Non-linear Optical Properties of a Molecular Ion Confined in GaAs-GaAlAs Semiconductor Ring nanostructure under Intense Laser Field.

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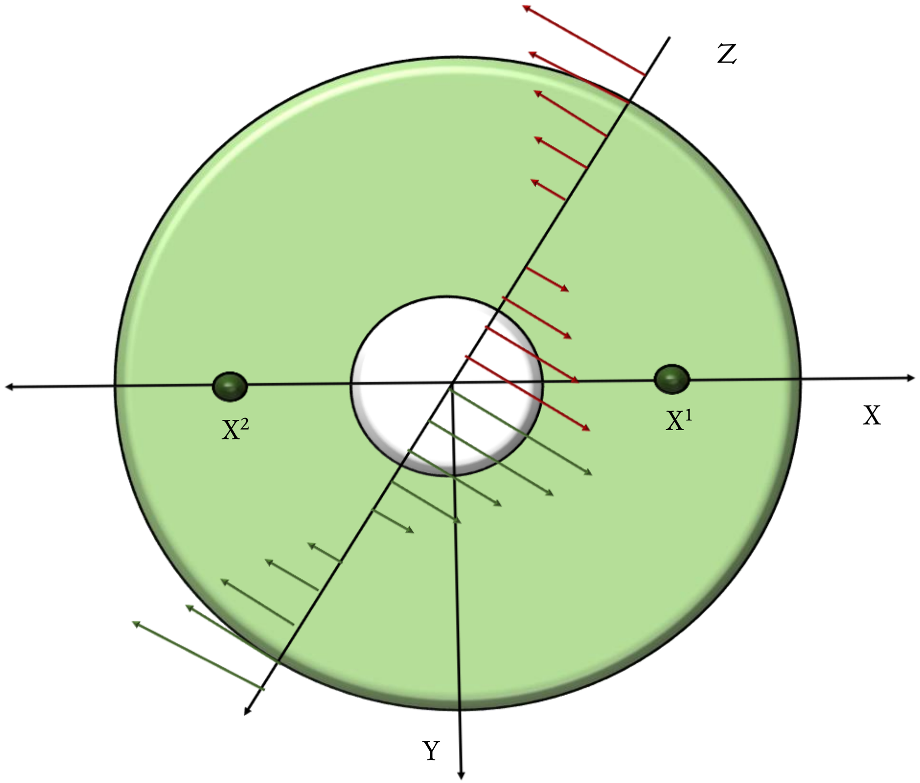


Abstract

Donors confinement and the tunning of electronic properties in these nan nanostructures have been modified by an intense short-pulse laser that controls the matter-light interaction and allows their application to novel optoelectronic devices.

In this regard, we consider the simplest molecular ion D_2^+ confined into GaAs-GaAlAs quantum ring under external probes of intense laser fields. The non-linear intraband optical absorption coefficient as a function of incident photon energy is calculated within the effective mass approximation and compact density-matrix formalism.

This study analyzes the influence of the geometrical factors: quantum ring radii, width, and two donor positions on the above mentioned linear optical properties. Additionally, we study under what conditions these geometric factors and the variations of the external fields' intensities can lead to either a redshift and a blueshift of the resonant peaks of the intraband optical absorption spectrum.

Theoretical model

Schrödinger equation, which includes the laser effect:

$$\left[-\frac{\hbar^2}{2m^*}\nabla^2 + V_{QR}(\overrightarrow{r},\alpha_0) + V_C(\overrightarrow{r},\vec{\alpha}_0) + V_{DD}\right]\Psi_0 = E\Psi_0 \ (1)\,; \quad \alpha_0 = \sqrt{\frac{8\pi I}{c}}\frac{e}{m^*\omega^2}\,; \quad V_C(\vec{r},\vec{\alpha}_0) = -\frac{e^2}{2\varepsilon}\sum_{i=1}^{2}\sum_{j=1}^{2}\frac{1}{\varepsilon\left|\vec{r} - \vec{R}_j + (-1)^i\ \vec{\alpha}_0\right|}$$

Where:

$$V_{QR}(R,\alpha_0) = \frac{V_0}{\pi}Re\left[\pi - \Theta\left(\alpha_0 - x - Re\sqrt{R_{in}^2 - y^2}\right)arccos\left(\frac{Re\sqrt{R_{in}^2-y^2}+x}{\alpha_0}\right) + \Theta\left(\alpha_0 - x - Re\sqrt{R_{out}^2 - y^2}\right)arccos\left(\frac{Re\sqrt{R_{out}^2-y^2}+x}{\alpha_0}\right) - \Theta\left(\alpha_0 + x - Re\sqrt{R_{in}^2 - y^2}\right)arccos\left(\frac{Re\sqrt{R_{in}^2-y^2}-x}{\alpha_0}\right) + \Theta\left(\alpha_0 + x - Re\sqrt{R_{out}^2 - y^2}\right)arccos\left(\frac{Re\sqrt{R_{out}^2-y^2}-x}{\alpha_0}\right)\right]$$ [1,2]

Optical Properties

$$\alpha^1(\omega) = \omega\sqrt{\frac{\mu_0}{\epsilon_0\epsilon_r}}\left[\frac{e^2\sigma\hbar\Gamma_{i_f}\left|M_{i_f}\right|^2}{\left(E_{i\ f}^{\omega}\right)^2 + \left(\hbar\Gamma_{i_f}\right)^2}\right]$$

$$\alpha^3(\omega,I) = -\omega\sqrt{\frac{\mu_0}{\epsilon_0\epsilon_r}}\left(\frac{e^4 I}{2n\epsilon_0 c}\right)\left\{\frac{\sigma\hbar\Gamma_{i_f}\left|M_{i_f}\right|^2}{\left[\left(E_{i\ f}^{\omega}\right)^2 + \left(\hbar\Gamma_{i_f}\right)^2\right]^2}\right\}\mathrm{X}\left\{4\left|M_{i_f}\right|^2 - \left|M_{f_f} - M_{i_i}\right|^2\left[3E_{i\ f}^2 - 4E_{i_f}\hbar\omega + \hbar^2\left(\omega^2 - \Gamma_{if}{}^2\right)\right]\right\}$$

Results

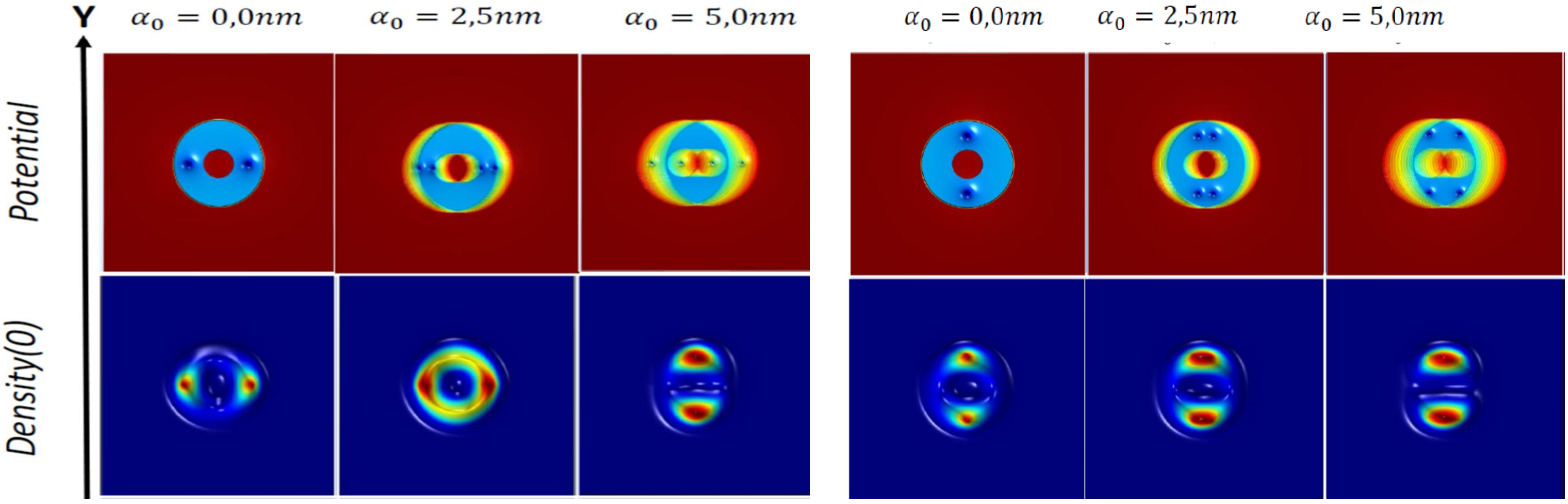


Fig 1 The contour plots of the *D*2+ potential energy of the electron in the x-y plane are shown in row 1. The electron probability density distributions in the x-y plane for the ground state are displayed in row 2. Donors along axis X are left, and Donors along axis Y are right.

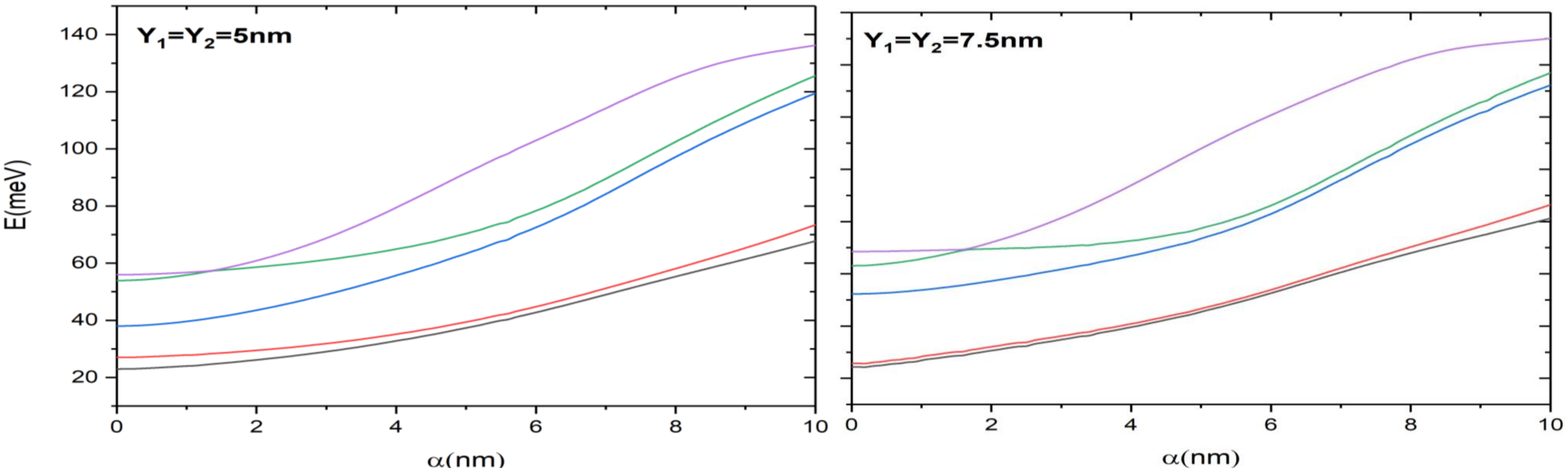


Fig 2. Ground state of *D*2+ energies and four excited states, as a function of the dressing parameter $\alpha 0$.

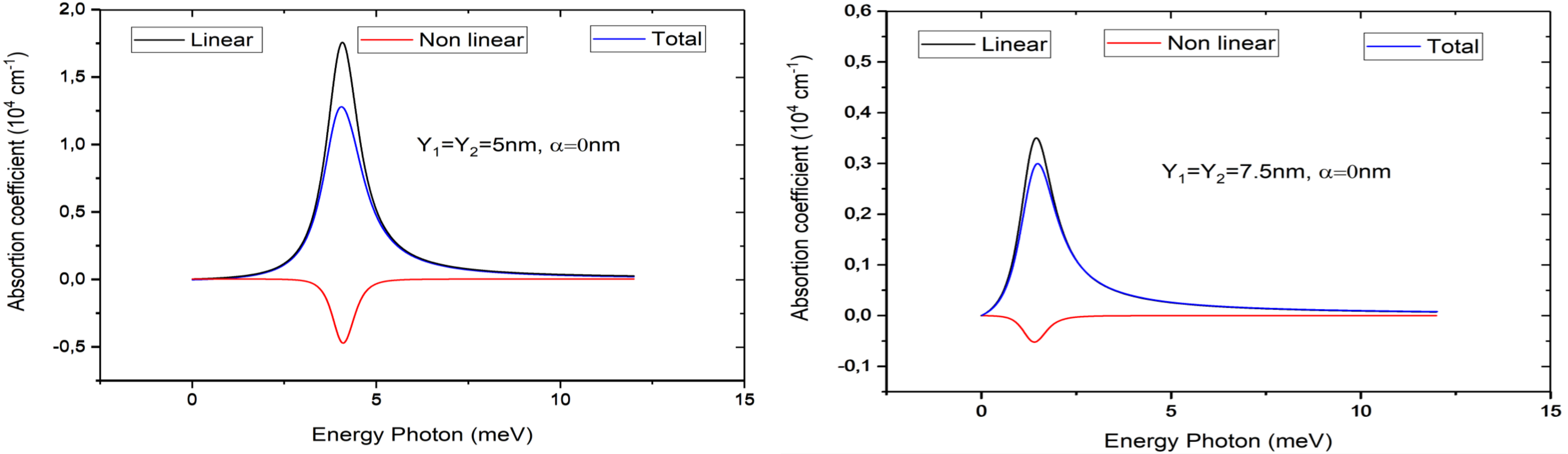
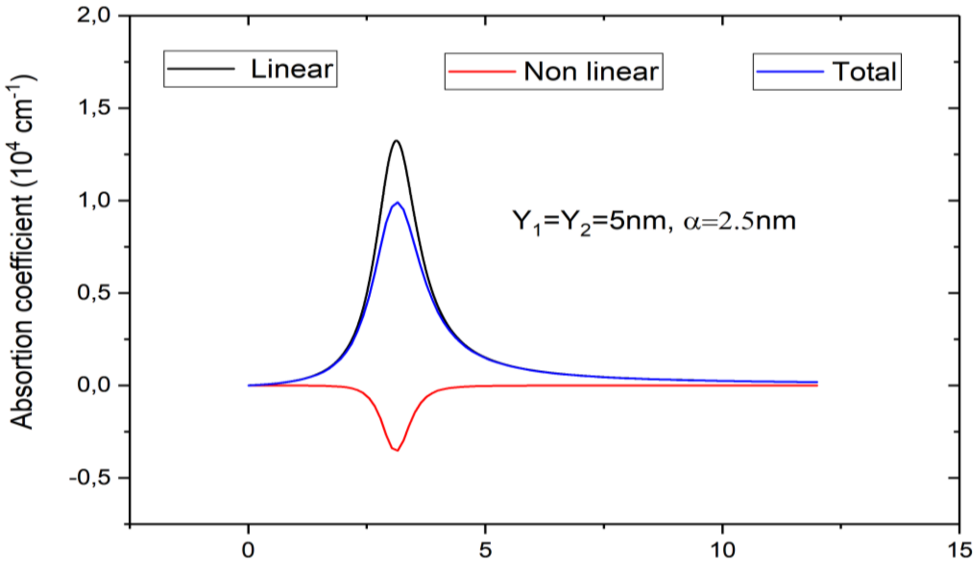
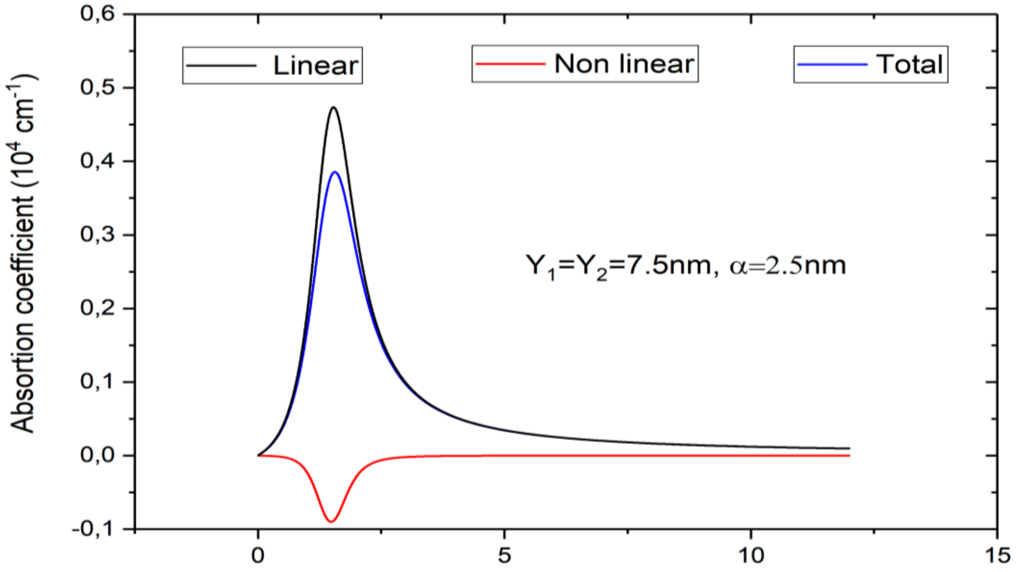
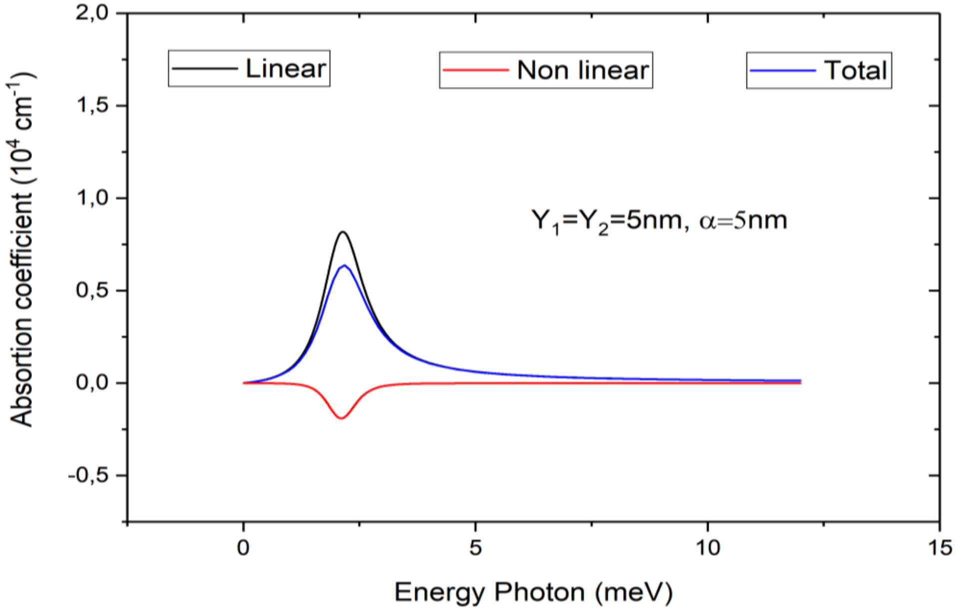
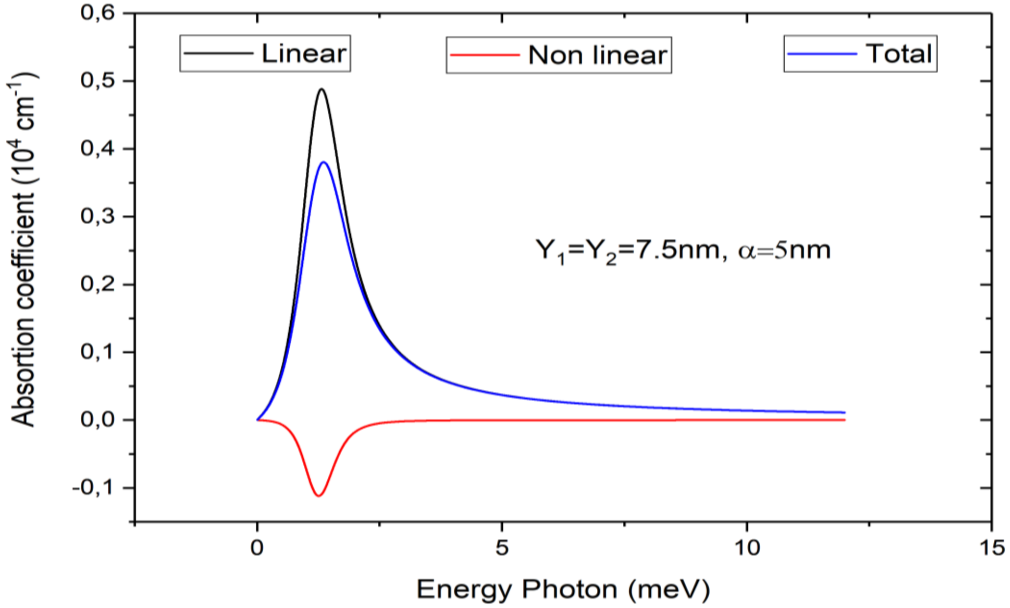


Fig 3. Linear, nonlinear and total coefficient absortion on function of the photon energy, donors along *Y=5nm(left), 7.5nm(right)*, and laser effect, $\alpha 0$ *=0nm*, *2.5nm and 5nm*









[1] M.G. Barseghyan, A.A. Kirakosyan, D. Laroze, Optics Communications 383 (2017) 571–576.
[2] A. Radu, A.A. Kirakosyan, D. Laroze, M.G. Barseghyan, Semicond. Sci. Technol. 30(2015) 045006.