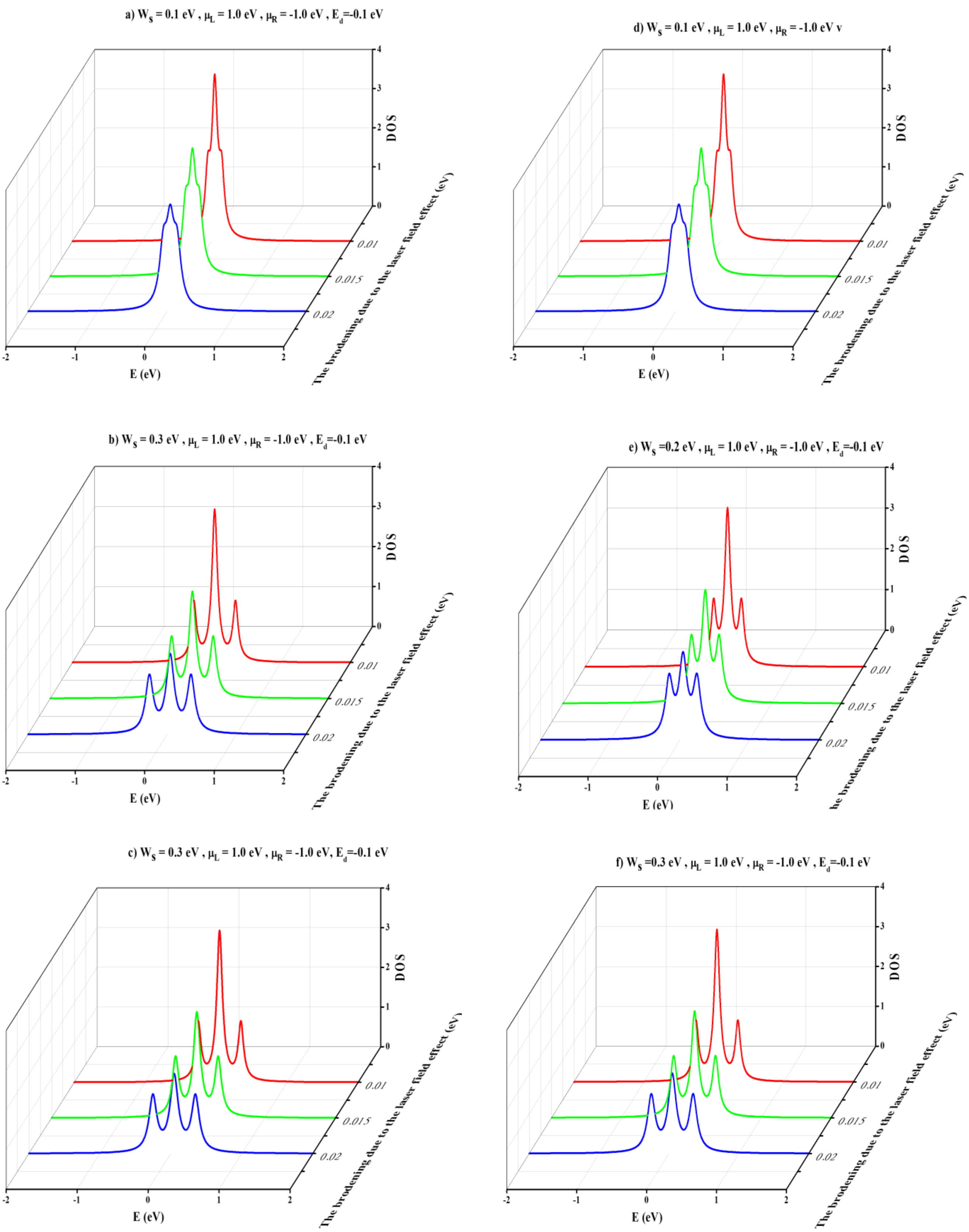

Figure-5 The density of states DOS as a function of the system energy E(eV) in the presence of a laser field with frequency $W_S = 0.1,0.2,0.3$ eV and broadening $\Delta_s = 0.01,0.015,0.02$ eV when $E_d = -0.1$ eV for the cases $(\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma})$ in a,b, and c $(\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma})$ in d,e, and f

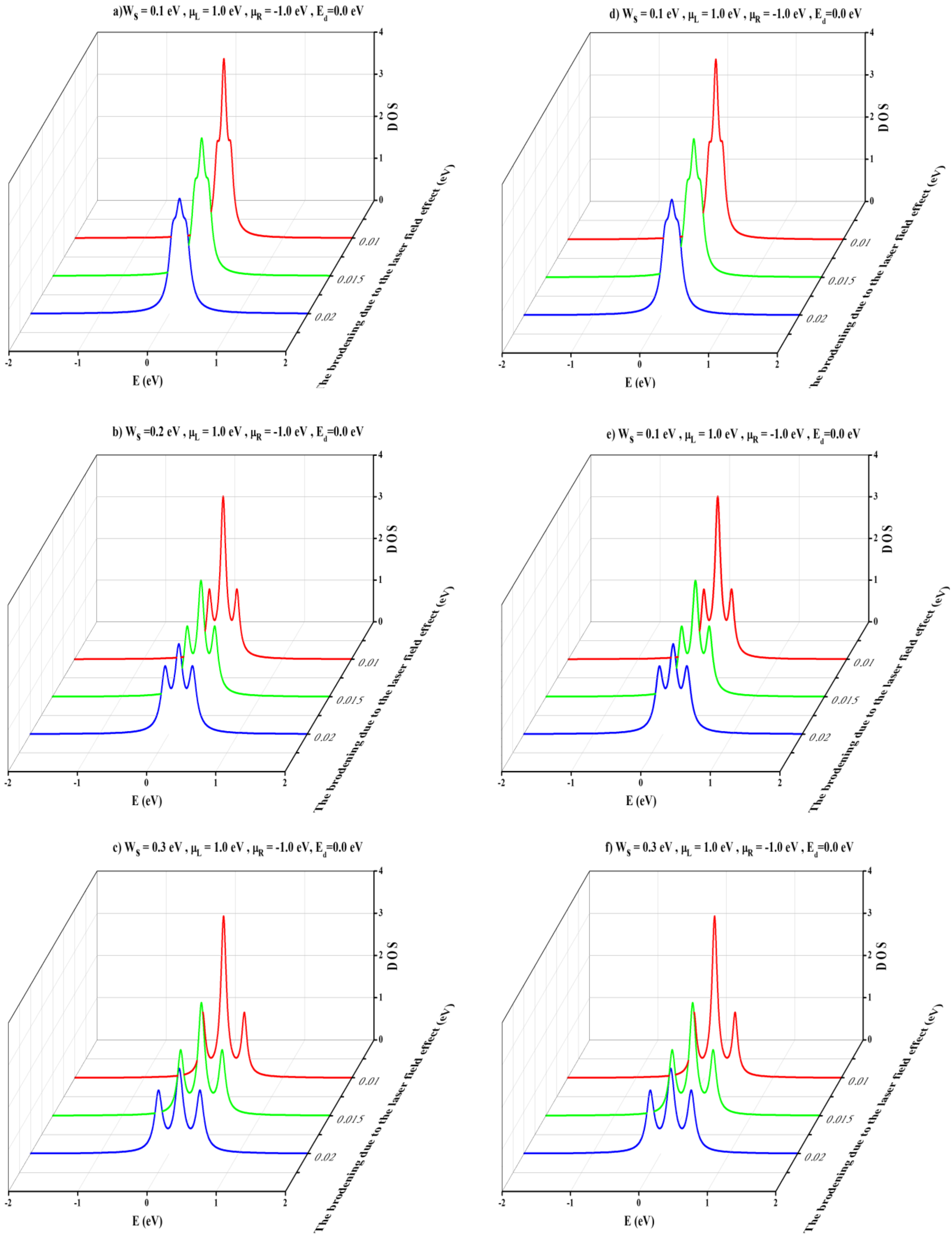

Figure-6 The density of states DOS as a function of the system energy E(eV) in the presence of a laser field with frequency $W_S = 0.1,0.2,0.3$ eV and broadening $\Delta_s = 0.01,0.015,0.02$ eV when $E_d = 0.0$ eV for the cases $(\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma})$ in a,b, and c ($\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma}$) in d,e, and f

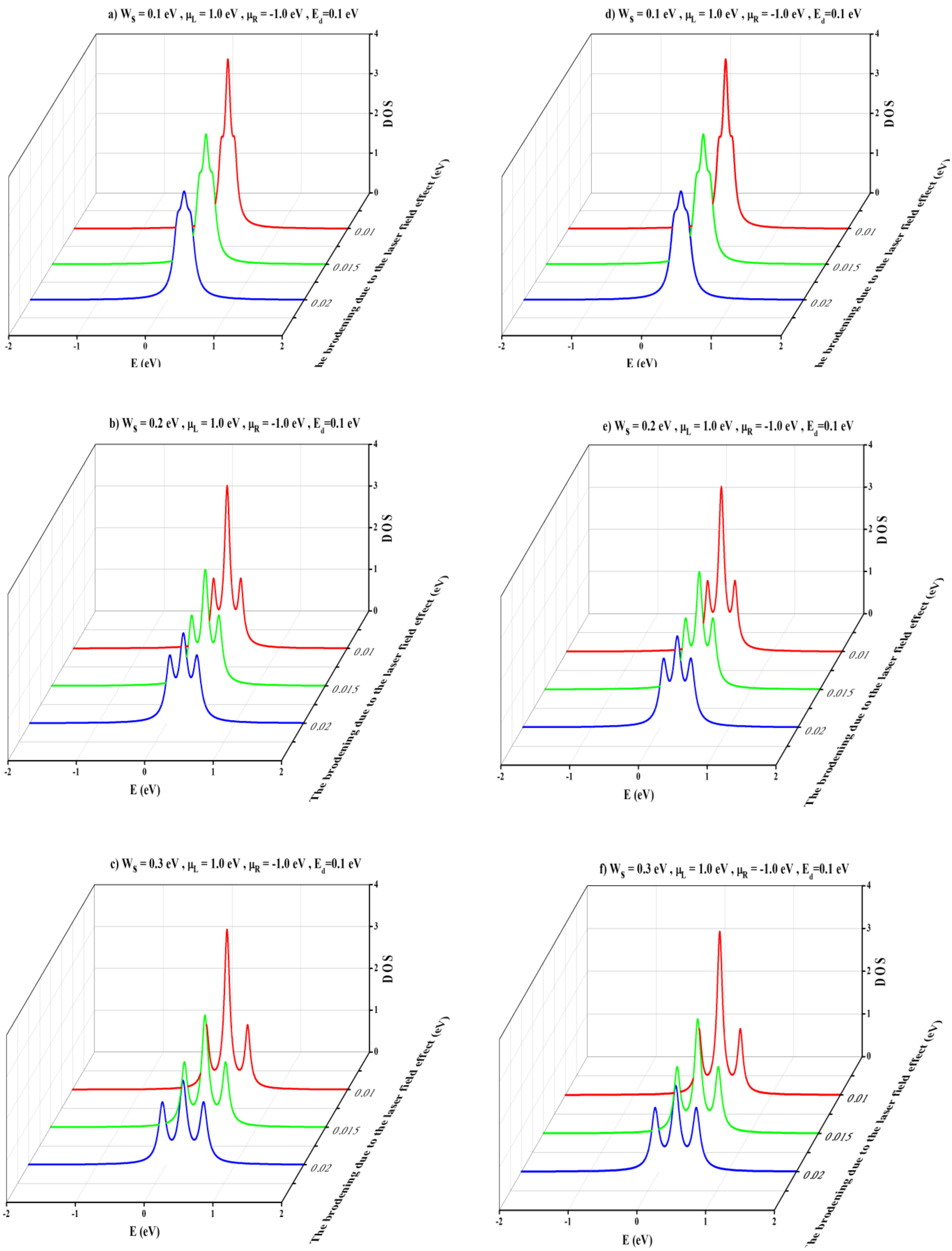

Figure-7 The density of states DOS as a function of the system energy E(eV) in the presence of a laser field with frequency $W_S = 0.1,0.2,0.3$ eV and broadening $\Delta_s = 0.01,0.015,0.02$ eV when $E_d = 0.1$ eV for the cases $(\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma})$ in a,b, and c $(\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma})$ in d,e, and f

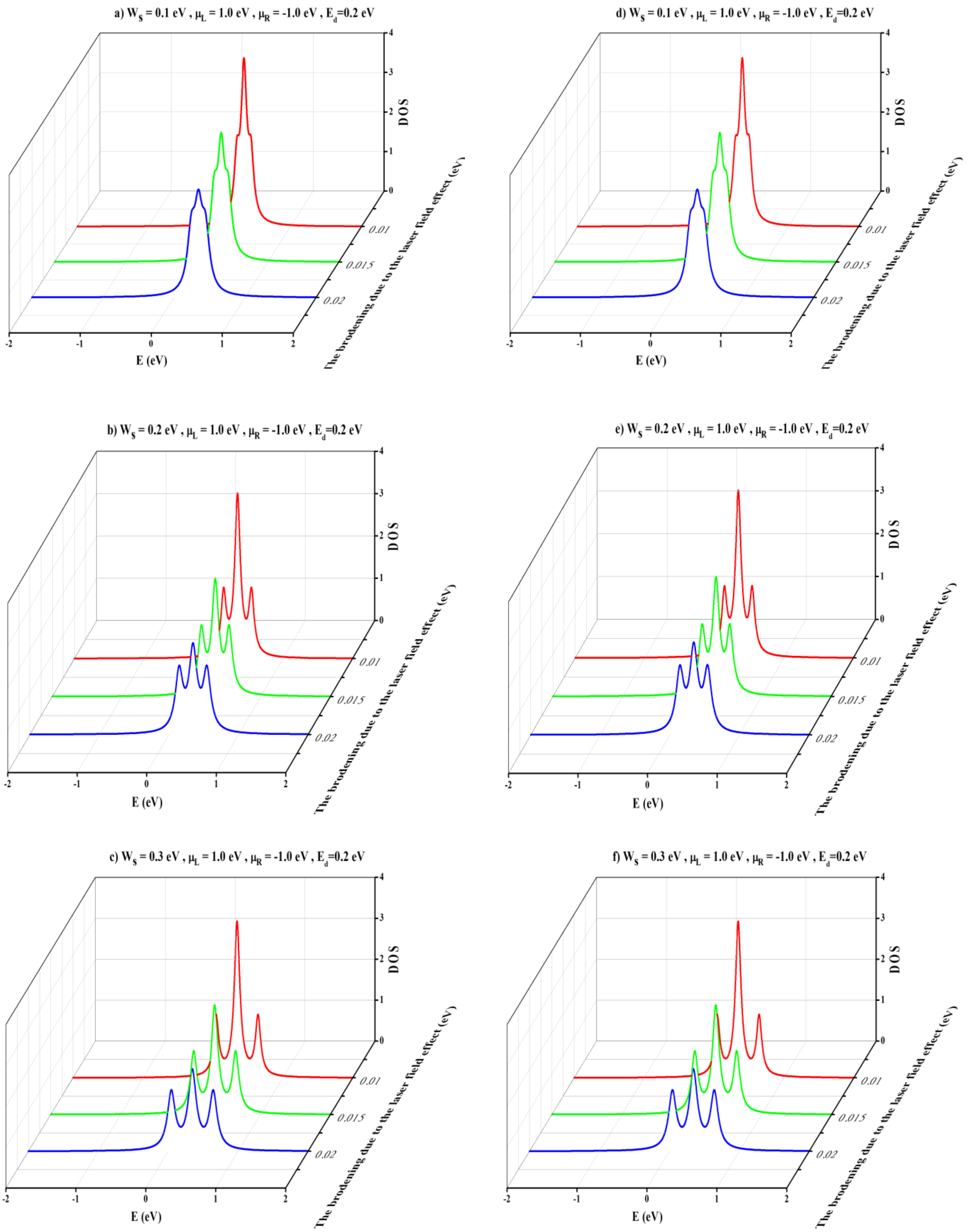

Figure-8 The density of states DOS as a function of the system energy E(eV) in the presence of a laser field with frequency $W_S = 0.1,0.2,0.3$ eV and broadening $\Delta_s = 0.01,0.015,0.02$ eV when $E_d = 0.2$ eV for the cases $(\Delta_\alpha^{+\sigma} < \Delta_\alpha^{-\sigma})$ in a,b, and c $(\Delta_\alpha^{+\sigma} > \Delta_\alpha^{-\sigma})$ in d,e, and f

5. Conclusions

In our study, a mathematical model is developed that describes the interaction of a quantum dot placed between two nonmagnetic leads in the presence of a laser field that affects the quantum dot. The equations describing the device under study were solved in a self-consistent solution based on the time-independent Anderson-Newns model. All parameters were entered, and the model was optimized to obtain physically acceptable solutions. To examine the electronic properties of the system, the density of states was calculated in the absence and presence of the laser field and the effect of the bias voltage on it. the density of states is computed using them in the two regimes ($\Delta_{\alpha}^{+\sigma} < \Delta_{\alpha}^{-\sigma}$ and $\Delta_{\alpha}^{+\sigma} > \Delta_{\alpha}^{-\sigma}$), it is found that the electronic properties (density of states) of the system are decreasing, and the energy windows increase as the parameters (frequency W_s=0.1,0.2,0.3 eV and broadening due to the laser field $\Delta_s = 0.01, 0.015, 0.02$ eV) increase. The peaks of the density of states are shifted to positive energy for the system when the gate voltages V_g increase. These findings have significant implications for nanotechnology, and the laser can be employed as a tool to facilitate the movement of electrons throughout the system.

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